

Durability Evaluation of Embedded GFRP Rebars in Concrete Bridges after More Than Ten Years of Service

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ABSTRACT: Corrosion has been an issue in the civil engineering industry since the day steel was used as a building material. The National Association of Corrosion Engineers estimated a corrosion repairing cost of eight billion dollars per year. Thus, finding an alternative has been a must. One of these alternatives is glass fiber reinforced polymer (GFRP). It presents itself as a solid candidate not only because of its high resistivity to corrosion but also because of its cost efficiency. The goal of this study is to assess the durability performance of GFRP rebars embedded in several bridges across the United States. GFRP rebars were extracted from bridges located in Missouri and Texas States and then were tested for durability at different universities, one of them was Missouri University of Science and Technology. Several tests were conducted on these extracted rebars and the surrounding concrete including: energy dispersive spectroscopy, short bar shear, burn-off, pH, carbonation depth, and chlorides content. Regarding the results, energy dispersive spectroscopy did not show any changes in the GFRP's chemical compositions. Burn-off test did not also show any significant changes in the fiber content. However, short bar shear (SBS) showed some substantial changes for one of the bridges. Carbonation depth test did not show any signs of carbonation attack for the Southview Bridge and was between 13 mm to 25 mm in Sierrita de la Cruz Creek Bridge.

1 INTRODUCTION

Corrosion in reinforced concrete bridges is a major issue around the world and its repairs is considered very costly (Andrew, 2018). Therefore, efficient and more costly-effective alternatives need to exist. Glass fiber reinforced polymer (GFRP) can be considered as a strong candidate to replace mild steel rebars owing to its high corrosion resistivity and cost-effectiveness. The usage of GFRP is still relatively new due to the lack of long-term durability data (Micelli et al. 2004). Thus, to gain the industry's confidence to use GFRP, more durability data has to exist for building codes and standards. In 2005, Mufti's team conducted an assessment for GFRP rebars implanted in several bridges across Canada to evaluate their durability performance after being in service for eight years (Mufti et al. 2005). Several material characterization tests were conducted on these rebars. The resulted showed that there were no sings of degradation nor changes in the chemical composition of the rebars. Another study in 2016 was undertaken by Gooranorimi et al. to evaluate the long-term durability of GFRP rebars extracted from bridges in the State of Texas. The test results indicated that there were neither microstructural deterioration signs nor chemical compositions changes after that service period. In this study, numerous durability assessment tests were conducted on GFRP rebars extracted from two bridges after being in service for more than ten years. To have a better understanding of the GFRP durability performance, not only the GFRP rebars were investigated, but the surrounding concrete was assessed to see what the surrounding ambient of these rebars and how that influenced the durability results of the rebars. The tests



conducted were energy dispersive spectroscopy (EDS), short bar shear (SBS), Burn-off, pH, carbonation depth, and chloride content.

2 BRIDGES INFORMATION

Two bridges were involved in this research and they were the Southview Bridge (SV) located in the State of Missouri - USA, and the Sierrita de la Cruz Creek Bridge (SC) located in the State of Texas - USA. The SV Bridge spans Carter Creek in Rolla, Missouri. The bridge initially consisted of four box culverts and had only one one-lane. In 2004, an expansion was made by adding two more spans to the original ones. The total length and width of the bridge became 21 m and 12 m, respectively. Two sizes of Aslan GFRP rebars (13 mm and 19 mm) were implemented as a part of the main bridge deck reinforcement. In addition, another group of 13-mm rebars were utilized to resist shrinkage and temperature effects. In Texas, the SC Bridge is located north-west of the Amarillo, Texas. The bridge length and width were 24 m and 14 m, respectively. In 2000, a bridge replacement took place to replace the original bridge that had a significant structural deficiency due to a harsh corrosion attack. GFRP rebars were used to replace the steel reinforcement due to its high effectiveness against corrosion. To monitor the behavior of the rebars, a group of witness rebars were implanted during the bridge retrofit at the overhang, midspan, and control joints. In both bridges, sand coated GFRP rebars were used to permit for an apt bond between the rebar and surrounding concrete. Additionally, E-glass-vinyl ester Aslan GFRP rebars were used in both bridges. However, the formulation of the SC Bridge resin was a little different from the one used in the SV Bridge.

3 SPECIMENS EXTRACTION AND PREPARATION

A few cores with a diameter of 102 mm was extracted from each bridge in 2015. Upon extraction, the bridge holes were instantly filled with fast-curing cementitious grout. The total cores extracted from the SV Bridge and the SC Bridge were 20 and 5 respectively. After that, the cores were inventoried at the University of Miami before they (some of them) were shipped to the Missouri S&T for testing. Two cores from the SV Bridge and one core from the SC Bridge were received from Miami University. All the specimens were conditioned before testing in order to obtain realistic measurements and avoid any disturbing factor that could have been introduced during specimens transporting and/or storing. Specimens conditioning comprised of keeping the specimens hermetically sealed and exposing them, in certain cases based on a standard, to solution, temperature, and/or both. Fig. 1 shows specimen's preparations.



Fig. 1: Specimens preparation (A) SEM and EDS sectioning (B) sonic bath

4 GFRP AND CONCRETE EXPERIMENTS

4.1 Scanning electron microscopy (SEM)

In order to check for microstructural deteriorations, a Helios Nanolab 600 SEM device was selected to conduct the test. Two specimens with no more than 25.4 mm diameter and less than 13 mm thick were used to perform the test. Before using the SEM device, the specimens were prepared and conditioned. The preparation involved smoothen the surface by using several grades of sand papers and then polishing. After preparation, the specimens were placed inside an oven for 2 days at 40°C to get rid of any access moisture as part of the specimens conditioning. After the two-day oven exposure, a gold coating was applied on the specimen's surface in order to obtain a better backscattered electron reaction and thus a better quality image can be gained from the SEM device.

Inside the SEM, different magnification levels were utilized to check for not only the fibers and resin, but also the interfacial transition zone (ITZ) between the GFRP rebar and the surrounding concrete. The SEM results exhibited that there were no signs of microstructural deteriorations in the GFRP's fiber and resin. Also, there was no damage to the ITZ and all the interfaces between the GFRP rebar and surrounding concrete were intact and properly attached to each other. Fig. 2 shows SEM images of the SC Bridge.

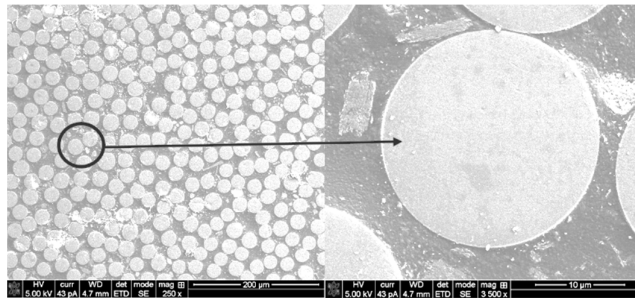


Fig.2:SEM image – X250 and X3500

4.2 Energy dispersive spectroscopy (EDS)

EDS test was conducted to see if there were signs of chemical elemental changes in the rebars after being in service for over ten years and exposed to different kinds of harsh environments. The same device used in the SEM test was used to conduct the EDS. Also, the same specimens used in SEM were used in EDS. A 10 to 20 KeV electron beam was applied to the specimens. EDS results were displayed as graph with two axes in which Y-axis indicates the number of X-rays applied by the detector and X-axis gives the level of energy of those counts. The results exhibited that there were no signs of chemical changes. Al, Ca, and Si were found when the fiber was tested. In the resin, C, the main element was observed. Na was observed too, but since it was also present in the control specimens, their appearance was not taken as a sign of alkaline attack. Fig. 3 illustrates the results.

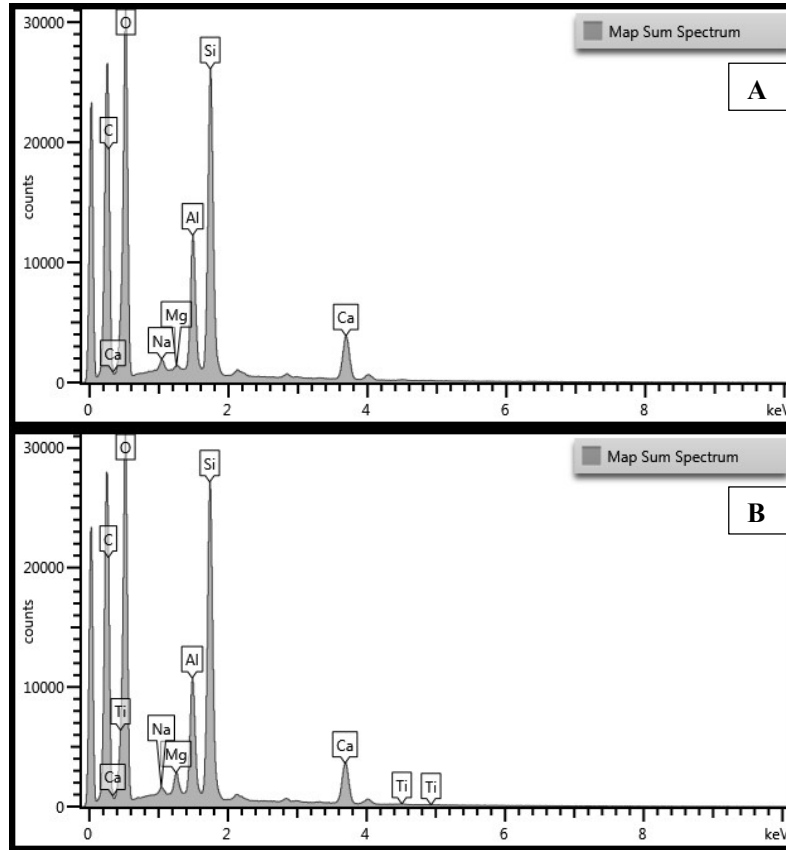


Fig. 3: EDS elemental analysis- (A) Sierrita de la Cruz Creek Bridge (B) Southview Bridge

4.3 Short bar shear (SBS)

ASTM D4475 was implemented to conduct this test (ASTM-D4475, 2016). Per ASTM, it is very encouraged to have at least three specimens for a test, but due to the specimen core limitations, the authors were not able to conduct more than one test for each bridge. A universal machine was used to conduct the test. A loading rate of 13 mm/min. was implemented to avoid dynamic load state. Three-point load setup was used with a center-to-center span between supports of 3 to 5 times the rebar diameter. The specimens were kept deflecting under loading until a horizontal shear failure took place. The specimen diameter and length were 19 mm and 57 mm, respectively. The horizontal shear failure occurred with a peak load around 13.4 kN. The horizontal shear was calculated following the ASTM D4475, as shown in equation 1 below.

$$S = 0.849P/d^2$$

Where the P is the peak load, d is diameter of a specimen, and S is the horizontal shear stress. The results were compared to tests conducted previously in Missouri S&T on the same bridges but different rebars. The results of the current tests were in match with the previous tests for the SV bridge. However, for the SC bridge, the SBS test results were only in match with the previous tests conducted at Missouri S&T. SBS test results were lower than those resulted from testing the control rebars at Hughes Brothers in 2000. Table 1 shows the results.

Table 1: Horizontal shear test results

Bridge	Southview			Sirreta de la Cruz		
Specimen	CM-2017	CM1	CM2	CT-2017	CT	CC
Diameter, mm	19	19	19	19	19	19
Span length, mm	57	57	57	57	57	57
P, Peak Load, kN	12.8	13	12.6	14.4	13.8	20.5
S, Interlaminar Shear Stress, MPa	30	31	29.6	34	32.5	48.3

CM-2017: Cores from Southview Bridge tested in 2017 at Missouri S&T

CM1&2: Cores from Southview Bridge tested for this study at Missouri S&T

CT-2017: Cores from Sirreta de la Cruz Creek Bridge tested in 2017 at Missouri S&T

CT: Cores from Sirreta de la Cruz Creek Bridge tested at Missouri S&T

CC: Control Cores from Sirreta de la Cruz tested at Heghes Brothers in 2000

4.4 Burn-off Test

This test is also called fiber content test and is utilized to determine the ignition loss of cured resin. ASTM D2584 was followed to conduct the test. The specimens were cut into little pieces about 5 grams each. Next, the specimen was weighed before it was replaced inside a muffle furnace at 575°C until the resin was completely gone. Finally, the fiber content was determined based on the weight difference between the before and after the furnace entrance. Table 2 shows the test results.

Table 2: Burn-off test results

Bridge	Southview			Sirreta de la Cruz	
Specimen	CM-2017	CM1	CM2	CT-2017	CT
Number of samples	4	3	3	3	3
Fiber Content %	72.6	69.9	71.8	82.4	81.6
Resin Content %	27.4	30.1	28.2	17.6	18.4
Coefficient of variation %	1.79	4.32	3.34	2.39	3.07

CM-2017: Cores from Southview Bridge tested in 2017 at Missouri S&T

CM1&2: Cores from Southview Bridge tested for this study at Missouri S&T

CT-2017: Cores from Sirreta de la Cruz Creek Bridge tested in 2017 at Missouri S&T

CT: Cores from Sirreta de la Cruz Creek Bridge tested at Missouri S&T

4.5 pH

This test was utilized to evaluate the levels of alkalinity in the concrete medium. The normal range of concrete's pH, considering the bridges' ambient environment, was around 11 and 12. To measure the pH levels in concrete, Grubb procedure was utilized (Grubb et al., 2007) where two grams of concrete powder was mixed with distilled water in a 1 to 1 mass ratio. A set time of one minute was given to the mixture to enable it become a thick muddy-like solution. Next, pH strips were used to measure the solution's alkalinity. The test was conducted three times per each core. The results showed that the pH levels of the SV Bridge were a little over 12 (a little high) while for the SC Bridge, the pH levels were within 11 and 12.

4.6 Carbonation depth

Concrete cover protects steel reinforcement in RC structures from corrosion. The cover, though, is exposed to carbon dioxide of the surrounding atmosphere. When the carbon dioxide reacts with the alkalis in the concrete, concrete pH falls down. As a result, the alkalinity level in concrete will be reduced and expose the concrete to carbonation attack. It has been proposed that corrosion takes place when the depth of carbonation is equal to the concrete cover. To conduct the test, RILEM-94 (RILEM and Materials, 1994) was implemented where 1% of phenolphthalein was added to a 70% ethyl alcohol solution to form a solution used as an alkalinity indicator. The solution was sprayed to a fresh cut of the concrete core's surface. Next, an observation was made to the color of the surface, if the surface's color turned from concrete grey color to purple, it indicates there is no carbonation attack as the medium is alkaline. The darker the purple color is, the more alkaline the medium is. The results showed that for the SV Bridge, there were no signs of carbonation attack. However, in the SC Bridge, a carbonation depth of 13 mm to 25 mm was observed. Fig.4 shows the results of the carbonation depth test.



Fig. 4: Carbonation depth test (A) Southview Bridge (B) Sierrita de la Cruz Creek Bridge

4.7 Chlorides content

The main source of corrosion is chloride (Sagues, 1997). Therefore, a chlorides content test was performed to evaluate the levels of chlorides in the GFRPs surrounding concrete. Mainly, there are two techniques to find the chlorides levels, acid-soluble and water-soluble techniques. The acid technique can be used to find the total content of chlorides which are the chlorides trapped inside the concrete voids and the ones that damage the oxide films surrounding the rebar. In this test, acid-soluble technique was applied to measure the chlorides content (Transportation, 2012). A concrete powder of 1 ½ grams was taken out of the cores and was then added to a chloride agent vials and left out for 24 hours to let the agent's reaction takes place. Next, the calibration process was taken place where different concentrations of chloride solutions were used to draw the chlorides content curve. After calibration, a voltage meter was utilized to measure the chlorides content from the vials. The reading was then compared to the calibration curve to see the level of significance of chlorides. It was found that chlorides content in both bridges were insignificant.

5 CONCLUSIONS

5.1 *Southview Bridge (SV)*

- SEM exhibited no signs of microstructural deteriorations.
- EDS exhibited no signs of chemical elemental changes.
- SBS results were in match with those resulted from previous tests (same rebars but different cores).
- Fiber content results were in match with those resulted from previous tests (same rebars but different cores).
- pH levels were a little high for such concrete (little over 12).
- Carbonation depth was not present in this bridge.
- Chlorides level was insignificant.

5.2 *Sierrita de la Cruz Creek Bridge (SC)*

- SEM showed no signs of degradations.
- EDS exhibited no signs of chemical elemental changes.
- SBS results were in match previous tests results (same rebars but different cores).
- Fiber content results showed no signs of fiber loss and were in match with the previous tests results (same rebars but different cores).
- pH levels within the normal range, between 11 and 12.
- Carbonation depth was present with a depth between 13 mm to 25 mm.
- Chlorides content was insignificant.

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