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Strengthening of RC Elements using Carbon Fiber Reinforced Polymer – Review

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ABSTRACT

Structures sometime need to be repaired or reinforced to enhance its structural life and performances. There are many ways to strengthen structures. This research investigates the potential of using Carbon Fiber Reinforced Polymer (CFRP) as reinforcement to Concrete members. In this study, use of CFRP as reinforcement was explored. The CFRP reinforcement is applied in strip form, which is more economical compared to wrapping or forming it into bar shape, because it easier and uses less fiber to achieve similar performance. Samples of CFRP reinforced concrete members were tested to failure in four point bending test. The results obtained are compared with performance of steel reinforced concrete. From the research, we can conclude that the CFRP reinforced concrete members give the required resistance and strength as designed, with behavior similar to those reinforced with steel bars.

Key Words

CFRP, Wrapping, Structural members, Reinforced concrete

1. INTRODUCTION

CFRP is sometimes referred to as Carbon Fibre Reinforced Plastic is similar to fibre glass. Carbon fibre is woven into a textile material and resin such as epoxy resin is applied and allowed to cure. The resulting material that is very strong as it has the best strength to weight ration of all construction materials. It is an improvement on glass fibre reinforced plastic, although much more expensive. Carbon Fibre Reinforced Polymer (CFRP) as externally bonded reinforcement is a technically sound and practically efficient method of strengthening and upgrading reinforced concrete (RC) members. CFRP are used to retrofit and repair structurally deficient infrastructure such as bridges and buildings. Using CFRP reinforcing bars in new concrete can eliminate potential corrosion problems When RC members are strengthened with externally bonded CFRP, the bond between CFRP and RC substrate significantly affects the members loading capacity

2.1 CEMENT

In this study Ordinary Portland Cement (OPC) was used. Many tests were conducted to cement like specific gravity, consistency and initial setting time. The cement is tested for various properties like specific gravity, Initial setting time, Standard Consistency in accordance with IS 383:1970.

2.2 FINE AGGREGATE

The locally available river sand was used as fine aggregate in the present investigation. The sand is tested for various properties like specific gravity, fineness modulus in accordance with IS 383:1970. The specific gravity of Fine aggregate was found to be 2.16.

2.3 COARSE AGGREGATE

Coarse aggregate are the crushed stones, which is used for making concrete. The aggregate is tested for various properties like specific gravity, fineness modulus in accordance with IS 383:1970.

2.5 WATER

Water is the least expensive but most important ingredient of the concrete. The water, which is used for making concrete should be clean add free from harmful impurities like oil, alkalis, acids etc. Generally a pH value of 6 is used in water.

3. LITERATURE REVIEW

Tom Norris et al., (1997) have studied Shear and flexural strengthening of RC beams with carbon fiber sheets. The CFRP sheets are epoxy bonded to the tension phase and the web of concrete beams. It's consisted of casting 19 concrete beams pre-cracking most of the beams applying FRP to the tension flange and web; thirteen of the beams were over reinforced. Three types of FRP systems Continuous fiber sheets, unidirectional fabric and Cross ply fabric were used in the study. There was a little difference between the various forms of fibers used.CFRP sheets can provide increase in strength and stiffness when bonded to web and tension face.

Timothy H. Topper et al., (2007) have studied on the effect of the confinement provided by transverse carbon fiber reinforced polymer (CFRP) sheets on the fatigue bond strength of steel reinforcing bars in concrete beams. Reinforced concrete bond-beams 150X250X2000 mm were tested. Smooth stirrups, a smooth bar was provided in all the beams. A total of 19 tests were performed under repeated loading and four tests were carried under static loading. The specimens were divided into unwrapped beams and wrapped beams. The fatigue limit of bond between concrete and steel fails by a brittle splitting mode under repeated loading. Adding CFRP increased the fatigue bond strength.

A.A. El-Ghandour et al., (2010) studied the CFRP flexure and shear strengthening efficiencies of concrete beams. Half-scale beams, with different flexure and shear internal steel ratios, were tested in three-point bending. Flexure or shear-critical beams were provided with CFRP longitudinal sheets or U-wraps. At high flexural damage, reduction in shear strengthening efficiency was noted at higher ductility. Linear Variable Distance Transducers (LVDTs) were used to measure the deflections. The research conducted showed that the CFRP flexural or shear strengthening efficiency is sensitive to the shear or flexure level of damage, respectively.

K.S.Al-Jabri et al., (2011) have studied about damaged/repaired reinforced concrete (RC) beams. It consisted of RC rectangular beam specimens exposed to accelerated corrosion. The corrosion rate was varied from 5% to 15% which represents loss in cross-sectional area of the steel reinforcement in the tension side. All specimens were loaded in four-point loading, the load was applied using hydraulic actuator. Bonding of the CFRP to the concrete was achieved by using epoxy adhesive. The beams were tested after one week from applying the CFRP. There is a reduction in strength due to corrosion. Beams repaired with CFRP without replacing the damaged concrete zone need to be anchored by U-shaped CFRP strips to enhance the structural performance. To verify the results and to predict the strength of corroded RC repaired with CFRP a non-linear analysis program was developed.

Adrian K. Y. Hii et al., (2013) studied torsional strengthening of solid and box-section reinforced concrete beams with externally bonded carbon fiber-reinforced polymer (CFRP). Six medium scale reinforced-concrete beams of 500X350 mm cross-section were constructed for this test. Two specimens were solid sections while the rest were box sections .The reinforcement layout was designed to be slightly below the minimum torsional capacity required in current design standards. CFRP sheets and epoxy resins were externally bonded using the wet lay-up method. As expected, the cracking strengths were lower for the box section RC beams compared to the corresponding solid specimens.

Asad Ur Rehman Khan Et Al., (2013) study deals with the use of externally bonded CFRP wraps instead of strips to strengthen RC beams in flexure with and without end anchorages. In this study six (06) rectangular reinforced concrete beams having width, depth and length were tested. The beams were divided in to two groups of three beams based on the shear span to depth ratio used, one without end anchorage and other with end anchorage. Experimental investigations are presented in terms of ultimate load carrying capacities, failure modes and deflection curves. RC beams wrapped with CFRP at bottom and extended on sides provided with and without ends anchorages, improved the structural performance of the beams in terms of stiffness, load carrying capacity and ductility.

Francesca Ceroni et al., (2013) have studied about bond tests performed on concrete blocks externally strengthened with carbon fiber sheets. Concrete specimens had a square section and a length; the reinforcement was a CFRP sheet glued on only one side. The tensile load was applied to the CFRP sheet by gripping its end in a universal machine and applying compression to the concrete block that was positioned in a stiff steel frame. Most specimens with and without anchorages failed due to deboning at the interface. When the bond length is reduced or two layers of fibers are applied with the same area as one layer, the deboning load is known to decrease.

Georges El-Saikaly et al., (2014) studied the fatigue performance of RC T-beams strengthened in shear for increased service load using prefabricated CFRP L-shaped laminates. Six laboratory tests were performed on full-size 4520 mm-long T-beams. The specimens were subjected to fatigue loading up to six million load cycles at a rate of 3 Hz. Two categories of specimens unstrengthened and strengthened were used. Test results were compared with the upper fatigue limits specified by codes and standards. The specimens that did not fail in fatigue were then subjected to static loading up to failure. The feasibility of using CFRP L-shaped laminates to extend the service life of RC T-beams subjected to fatigue loading.

Hossein Azimi et al., (2014) have studied Flexural strengthening of reinforced concrete slab–column connection using CFRP sheets. The experimental study was particularly conducted to examine whether there is enough anchorage with the use of CFRP wrapping. Series of tests were conducted on six flat slab–column connection specimens organized in two groups of three specimens each. The first group included three control specimens with central, eccentric, and edge columns, respectively. The second group was geometrically identical to the first group, though with CFRP sheets installed on the tension side of the slab to increase flexural capacity at the negative moment region. The proposed strengthening technique using CFRP sheets as tension reinforcement applied on the region of slab–column connection was proven to be effective in increasing the flexural strength and stiffness.

Hui Peng et al., (2014) have studied, by using prestressed NSM FRP strips can combine the advantages of these two strengthening methods and it thus becomes very attractive to further promote FRP applications in retrofitting concrete structures. In this paper, a total of 7 rectangular reinforced concrete beams were constructed for static load tests, of which 1 specimen was the reference beam and the other 6 beams were strengthened with FRP strips. The behavior and failure modes of these specimens were investigated, the difference of the mechanical performance due to various strengthening techniques was compared, and the effect of parameters, was analyzed. The testing results showed that the load-carrying behavior of flexural members could be improved significantly by strengthening with prestressed NSM FRP strips. It was proven that these failure modes can be avoided by extending the bond length of FRP strips or using U-wraps of CFRP sheets.

Jovan Tatar et al., (2015) have studied utilization of small-beam three-point bending test specimens to study FRP–concrete bond performance when subjected to accelerate conditioning environments (immersion in water and exposure to high humidity at elevated temperatures). A material characterization study was performed on epoxies to determine how the material degradation mechanism changes depending on the conditioning environment. Five different composite systems were used in the study, all composites were unidirectional carbon-fiber-reinforced polymer (CFRP), typically used for external strengthening of load carrying members. CFRP laminate specimens failed prematurely by composite rupture or at the adhesive–composite interface.

M. Khelifa et al., (2015) have studied finite element analysis of flexural strengthening of timber beams with Carbon Fibre-Reinforced Polymers. All the beams had the same square cross-section geometry and were loaded under four-point bending, but had different numbers of CFRP layers. The Abacus software was used, and different material models were evaluated with respect to their ability to describe the behavior of the solid timber beams. Elasto-plastic behavior with damage effect was assumed for the timber material, linear elastic isotropic model was used for the CFRP, and a cohesive model was used to represent the interaction between two adherent surfaces (CFRP and timber).

M.R.T. Arruda et al., (2015) studied about numerical investigations on the bond between concrete and CFRP strengthening systems at elevated temperatures. The numerical study was developed using the commercial package Abacus and comprised the simulation of double-lap shear tests. The two types of specimens (EBR and NSM) were first heated up to elevated temperatures, and then loaded up to failure. They conducted double-lap shear tests and reported the following tendencies: (i) increasing failure loads for temperatures lower than the Tg of the adhesive and (ii) decreasing failure loads for temperatures higher than the Tg of the adhesive. It can be seen that the relative differences between predicted and experimental results are very low (relative differences ranging between 0.4% and 8.3%), confirming the accuracy of the proposed bond–slip relationships

Samiullah Qazi et al., (2015) studied Strut-and-tie model for a reinforced concrete wall strengthened with carbon fibre-reinforced polymers .The effective height of the walls was 610 mm, the width was 900 mm and the thickness was 80 mm. The compressive strength of concrete was 35 MPa ± 5 MPa. The proposed simplified strut-and-tie model successfully predicted the load response behavior of short wall specimens with reinforced concrete and reinforced concrete strengthened with carbon fibre-reinforced polymer. The evaluated load displacement curve was similar to the experimentally measured. The model is developed based on a truss analysis of the RC strut and tie model.

Xu Zhang et al., (2015) have studied about CFRP strengthening reinforced concrete arches: Strengthening methods and experimental studies. To improve the strength, stiffness and ductility of reinforced concrete (RC) arches, carbon fiber reinforced polymers (CFRPs) were applied through bonding and bonding/wrapping techniques. Span of the arch is 1000 mm. The rise is 500 mm. Rise-to-span ratio is 0.5. Thickness of the arch is 100 mm. The width is 300 mm.Span-to-thickness ratio is 10. HRB 335 steel rebars of 8 mm diameter were used to reinforce the concrete. It is found that bonding/wrapping technique is much more effective than bonding method. Strengthening effect of CFRP to the semi-circular arch whose rise-to-span ratio is 0.5 is much smaller than in arches with smaller rise-to-span ratio.

Yentl Swolfs et al., (2015) studied ductility in hybrid carbon fibre/self-reinforced composites through control of the damage mechanisms. Carbon fibre composites possess excellent mechanical properties, but suffer from brittleness. Unidirectional carbon fibre-reinforced polypropylenes were used. Quasi-static tensile tests were performed according to ASTM. Tensile samples were water jet cut to minimize damage to the sample edges. The damage mechanisms after CFRPP failure need to be controlled to achieve pseudo-ductility in SRPP/CFRPP hybrid composites. These conclusions can also be used to control the damage mechanisms and achieve ductility in other hybrid composites.

Yungon Kim et al., (2015) have studied about Shear behavior of full-scale reinforced concrete T-beams strengthened with CFRP strips and anchors. Nine tests were conducted on 1220 mm deep T-beams strengthened in shear using Carbon Fiber-Reinforced Polymer (CFRP) strips and CFRP anchor. The shear contribution of FRP was larger in beams with less transverse steel reinforcement. Because CFRP and steel reinforcement have different material and bond properties, interactions between the two materials need to be taken into account when determining the shear capacity of a strengthened member. CFRP anchors were therefore able to maximize the shear strength contribution of CFRP strips

Zhimin Wu et al., (2015) have studied Analytical Solution for Fracture Analysis of CFRP Sheet–Strengthened Cracked Concrete Beams. Theoretical analysis of FRP plate- or sheet-strengthened cracked concrete beams is necessary for estimating service reliability of the structural members. The interfacial deboning is modeled as the interfacial shear crack propagation in this paper. Four different stages are discussed after initial cracking state of the concrete. At the first stage, only fictitious crack propagation occurs in the concrete. At the second stage, macro crack propagates in the concrete without interfacial deboning. At the third stage, both vertical macro crack propagation in the concrete and horizontal shear crack propagation.

The validity of the proposed analytical solution is verified with the experimental results and numerical simulations. It can be concluded that the proposed analytical solution can predict the load-bearing capacity of CFRP sheet-strengthened cracked concrete beams with reasonable accuracy.

G. Ramos et al., (2015) studied the deboning behavior of carbon fiber-reinforced polymers used to strengthen beams in bending. Bond tests on prismatic beams of 150X150X600 mm, full-scale tests on 7.20 m span beams were conducted. Two systems (bidirectional flexible sheet applied with a wet lay-up method and prefabricated and unidirectional carbon fiber sheets) of reinforcement with carbon fibers were tested. The failure mechanism observed in these test series is known as "pelling". The process starts when the flexure at the center of the specimen generates a tensile stress concentration in the concrete, in the zone next to the joint. This produces cracking of the concrete in this zone, with a main crack that later propagates along the concrete-fiber interface, producing the peeling effect.

Sungnam Hong et al., (2016) has studied effect of prestress and transverse grooves on reinforced concrete beams prestressed with near-surface-mounted carbon fiber-reinforced polymer plates. The prestressed NSM CFRP strengthening technique combines the efficiency of the external prestressing method with the advantages of non-corrosive and light-weight CFRP reinforcement. Eight rectangular concrete beams, each 3.2 m in length, were fabricated. Their clear span was 3 m, and the bonded length of the CFRP plates was 2.8 m. A strengthening system with a prestressing bed was used to strengthen the concrete beams. In the control beam, concrete crushing occurred in the compression zone of the midspan after yielding of the tension steel. This failure is typical of under-reinforced concrete beams; it is an expected mode that occurs because of tensile failure induced by including a smaller amount of tension steel than compression steel.

CONCLUSION

From this study concluded that, CFRP has a high tensile strength, a high modulus and is also light in weight and easy to handle. Although, CFRP applications are gaining popularity in seismic retrofitting, their long term behavior is still not very well known. While strengthening of the buildings with CFRP several layers of epoxy based adhesives are used. Those layers of materials as well as CFRP wrapped concrete may therefore be affected by different stress levels and environmental changes. FRP composite materials have experienced a continuous increase of use in structural strengthening and repair applications around the world, in the last decade. In addition, when the FRP was compared with steel materials, it was found that it provided unique opportunities to develop the shapes and forms to facilitate their use in construction.

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