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Durability Evaluation of Bridge-Extracted GFRP Bars

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Abstract

A recent collaborative study investigated the durability of GFRP reinforcement bars extracted from bridges with 15 to 20 years of service. The scope of the investigation included physical, mechanical and chemical properties. The tests performed included fiber content, water absorption, scanning electron microscopy (SEM) imaging, energy dispersive X-ray spectroscopy (EDS), horizontal shear strength and differential scanning calorimetry. The tests results were compared to data on pristine bars at the time of installation or to current standards when no data was available. SEM and EDS tests, providing information of the visual appearance and chemical composition of cross-sections of bars, are the focus of the present paper. The results showed no difference in elemental composition of fibers near the surface and in the interior of the bars, indicating that the fibers were chemically unaffected after 15 to 20 years of service.

Keywords: GFRP bars; durability; SEM; EDS; bridges

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Introduction

GFRP rebars were extracted from eleven bridges in the United States and evaluated in the laboratories of the University of Miami (UM), Pennsylvania State University (PSU), Missouri University of Science and Technology (S&T) and Owens Corning Composites (OC) [1]. The investigated bridges have been in service for 15 to 20 years and were built with GFRP bars as the primary reinforcement in the bridge deck and other ancillary structures. The extracted bars underwent a variety of tests, including fiber content, water absorption, scanning electron microscopy (SEM) imaging, energy dispersive X-ray spectroscopy (EDS), horizontal shear strength and differential scanning calorimetry, to determine their current condition and compare with data from the time of installation or to current standards when original data is not available. Most tests complied with minimum requirements for quality control and specification of ASTM D7957 [2]. Tensile strength was comparable to the original data obtained for material acceptance [3], indicating superior real-time durability performance versus typical accelerated testing results [4]. SEM and EDS are chosen as the focus of the present paper as these tests provide information on the visual appearance and chemical composition of cross-sections of the bars, which can potentially be correlated with the mechanical test results.

Test performed

SEM

SEM provides images with profound depth and detail and, therefore, is an effective micro analysis procedure. SEM can reach a magnification of 300,000X and consequently yield images with important information such as texture, surface variation, density and material composition.

SEM imaging was performed on GFRP bar samples from the following bridges: Gills Creek, Bettendorf, O'Fallon, Salem Ave., Sierrita de la Cruz Creek, Thayer Road, Roger's Creek, McKinleyville, Cuyahoga, Walker Box Culvert and Southview. The SEM images were taken at the laboratories of the University of Miami, Missouri S&T and Owens Corning.

The SEM images were taken on the full cross section of the extracted bars. The procedure for preparing the samples at the University of Miami and Missouri S&T included cutting the bar into specimens of approximately 6 mm in length using a water-cooled diamond saw. The samples were then sanded according the procedure shown in Table 1 and polished with 1µm and 3 µm polish cloth for 3 minutes. After polishing, samples were sputter-coated with gold to allow for high magnification microscopy without charge accumulation.

Table 1. Sanding procedure

FEPA Sanding Disc Grit	Spindle Speed (rpm)	Table Speed (rpm)	Force (N)	Cycle Time (min)	Number of Cycles
P320	65	120	4.5	2	1
P800	65	120	4.5	2	1
P1200	65	150	4.5	2	1
P2400	80	150	9	2	1
P4000	80	150	9	2	1

EDS

EDS can be performed at the same time as SEM when EDS detectors are used. EDS provides the chemical composition of the sample. EDS was also performed at the University of Miami, Missouri S&T and Owens Corning for bar samples from all eleven bridges.

Analysis and Results

SEM

Figures 1, 2 and 3 show representative SEM images from selected GFRP bars. In general, the SEM images presented minimal evidence of fibers being negatively affected by concrete environment over time. Resin rich areas appeared as dark swirls in low magnification images. Fibers that presented physical damage were generally located on the outer perimeter of the bar cross-section. Most of the observed fiber damage appeared to be due to specimen preparation (e.g. saw cutting, polishing) as the damage appeared near resin voids where the fibers have little mechanical support. Other fiber imperfections in the periphery region appear to have been scuffed during bar production, as the interface and matrix around such sites was completely intact (Figure 1). Overall, the SEM investigation revealed little of the fiber/matrix debonding, matrix, cracking, and fiber cracking seen in accelerated testing [4].

A quantitative assessment of fiber degradation due to environmental effects was established by counting the fibers with obvious signs of environmental degradation in one quadrant of the bar cross section and multiplying by four to obtain a full cross-section of the bar. This approach was justified by the fact that the distribution of degraded fibers was practically uniform along the perimeter of a bar cross-section. For example, in the case of Gills Creek Bridge (Figures 2 and 3), it was estimated that 192 out of 352,000 fibers were environmentally degraded. For extrapolation of degraded fibers, it was estimated (also from counting fibers in one quadrant and multiplying by four), that 412 out 352,000 fibers were damaged. In other words, about 0.05% to 0.12% of fibers were deteriorated due to environmental effects. Such minimal deterioration can be expected to have a negligible impact on tensile properties.

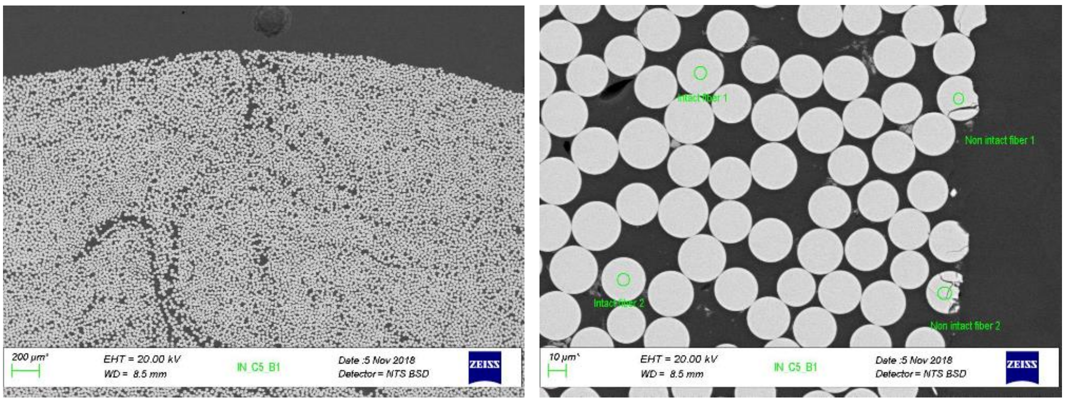

Figure 1: Images from Thayer Road bar. Edge of cross-section and partial fibers

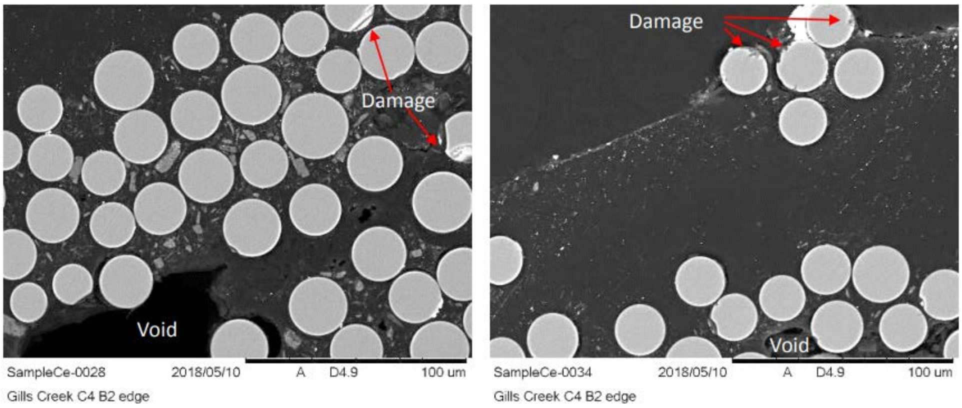

Figure 2: Images from Gills Creek bar. Edge of cross-section with fiber damage.

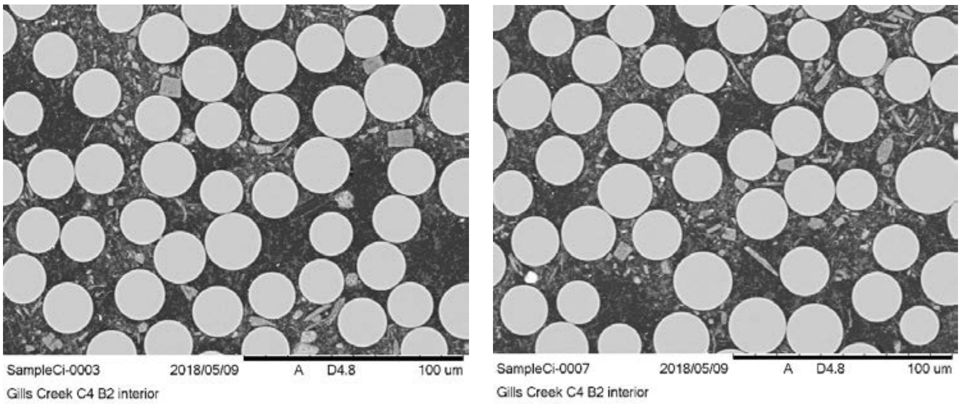

Figure 3: SEM images from Gills Creek bridge. Interior with no fiber damage.

EDS

The results of EDS analysis showed the predominance of Si, Al, Ca (from glass fibers) and C (from the matrix) chemical elements in the extracted samples. For the Roger's Creek bar in Table 2, no difference in chemical composition was seen in pristine fibers evaluated near the center of the bar and partial fibers seen near the periphery. Figure 4 shows an example EDS result for Sierrita de la Cruz bridge, where the vertical axis corresponds to the counts (number of X-rays received and processed by the detector) and the horizontal axis presents the energy level of those counts.

Table 2: EDS result from Roger's Creek bridge.

Sample Name		Na	Mg	Al	Si	Ca	Ti	Fe	Total
KY_C2_B2	Central fiber (avg)	1.50	0.70	14.50	60.40	22.20	0.50	0.20	100.1
KY_C4_B1	Central fiber (avg)	1.40	0.70	14.40	60.10	22.40	0.60	0.30	100.0
KY_C2_B2	Partial fiber (avg)	1.50	0.70	14.50	60.30	22.30	0.60	0.20	100.0
KY_C4_B1	Partial fiber (avg)	1.50	0.70	14.30	60.00	22.50	0.60	0.30	99.9

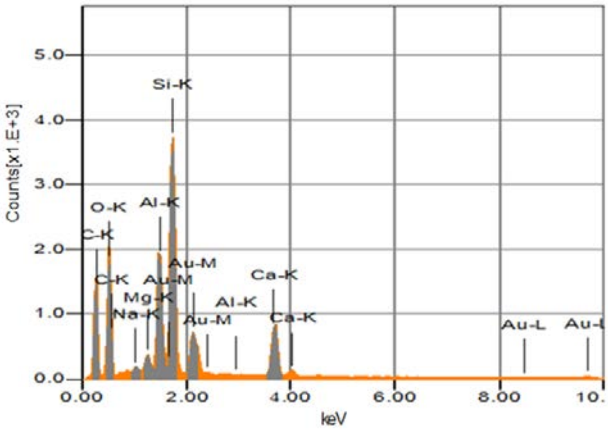

Figure 4: EDS result from Bettendorf bridge.

Conclusions

SEM and EDS evaluation GFRP bars extracted from 11 bridges with 15 to 20 years of service indicated minimal physical degradation of the fibers and no evidence of chemical attack by the environment. These results support the excellent tensile property durability of the bars reported in a companion paper and show that accelerated testing protocols may lead to pessimistic conclusions about the real-time performance of GFRP bars.

Acknowledgment

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