International Institute for FRP in Construction

FRPRCS-14, Belfast - June 2019

Flexure Critical Corroded RC Beams Strengthened with Carbon FRCM and Glass FRP

Bressan, J.[1], El Ragaby, A.[2], Ghrib, F.[1],

[1]*Department of Civil and Environmental Engineering, University of Windsor at Windsor, CAN*

[2]*Department of Civil and Environmental Engineering, University of Wisconsin-Platteville, USA*

Abstract

An experimental program was conducted to study the effectiveness of carbon fiber reinforced cementitious matrix (FRCM) and glass FRP in strengthening flexure critical, corroded reinforced concrete (RC) beams. Six RC beam specimens (250 mm deep, 150 mm wide, and 2440 mm long) were prepared and tested. Three specimens were used as control (un-corroded, 10% and 20% mass loss), and three corroded specimens were repaired/strengthened using carbon-FRCM, and glass FRP. The FRCM/FRP strengthening scheme includes two layers of fibers sheets partially wrapped up the sides along the tensile surface of the beam and U-shaped wraps at the loading points and near the end supports. The specimens were tested under monotonic four-points loading. Both Carbon-FRCM and glass FRP strengthening significantly improved the flexural capacity.

Keywords: Reinforced Concrete, Corrosion, GFRP Sheets, FRCM, carbon, strengthening

Corresponding author's email: elragabya@uwplatt.edu

Introduction

Rehabilitation solutions for Reinforced concrete (RC) structures affected by corrosion damage is increasingly becoming a matter of utmost interest to owners, construction industry and researchers. FRP strengthening has been experimentally tested for strengthening flexure critically corroded RC beams [1-3]. Recently, FRCM strengthening of flexure critical corroded RC beams has been investigated as well [4-5].

Experimental Program

An experimental study was conducted on the effectiveness of glass FRP and carbon FRCM as strengthening materials for flexure critical RC beams subjected to corrosion damage. Six flexural critical reinforced concrete (RC) beams were prepared (250 mm depth, 150 mm width, and 2440 mm length). The test matrix included specimens D0 (un-corroded), D10 (10% mass loss corrosion), and D20 (20% mass loss). In addition, three strengthened specimens; D20-G strengthened with glass FRP, and D10-C and D20-C strengthened with carbon FRCM, were tested under monotonic load until failure. The concrete bonding surface for the FRCM was made rough whereas the FRP strengthened specimen surface was smoothed for optimal bonding. The concrete had a compressive strength of 24 MPa at 28 days, and the tensile steel had a yield strength of 510 MPa.

Accelerated Corrosion Process

The test specimens were subjected to an accelerated corrosion process where specimens were partially submerged in 5% NaCl saltwater solution. A current of 730 mA (341 $\mu A/cm^2$) was impressed into the beams. The internal tensile rebar acted as the anode, and an external 6 mm stainless steel rod submerged beside the beam acted as the cathode. The specimens were corroded for 26.5 and 53 days to reach 10% and 20% tensile steel mass loss respectively. After testing of the control specimens, corroded bars were extracted and the mass loss was verified.

Glass FRP and Carbon FRCM Systems

The glass FRP sheets consisted of SikaWrap Hex-100G unidirectional fibers and Sikadur 300 two-part epoxy that has a tensile strength of 611 MPa, a tensile modulus of 27.4 GPa, and a rupture strain of 2.24% [6]. The carbon FRCM sheets consisted of Ruredil X Mesh C10 bi-directional fibers and Ruredil X Mortar 25 mortar mix that has a tensile strength of 1031 MPa, a tensile modulus of 79.73 GPa, and a rupture strain of 1.0% [7].

Strengthening Scheme

The strengthened specimens had 2 layers of FRP or FRCM sheets placed along the tensile face and partially wrapped up the sides 75 mm high with the primary direction of the fibers running in the longitudinal direction. Two layers of U-shaped FRP/FRCM sheets were placed under the loading points and near the end supports (fig.1).

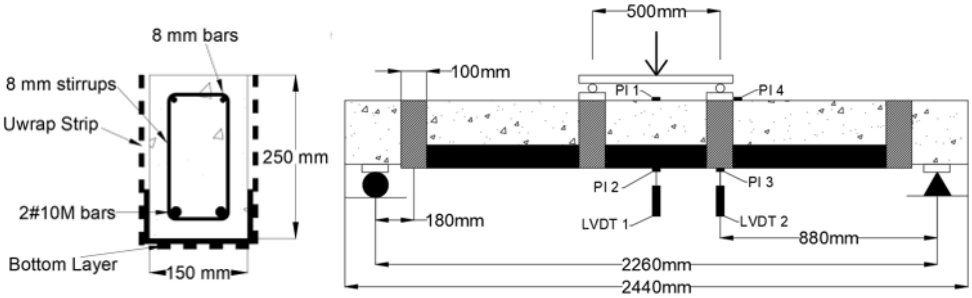

Figure 1: Strengthening scheme and instrumentation

FRP and FRCM Installation

Before applying the FRP, the corners of the beams were rounded to a ½" radius. The two-part epoxy was mixed using a low speed drill. The epoxy was applied to the beams' surface. The FRP fiber meshes were then impregnated with epoxy with a roller and then applied (fig. 2).

For specimens strengthened with FRCM, the mortar was mixed with water using a slow speed drill. The mortar was first applied to the concrete surface using a trowel, followed by the first layer of the flexural FRCM fiber mesh. The mesh was impregnated in the mortar and then another layer of mortar was applied. The final flexural FRCM mesh was then applied in the same manner. Similarly, U-wraps were applied to the FRP reinforced specimens (fig. 2). Each applied layer of mortar was 3-4 mm thick.

Instrumentation and Test Setup

The specimens were tested monotonically under four-point loading using a 500 kN hydraulic actuator. The displacement-controlled loading rate was 2 mm/min. Two LVDTs were used to measure the deflection at midspan and the loading point. The strain was measured using 50 mm PI gauges both at the top and bottom of the specimen within the midspan (fig.1). 60 mm strain gauges were also placed on the concrete compression face to verify the PI gauges. The data acquisition rate was 1 second.

Figure 2: FRP (left) and FRCM (right) strengthening

Results and Discussion

All 6 specimens experienced steel yielding before failure. Specimens D0, D10, and D20 failed by concrete crushing at the midspan. D10-C, and D20-C failed by fiber slippage before FRCM debonding and finally concrete crushing within the midspan region. D20-G failed by the combination of FRP flexural sheets and U-wraps debonding within the shear span and the concrete debonding from the corroded tensile steel. Part of the de-bonded concrete remained attached to the FRP. This was followed by a shear failure mode.

Load – Deflection

Figures 4-a and b show comparisons of the load – deflection responses of the test specimens at the centre of the midspan. It can be noticed that the corrosion damage slightly reduced the yielding and ultimate loads by about 10%. Meanwhile, the carbon FRCM strengthening significantly increased the yielding and ultimate loads of D10-C and D20-C by more than 25% in comparison to D10 and D20 respectively. The carbon FRCM also increase the specimens' stiffness as both D10-C and D20-C developed their yield and ultimate loads at significantly lower deflection. The glass FRP strengthened specimen, D20-G, showed a significant higher yield load of 57.2% and 135.0% than D20 and D20-C as well as higher ultimate load of 14.9% and 61.7% higher than D20 and D20-C, respectively.

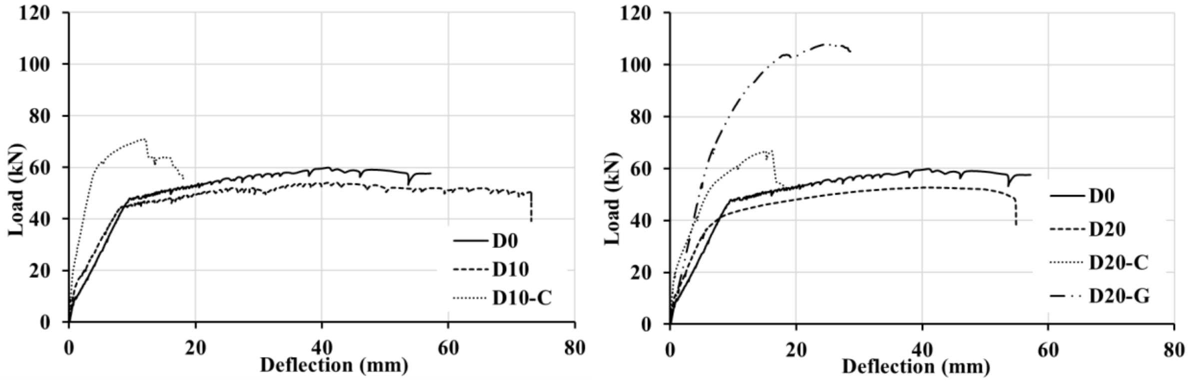

Figure 4: Load – Deflection: a-10% (left) and b- 20% (right) mass loss specimens

Load – Strain

The load – strain responses at the centre of the midspan are shown in figures 5-a and b. Specimen D20 did not have any reliable tensile strain results due to the malfunction of PI 2 and PI 3 gauges. The corrosion resulted in an increase of the compression and tension strains during loading when comparing specimen D10 to D0. The strain at the top surface of D10-C, D20-C, and D20-G were slightly lower at high load levels compared to D0, D10, and D20. The carbon FRCM significantly reduced the tension strain developed at the bottom of the beam when corrosion damage was present. This is seen when comparing specimens D10 and D10-C responses. In the pre-yielding phase, D20-G had a higher tensile strain than D0 up to 49 kN load level. However, at higher loads specimen D20-G had a significantly lower strain compared to D0. Before yielding, D20-C had a lower tension strain than D20-G indicating that the FRCM deformation is lower at pre-yielding load levels compared to glass FRP reinforced beams (D20-C and D20-G).

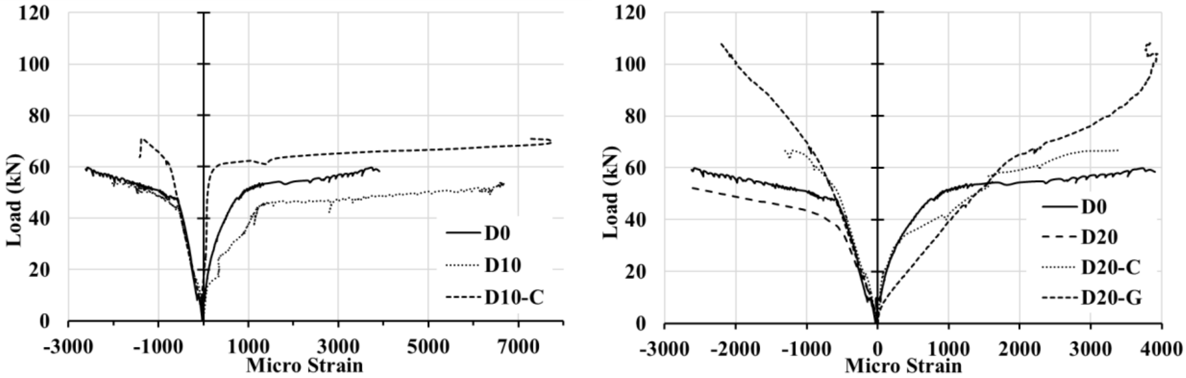

Figure 5: Load – Strain: a-10% (left) and b- 20% (right) mass loss specimens

Conclusions

- Carbon FRCM was successful in improving the performance of corroded beams in specimens D10-C and D20-C while keeping a ductile failure mode.
- Carbon FRCM and glass FRP significantly increased the yield and ultimate capacity compared to the corroded control specimens. The stiffness of the strengthened specimens increased significantly leading to lower ultimate deflections.
- Carbon FRCM strengthening reduced the tension strain significantly during pre-yielding phase, and performed similarly to the control beam in the post-yielding phase. Glass FRP reinforced beam had a higher tension strain in the pre-yielding phase, but this tension strain increased much slower as the load increased after yielding.

References

[1] G. G. Triantafyllou, T. C. Rousakis and A. I. Karabinis, "Corroded RC beams patch repaired and strengthened in flexure with fiber-reinforced polymer laminates," Composites Part B, vol. 112, pp. 125-136, 2017.

[2] J.-h. Xie and R.-L. Hu, "Experimental study on rehabilitation of corrosion-damaged reinforced concrete beams with carbon fiber reinforced polymer," Construction and Building Materials, vol. 38, pp. 708-716, 2012.

[3] T. El Maaddawy and K. Soudki, "Carbon-Fiber-Reinforced Polymer Repair to Extend Service Life of Corroded Reinforced Concrete Beams," Journal of Composites for Construction, vol. 9, no. 2, pp. 187-194, 2005.

[4] M. Elghazy, A. El Refai, U. Ebead and A. Nanni, "Effect of corrosion damage on the flexural performance of RC beams strengthened with FRCM composites," Composite Structures, vol. 180, pp. 994-1006, 2017.

[5] T. El-Maaddawy and A. El Refai, "Innovative Repair of Severely Corroded T-Beams Using Fabric-Reinforced Cementitious Matrix," Journal of Composites for Construction, vol. 20, no. 3, p. 04015073, 2016.

[6] “Ruredil X Mesh C10.” [Online]. Available: http://www.conspec-rep.com/pdf/FRCM-C10 Technical Data Sheet.pdf. [Accessed: 28-Mar-2019].

[7] “TM SikaWrap® Hex-100G.” [Online]. Available: https://can.sika.com/dms/getdocument.get/dc7ca73a-63e3-3736-b519-968586f81668/SikaWrapHex100G_pds.pdf. [Accessed: 28-Mar-2019].