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GFRP Bars Extracted from Bridges in Service for 15 to 20 Years

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Abstract

To evaluate the durability of Glass Fiber Reinforced Polymer (GFRP) rebars in concrete structures, a collaboration between the University of Miami, Penn State University, Missouri University of Science and Technology and Owens Corning Composites investigated GFRP rebars extracted from eleven bridges with 15 to 20 years of service. The investigated bridges are exposed to wet and dry cycles, freeze-thaw cycles and de-icing salts.

To study the durability of the GFRP rebars, 100 mm-diameter concrete cores (intersecting the reinforcement) were extracted from the bridges. A variety of tests were performed to evaluate the physical, mechanical and chemical properties of the GFRP bars and the condition of the surrounding concrete. The GFRP tests performed during this study were: fiber content, water absorption, differential scanning calorimetry (DSC), horizontal shear, scanning electron microscope (SEM), energy-dispersive X-ray spectroscopy (EDS), moisture content and modified tensile strength test.

The primary objective of this paper is to provide information on the overall scope of the project, the selected bridges and the types of tests conducted.

Keywords: GFRP bar; durability; bridge; in-service behavior

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Introduction

Glass fiber reinforced polymer (GFRP) bars have been used as the primary reinforcement in bridge decks and other ancillary structures. To evaluate the proposition that GFRP bars can increase the longevity of reinforced concrete, a collaborative study between the University of Miami (UM), Penn State University (PSU), Missouri S&T (S&T) and Owens Corning Composites (OC) investigated the condition of GFRP bars and surrounding concrete extracted from 11 bridges with 15 to 20 years of service.

To perform the investigation, concrete cores (intersecting the reinforcement) were extracted from the bridges. The GFRP bar coupons and surrounding concrete underwent a variety of tests to determine their current condition. The tests results were used to compare with data obtained from pristine GFRP bars at the time of installation. When test data from the time of installation was not available, results were compared to current bar standards, for reference. The objective of this paper is to review the testing procedures and present an overview of the conclusions from the testing program.

Selected Bridges

The eleven bridges investigated are located across the United States. Each of the bridges contains GFRP bars in the deck or other location and has been in service for at least 15 years. The bridge names and their respective state, given in parenthesis, are: Gills Creek Bridge (VA), O'Fallon Park Bridge (CO), Salem Ave Bridge (OH), Bettendorf Bridge (IA), Cuyahoga County Bridge (OH), McKinleyville Bridge (WV), Thayer Road Bridge (IN), Roger's Creek Bridge (KY), Sierrita de la Cruz Creek Bridge (TX), Walker Box Culvert Bridge (MO) and Southview Bridge (MO).

Sample Extraction

Concrete cores of approximately 100 mm in dia. by 150 mm in length were extracted from the bridges using a concrete core barrel. When possible, the targeted locations of extraction were areas with cracks and signs of environmental deterioration.

The number of extracted cores varied between bridges based on what was allowed by the owner. The inability to precisely locate the bars prior to coring resulted, at times, in samples with small-length bars, and in some cases no bar at all. Figure 1 shows typical extracted cores and bars.

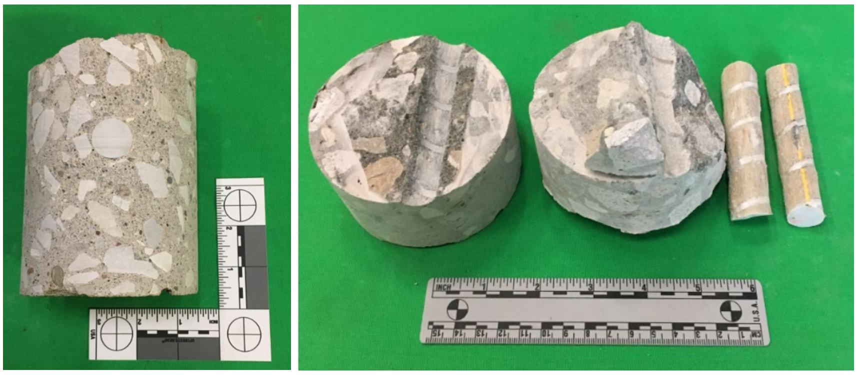

Figure 1: Extracted cores and bars

GFRP and Concrete Tests

To maximize the use of the small bar pieces for durability testing, an inventory for the GFRP samples was created. This inventory was evaluated along with the capabilities of the laboratory of each collaborator and, consequently, assignments were made and samples distributed. Due to the limited inventory, bars from the same bridge with the same nominal diameter were considered to be the same bar in order to achieve a minimum of three repetitions per test. The GFRP tests performed during this study were: fiber content, water absorption, glass transition temperature, horizontal shear strength, scanning electron microscope (SEM) inspection, energy-dispersive X-ray spectroscopy (EDS), moisture content and tensile strength.
As long-term durability of GFRP bars is related to the surrounding environment, evaluating the condition of the concrete is of relevance. The tests performed on concrete were: chloride penetration, carbonation depth and pH. These tests allow determining the concrete condition at the depth of the reinforcement, and, therefore, how such conditions may affect the durability of GFRP bars.

GFRP Test Results

Tests were performed in accordance with ASTM standards when possible. The results of the tests were compared to data collected at the time of bar installation or to current standards when data was not available.

Fiber Content
GFRP bars from all eleven bridges were tested for fiber content. All bars tested presented an average fiber percentage by volume higher than 70%, which is the minimum required by ASTM D7957 [1] for quality control and certification of GFRP reinforcement bars**.**

Water Absorption
Water absorption was performed on bars from the Gills Creek, O'Fallon Park, Salem Ave., Bettendorf Bridge, Cuyahoga, McKinleyville and Roger's Creek bridges. This test was performed in accordance with ASTM D7957 [1], which establishes a limit of 0.25% weight change at 24 hrs. and 1% weight change at equilibrium when the bar is immersed in 50°C distilled water. ASTM D570 [2] was followed to measure moisture uptake. At 24 hrs., all bars had less than 1% weight change, while some bars had weight changes of up to 2% at equilibrium.

Horizontal Shear
Due to the variable length of extracted specimens, bars from only eight bridges could be tested for horizontal shear strength. These bridges were O'Fallon Park, Salem Ave., Cuyahoga, McKinleyville, Thayer Road, Sierrita de la Cruz Creek and Southview. The bars were tested in accordance with ASTM D4475 [3]. The horizontal shear strengths ranged from 30 to 47 MPa. The Sierrita de la Cruz and Southview bars had shear strengths greater than those measured when the bars were installed.

Glass Transition Temperature
Glass transition temperature (T_g) of the bars was measured by differential scanning calorimetry (DSC) in accordance with ASTM E1356-08 [4]. Bars from eight bridges were tested by DSC: Bettendorf, Cuyahoga, Gills Creek, O'Fallon Park, Salem Ave., Roger's Creek, McKinleyville, and Thayer Road. The results were compared to the limit stablished by

ASTM D7957 [1] that specifies a T_g by DSC higher than 100°C. The Bettendorf and Salem Ave. bridges had T_g values higher than 100°C, while the Cuyahoga, Gills Creek, O'Fallon Park, Roger's Creek, McKinleyville, and Thayer Road bars had T_g values ranging between 80°C and 95°C.

SEM/EDS

SEM imaging and EDS analysis were performed in GFRP bars from all eleven bridges. Evidence of fibers being negatively affected by the concrete environment after 15 years in service is minimal and less than expected or predicted by accelerated test methods [5]. Physical damage on fibers was observed on the outer edge of some bars, typically near a void in the resin matrix. At times, damage is likely due to the specimen preparation procedure (saw cutting and polishing). Overall, it was estimated that approximately 0.05% to 0.12% of the total number of fibers was damaged.

Moisture Content

Moisture content of the bars was measured by drying the as-received bars to equilibrium in a forced-air oven set to 80°C, according to ASTM D5229 Procedure D [6]. Moisture content was performed on sample bars from five bridges: Gills Creek, Salem Ave., Bettendorf, O'Fallon Park and Cuyahoga. Of the two tests completed to-date, the moisture loss at equilibrium was less than 0.5%, which is within the 1% limit established by ASTM 7957 [1] for saturated moisture content at 50°C.

Tensile Strength

As the length of the GFRP bars extracted from Sierrita de la Cruz Creek exceeded that of bars from other bridges, it allowed for a modified tensile strength test. The modified tensile strength test used extracted bars cut into coupons of approximately 11 mm x 254 mm x 2.5 mm (width x length x thickness). These thin laminates were obtained from extracted bars as well as new bars. Full-size new generation virgin bars were also tested [7]. The results from the new generation virgin full-size bars were compared to data from tensile tests performed in 2000 on bars used in Sierrita de la Cruz Creek. Consequently, a correlation factor between the coupon ultimate tensile strength and the full-sized ultimate tensile strength was calculated and used to interpret results. It was found that the extracted GFRP bars had a reduction in strength of 2.1% over 17 years of service.

Concrete Test Results

Chloride Penetration

The chloride penetration test consisted of applying a 0.1M silver nitrate solution to fresh broken concrete cores. The difference in the color of the concrete due to the silver nitrate was difficult to identify in some of the samples. For some bridges, no chloride penetration was observed in the samples, and in the worst case, about 60 mm of chloride penetration was observed, a depth exceeding the location of the reinforcement.

Carbonation Depth

Carbonation depth was determined by using a phenolphthalein indicator solution sprayed over a freshly-cut concrete surface. The surface was monitored to observe any change in color. A surface turns pink when pH is above 9, and remains colorless when the pH is below 9. Concrete from eleven bridges were tested for carbonation depth. Most samples presented some carbonation near the surface, while others presented no carbonation. Sierrita de la Cruz Creek samples, however, presented significant depth of carbonation of about 40 mm.

pH

For the pH test two procedures were used: the procedure outlined by Grubb et al. [8] and a rainbow indicator from Germann Instruments, Inc. The pH of the samples varied between 9 and 13. The lowest average pH for was 10 for both Roger's Creek and McKinleyville bridges, while the highest average pH was 12.2 for both Cuyahoga and Gills Creek bridges.

Conclusions

A variety of tests were performed to assess physical-chemical and mechanical conditions of GFRP bars and its surrounding concrete from eleven bridges with 15 to 20 years of service. The results allow the evaluation of the long-term durability of GFRP reinforced concrete structures. Despite the challenge of working with a limited number of small samples, this study provides additional evidence to validate the long-term durability of GFRP bars in concrete structures. The results of the tests were overall positive and indicated minimal degradation of GFRP after at least 15 years of service.

Acknowledgments

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