Long-Term Durability of GFRP Internal Reinforcement in Concrete Structures

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March 2017

The Concrete Convention
and Exposition

Outline

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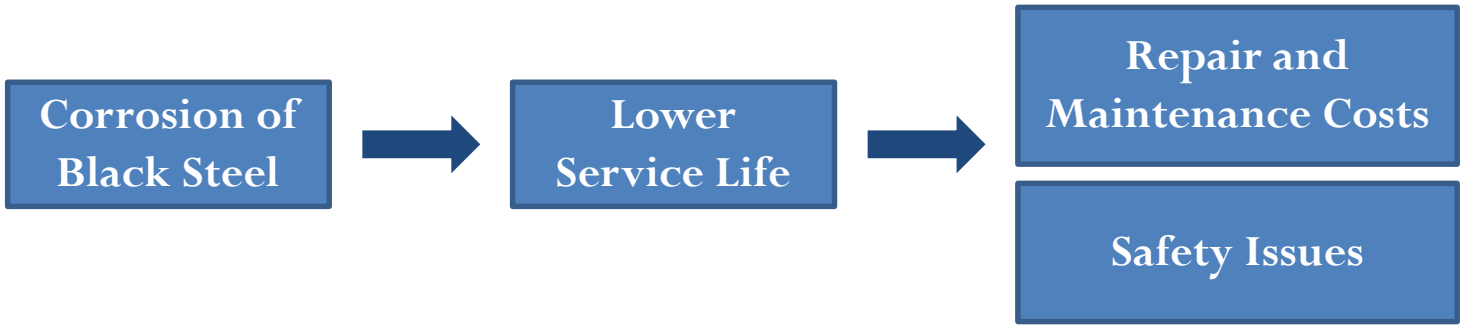
Introduction: GFRP Bars

- Glass fiber reinforced polymers (GFRP) bars are made of glass fibers (E, E-CR) as the load carrying member and the resin (Vinyl ester, polyester) to protect the fibers and transfer the load
- Steel is still the most common reinforcement for concrete but it suffers from corrosion problem

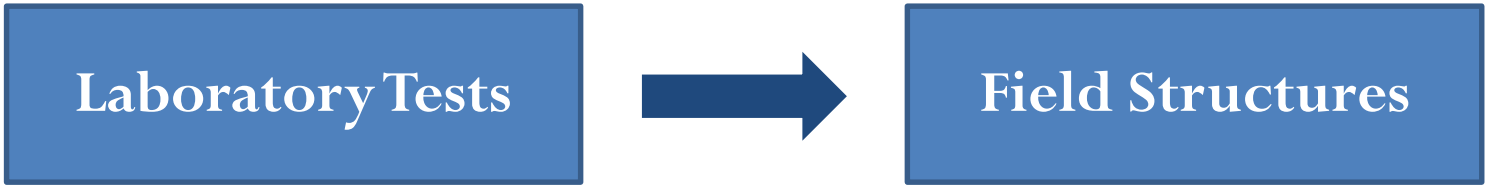
Introduction: GFRP Bars



- GFRP bars are emerging as an effective alternative for traditional steel reinforcement
  - High strength-to-weight ratio
  - Corrosion resistance
  - Higher service life of the structure
  - Magnetic transparency
  - Ease of demolishing

Introduction: GFRP Bars

- Confirmation of GFRP long-term durability in existing structures is critical to widespread acceptance in field applications



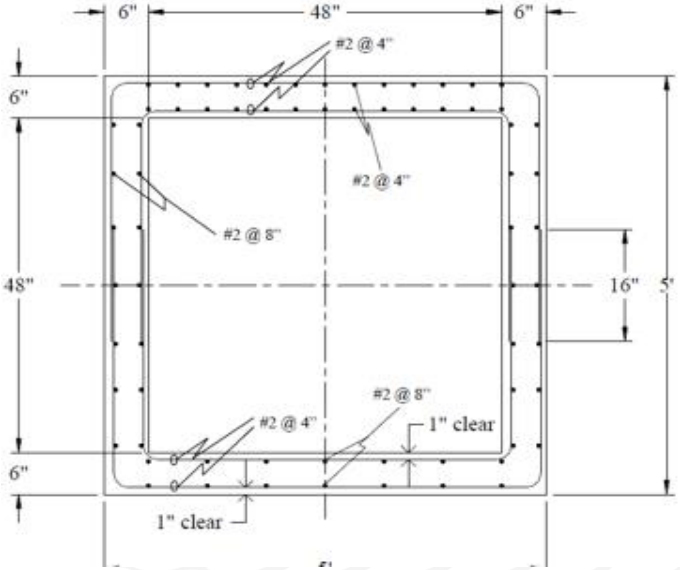
- Only a few studies of this type are available in the literature (Mufti et al. 2007, Gooranorimi et al. 2017)
- Two bridges located in the city of Rolla, Missouri which incorporated the GFRP bars were chosen as the case studies:
  - Walker Box-Culvert Bridge built in 1999
  - Southview Bridge built in 2004

Field Structures: Walker Box-Culvert Bridge

- It was built in 1999 on Walker Avenue in the City of Rolla, Missouri to replaced the old bridge (concrete with three encased steel pipes) which was unsafe to operate due to extensive corrosion of the steel pipes
- The new bridge is10.97 m (36 ft.) wide consisting of 18 boxes of 1.5 by 1.5 m (4.92 by 4.92 ft.) and the thickness of 150 mm (5.90 in.)

Field Structures: Walker Box-Culvert Bridge

- The RC boxes were entirely reinforced with No. 2 GFRP bars (E-glass & Polyester) pre-bent and cut to size by the manufacturer
- The bridge operates under the following environmental conditions: thermal range of -6 to +32 °C (21 to 90 °F), wet and dry cycles, freeze-thaw cycles and exposure to de-icing salt



Field Structures: Southview Bridge

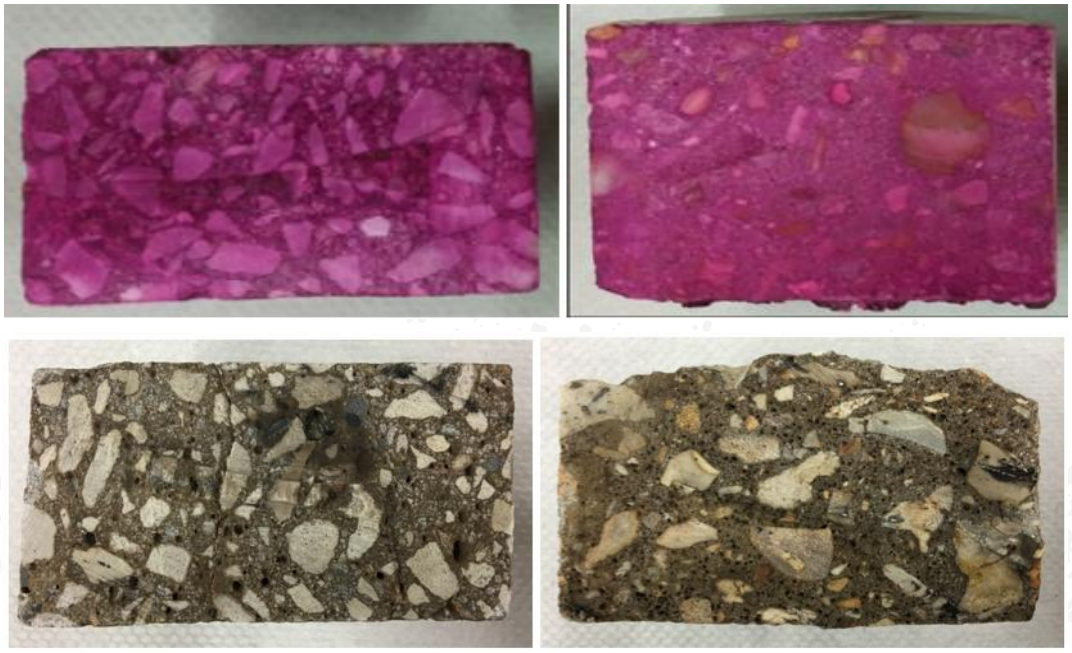
- Initially included four-cell steel reinforced concrete (RC) box-culverts
- The RC bridge slab went through an expansion in 2004 which included the construction of an additional lane and a sidewalk
- The new deck was built on three conventional RC walls as for the existing structure. The concrete deck of the complementary part implemented Nos. 3, 4 and 6 GFRP bars (E-glass &Vinyl ester) and No. 3 pre-stressed CFRP tendons

Sample Preparation and Extraction

- Expert personnel performed the sample extraction in 2016 for further investigation.
- Samples were extracted from the bottom surface of two of the boxes of Walker and from the deck of the Southview bridge
- GFRP coupons were properly prepared and polished for microscopic examination and mechanical tests

Concrete Characterization

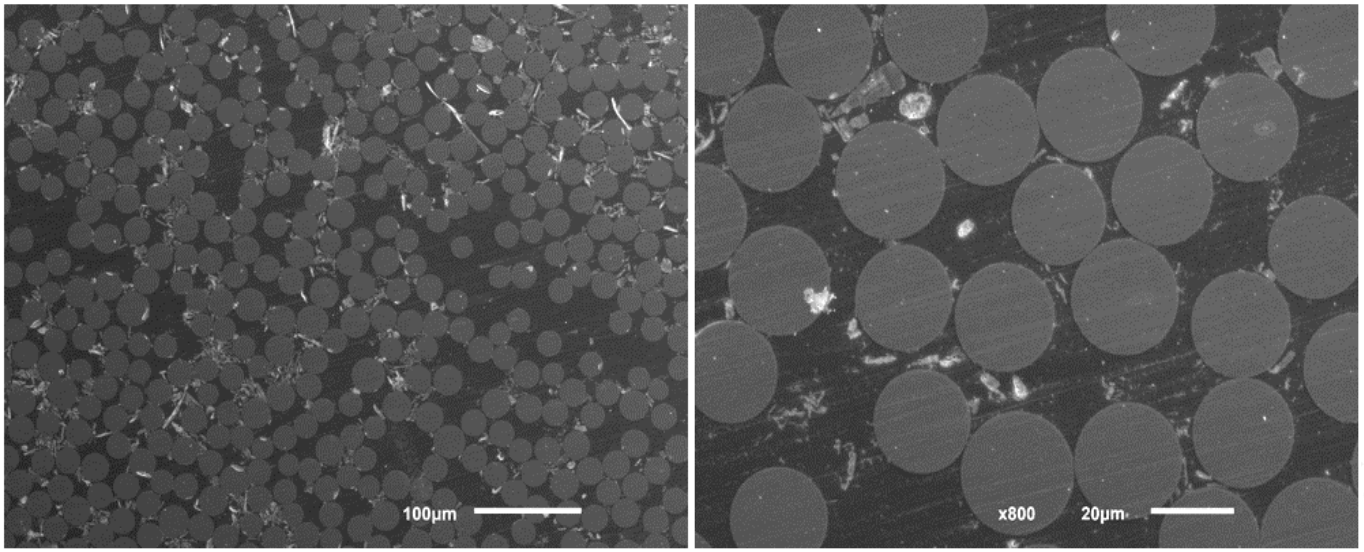
- Concrete pH was found to be in the range of 11-12 which is in agreement with the age and type of the concrete
- No sign of concrete carbonization and chloride diffusion was observed in the tested concrete samples



Walker Southview

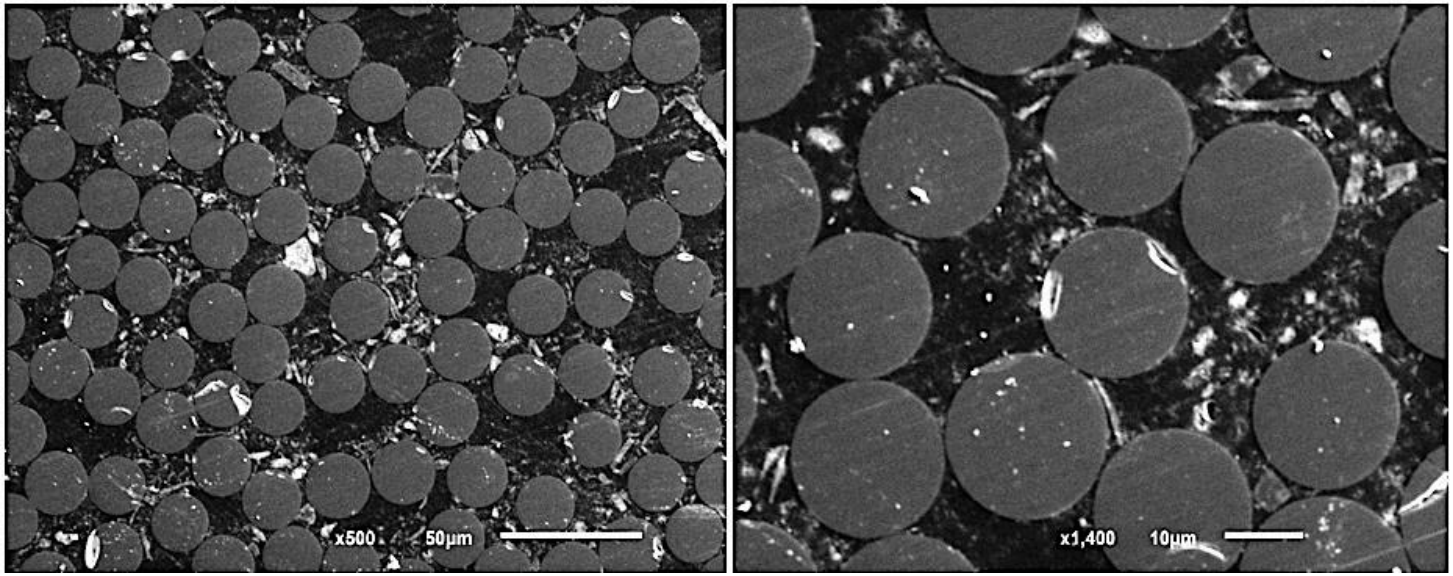
GFRP Characterization: SEM

- Mechanical tests and microscopic examination were performed on extracted GFRP coupons
- Scanning electron microscopy (SEM) was performed on GFRP samples from both bridges at different magnification levels.



SEM images of GFRP bar after 16 years of service in magnification levels of 200x (left) and 800x (right)

GFRP Characterization: SEM

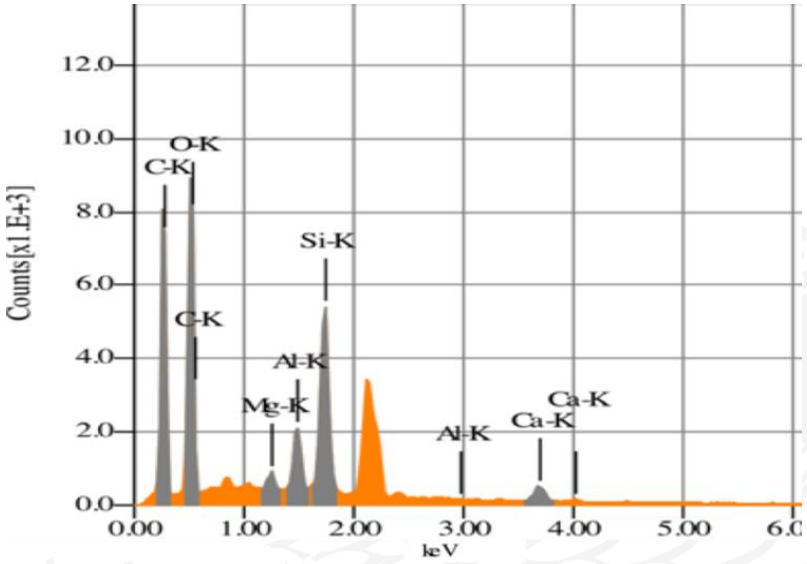


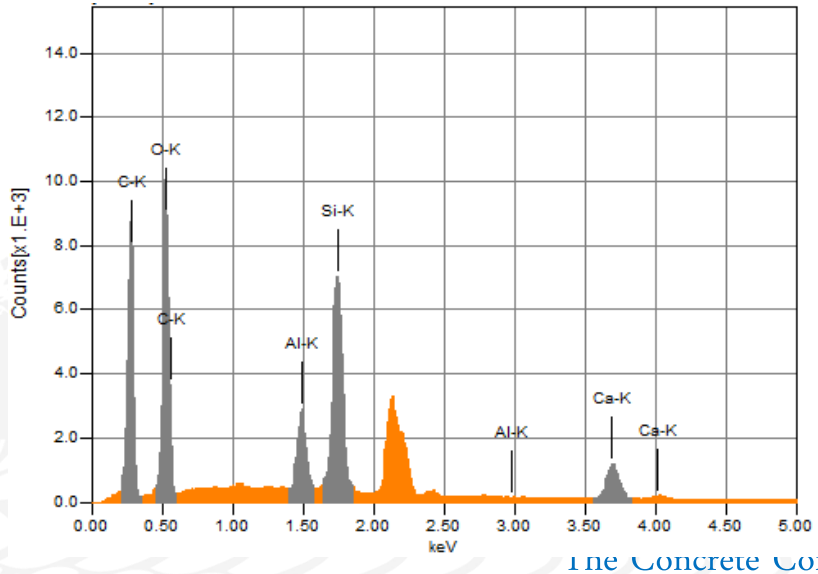
SEM images of GFRP bar after 11 years of service in magnification levels of 500x (left) and 1400x (right)

- No apparent sign of degradation in the fiber, matrix, and fiber-matrix interface was observed
- Glass fibers appeared to be intact without no loss of cross-sectional area.

GFRP Characterization: EDS

- Energy dispersive X-ray spectroscopy (EDS) was conducted
- No apparent sign of chemical attack was observed in GFRP samples (while a direct comparison is not possible)
- Si, Al, Ca (from glass fibers) and C (from the matrix) were the predominant chemical elements in the extracted samples

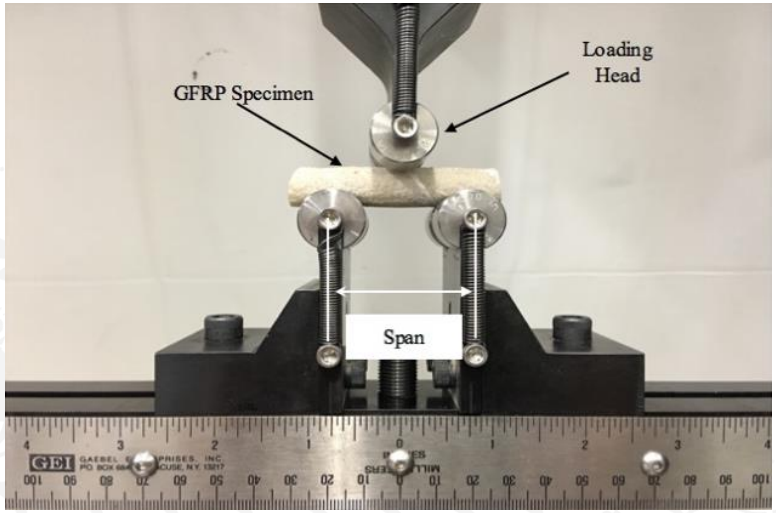




GFRP Characterization: Horizontal Shear

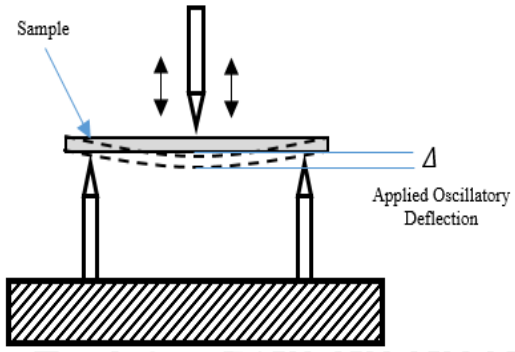
- The horizontal shear strength was determined following ASTM D4475
- The test was performed on three GFRP coupons extracted from Southview Bridge
- The extracted GFRP bars showed about 5% increase in horizontal shear strength compared to the samples produce in 2015. The increase may be a result of resin crosslinking over time

Nominal Diameter (mm)	Span Length (mm)	P_c			P_s		S_c (MPa)	S_s (MPa)	Ratio (S_s/S_c)
		No. of Samples	Average (kN)	CoV (%)	No. of Samples	Average (kN)			
13	38	5	8.8	2.4	1	9.33	46.5	49.1	1.05
19	57	5	20.5	3.6	2	21.7	47.9	50.7	1.06



GFRP Characterization: T_g

- Dynamic mechanical analysis (DMA) test was performed following ASTM E1640 standard to derive the glass transition temperature (T_g)
- The results were compared to the tests performed on GFRP bar produced in 2015
- T_g has increased probably due to curing of the resin over time if the resin is not 100% cured at time of production
- Results can serve for general comparison purpose due to change in the used constituent of the fibers/matrix by the manufacturer



	T_g^c			T_g^s		
Structure	No. of Samples	Average(°C)	CoV (%)	No. of Samples	Average (°C)	CoV (%)
Walker	3	81.0	16.9	3	111.9	2.5
Southview	3	81.0	16.9	3	100.6	2

GFRP Characterization: Fiber Content

- The fiber ratio measurement was followed by ASTM D2584 standard
- The results were compared to similar test performed in 2015
- The measured fiber contents after 16 and 12 years of field exposure were consistent with the expected values and well above the minimum fiber content requirement of minimum 70% by mass

Bridge	α_c			α_s		
	No. of Samples	Average (%)	CoV (%)	No. of Samples	Average (%)	CoV (%)
Walker	4	75.7	1.2	4	82.38	4.0
Southview	4	75.7	1.2	4	73.4	2.0

Conclusions

- GFRP and concrete samples were extracted from two bridges with more than a decade old
- The concrete pH was consistent with the concrete type and age
- No indication of carbonation and chloride diffusion was observed in the concrete samples
- Microscopic examination did not show any apparent sign of GFRP degradation in the fibers, matrix and fiber-matrix interface. No sign of chemical attack was observed
- The horizontal shear strength of the GFRP samples extracted from Southview bridge showed 5% increase compared to the bars produced in 2015
- T_g of the extracted GFRP samples was higher than that of the control samples produced in 2015 by the same manufacturer due to curing over time
- The result of fiber content measurement was consistent with the tests performed in 2015, showing "no apparent loss of fiber content in GFRP bars"
- This study confirms that GFRP bars maintained their microstructural integrity after 16 and 11 years of service

Thanks for your attention!

Question?