AMERICAN COMPOSITES MANUFACTURERS ASSOCIATION

Fiber Reinforced Polymer (FRP) ACI Guidelines and Field Installations

John P. Busel, FACI

National Concrete Consortium

April 25, 2018

Coeur d'Alene, ID

Outline

- About ACMA
- Introduction
- FRP Materials
- FRP Bars
- Standards & Specifications
- Applications
- Summary

About ACMA

- **World's largest composites trade association representing the entire composites industry supply chain:**

Manufacturers

Material Suppliers & Distributors

Composites Industry

3000+ Companies
280,000+ employees
North America
$30 Billion Industry

Industry Consultants

Academia

ACMA's Industry Council

- **Mission - Promote the use and growth of FRP reinforcement (rebar, tendons & grids) in concrete and masonry applications through development of quality procedures, industry specifications, performance standards, and field application guidelines.**

FRP-RMC

FRP Rebar Manufacturers Council

What are Composites? Fiber Reinforced Polymers (FRP)

- **Composites defined as:** materials created by the **combination** of **two** or more materials, to form a new and useful material with **enhanced properties** that are **superior** to those of the **individual constituents** alone
- **Composites material** –
  - Engineered materials which consist of more than one material type.
  - Combination of polymer matrix and fiber reinforcement

FRP Materials

Constituents

What is FRP?

Fibers

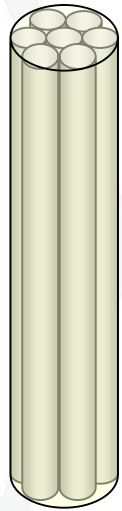
Provide strength and stiffness

Glass, Basalt, Carbon, Aramid

Matrix (polymer)

Protects and transfers load between fibers

Polyester, Epoxy, Vinyl Ester, Urethane



Fiber Composites Matrix

Creates a material with attributes superior to either component alone!
fibers **and** matrix both play critical roles in the composites material...

FRP Composites Rebar Features

- Impervious to chloride ion and chemical attack
- Tensile strength is greater that steel
- ¼ the weight of steel
- Transparent to magnetic fields and radar frequencies
- Electrically non-conductive
- Thermally non-conductive
- Fiber types: glass, basalt (emerging technology) and carbon

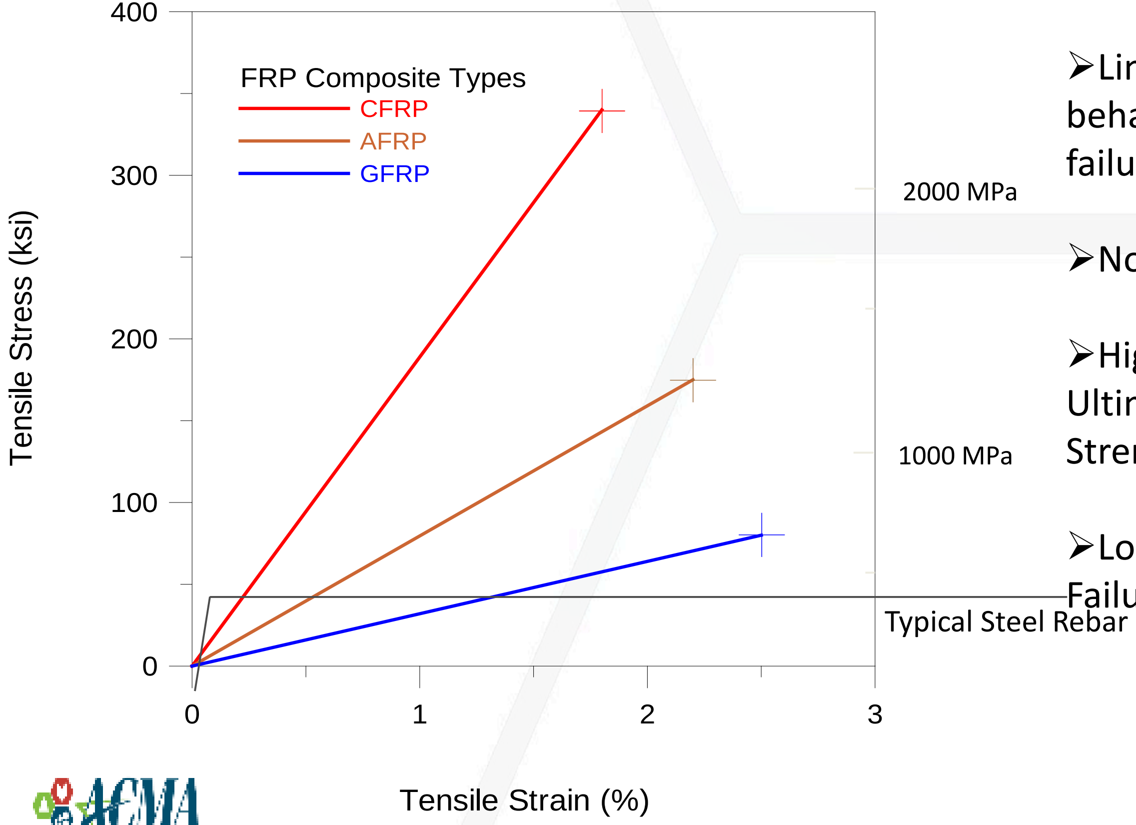
Where should FRP rebar be used?

- Corrosion: Any concrete member susceptible to corrosion by chloride ions or chemicals
- Alternative: To epoxy, galvanized, or stainless steel rebars
- Electro-magnetic: Any concrete member requiring non-ferrous reinforcement (toll booth area)
- Mining and tunneling: where machinery will "consume" the reinforced member
- Applications requiring Thermal non-conductivity

Why is FRP different from steel?

- **FRP is Anisotropic**
  - High strength in the direction of the fibers
  - This anisotropic behavior affects the shear strength, dowel action, and bond performance
- **FRP does not exhibit yielding: the material is linear elastic until failure**
  - Design should account for lack of ductility
  - Member does have substantial deformability
- **You design FRP different than steel**

Tensile Stress-Strain Characteristics of Reinforcement Fibers



- Linear elastic behavior to failure
- No yielding
- Higher Ultimate Strength
- Lower Strain at Failure

FRP Bar Properties Compared to Steel

	Steel	GFRP	CFRP
Yield Stress ksi (MPa)	40 - 75 (276 - 517)	N/A	N/A
Tensile Strength ksi (MPa)	70 - 100 (483 - 690)	70 - 230 (483 - 1600)	87 - 535 (600 - 3690)
Elastic Modulus X 10^3 ksi (MPa)	29 (200)	5.1 - 7.4 (35 - 51)	15.9 - 84 (120 - 580)
Yield Strain %	.14 - .25	N/A	N/A

Source: ACI 440.1R-15

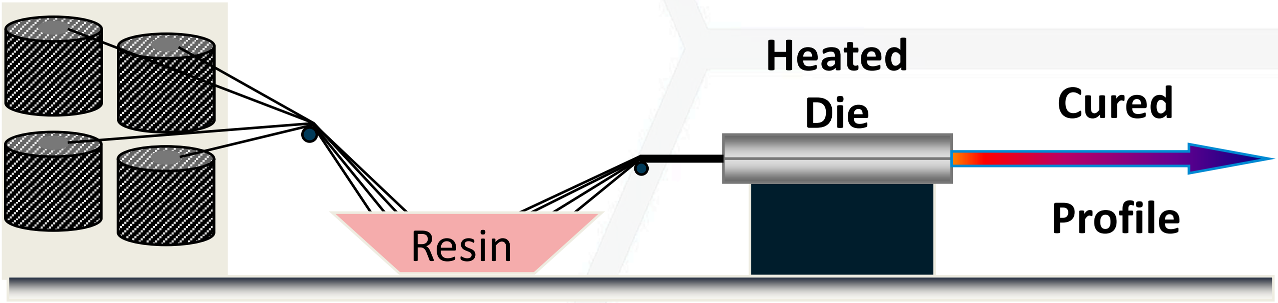
Typical GFRP Bar Properties

Bar Designation	Nominal Bar Dia. (in.)	Nominal Cross Sectional Area (in^2)	Guaranteed Tensile Strength (ksi)	Guaranteed Ultimate Tensile Force (kip)
2	¼	0.049	130	6.37
3	3/8	0.110	120	13.2
4	½	0.196	110	21.5
5	5/8	0.307	105	32.24
6	¾	0.442	100	44.20
7	7/8	0.601	95	57.10
8	1	0.785	90	70.65

Note: Basalt Fiber (BFRP) bar properties are equivalent or slightly higher than GFRP

Pultrusion Process

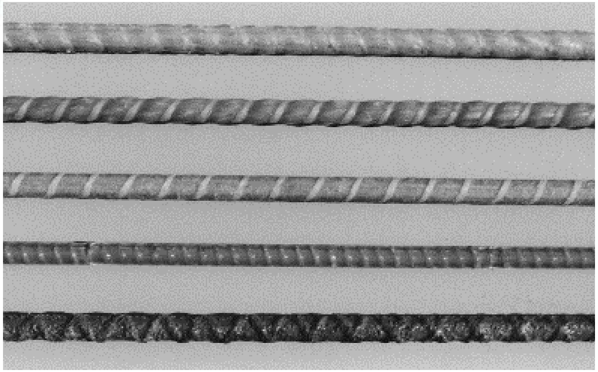
- Manufacturing method used to manufacture FRP bars



- Continuous manufacturing process, unlimited lengths
- Bends are manufactured in the plant

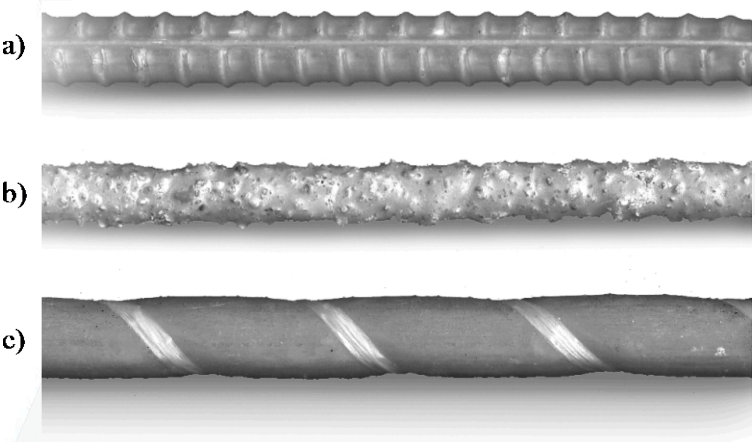
FRP Bar Types

- **Materials**
  - Glass/vinylester (most used)
  - Glass/polyurethane
  - Basalt/epoxy
  - Carbon/vinylester
- **Forms**
  - Solid
  - Round



FRP bar types

- **Surface**
  - ➢ Ribbed (a)
  - ➢ Sand Coated (b)
  - ➢ Helically Wrapped and Sand Coated (c)

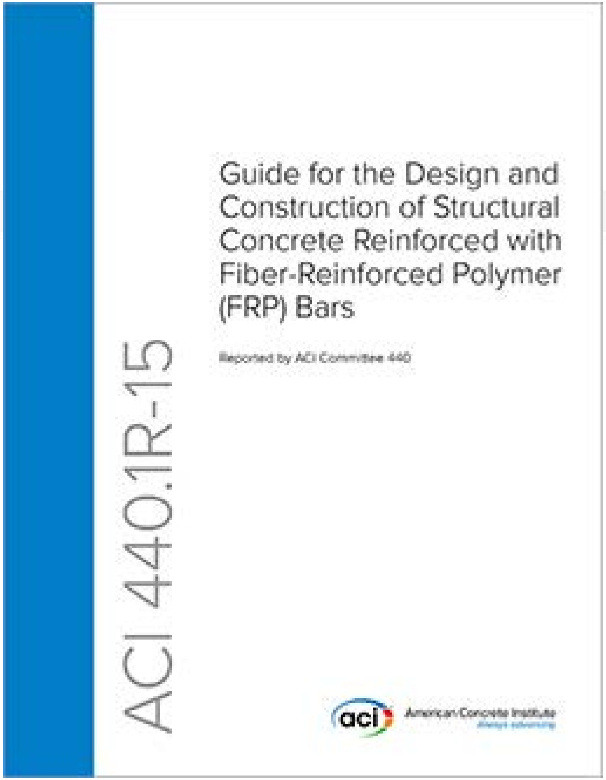


Innovation – hollow bar

Courtesy of Composite Rebar Technologies, Inc.

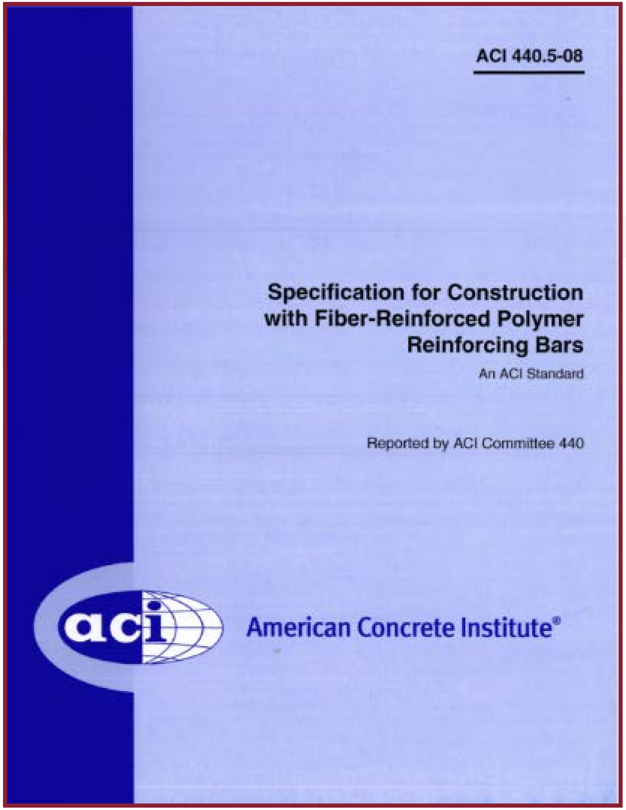
ACI – rebar design guideline

- Design principles well established through extensive research
- Non-mandatory language
- ACI 440.1R-15
  - 4th update to document
  - Current research added
  - Added direction on high temperature and fire effects
  - Design examples enhanced and reorganized.
- Guideline documents published in Europe and Japan using 440.1R



ACI – FRP Rebar Construction Spec

- ACI 440.5-18
  - o **Recently updated**
  - o **mandatory language** (standard document)
- GFRP bar
  - o preparation,
  - o placement (including cover requirements, reinforcement supports),
  - o repair, and field cutting


ACI 440.5-08

Specification for Construction with Fiber-Reinforced Polymer Reinforcing Bars

An ACI Standard

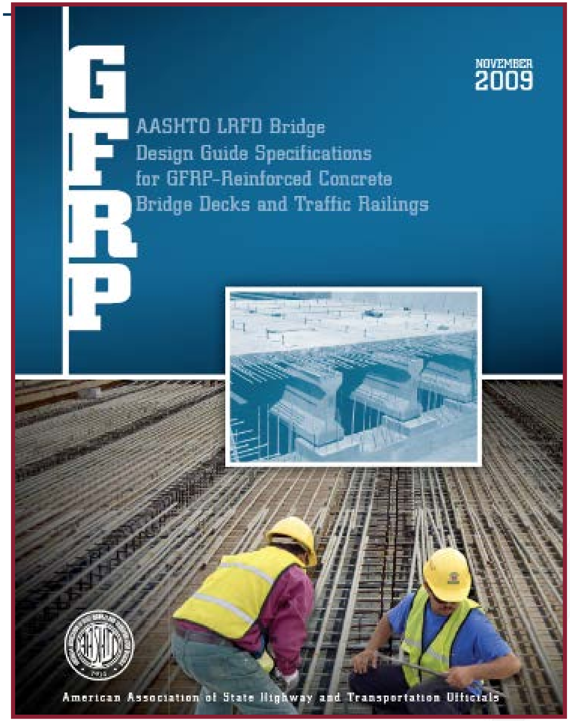
Reported by ACI Committee 440

American Concrete Institute®

ACI – Standard Under Development

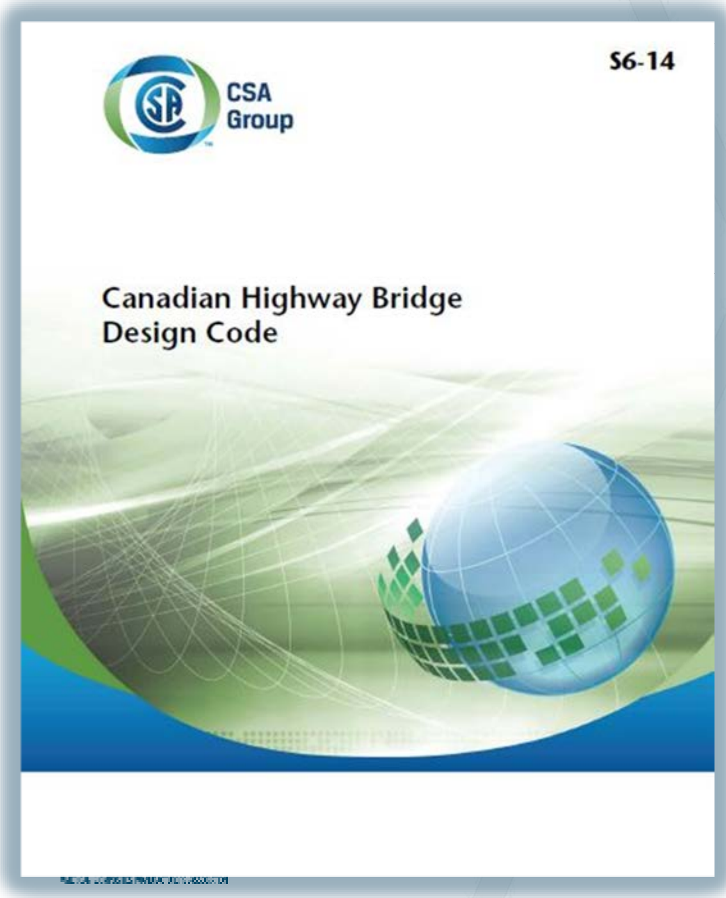
- **New FRP Rebar Design Code**
  - In 2014, ACI TAC approved a new standard development
- **Dependent Code**
  - Aligned with the exact chapters and structure ACI 318-14
  - Only chapters that impact FRP will be re-tooled to reflect the properties, characteristics, etc.
- **Draft nearly finished (2019)**

AASHTO design guide



- AASHTO LRFD design guide specifications published 2009
- Bridge decks and traffic railings, glass FRP (GFRP) bars
- ***Updated in 2018***, presented to ASSHTO SCOBS T-6 for review and vote by AASHTO (June 2018)
- Design algorithms and resistance factors, detailing, material and construction specifications
- All concrete elements for a bridge

Canada - Highway Bridge Design Code

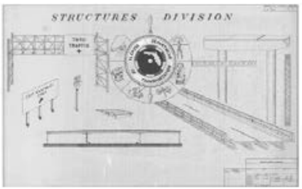


Technology transitioned from government-subsidized research projects to actual commercialization

Experience gained on viability of construction management practices where FRP reinforcement is adopted through traditional bid letting processes and competitive bidding from multiple FRP bar suppliers

End-user guidance spec's

FLORIDA DEPARTMENT OF TRANSPORTATION



FIBER REINFORCED POLYMER GUIDELINES (FRPG)

FDOT STRUCTURES MANUAL
VOLUME 4
JANUARY 2016

FDOT

Specifications and Estimates/Specifications/

Materials Manual Section 12.1, Volume II

FIBER REINFORCED POLYMER COMPOSITES

Section 12.1, Volume II

2016

FDOT

Design Standards

For Construction and Maintenance Operations on the State Highway System

Topic No. 625-010-003

State of Florida Department of Transportation
Office of Design
Mail Station 32
605 Suwannee Street
Tallahassee, Florida 32399-0450

ACMA
American Composites Manufacturers Association

International Code Council – Acceptance Criteria

- AC454 Glass Fiber-reinforced Polymer (GFRP) Bars for Internal Reinforcement of Concrete Members—Approved June 2014
- Establishes guidelines for evaluation of an alternative reinforcement for steel-reinforced concrete structures, where the codes do not provide design provisions, or requirements for testing and determination of physical and mechanical properties of this type of reinforcement products.

FRP Rebar ASTM Test Methods

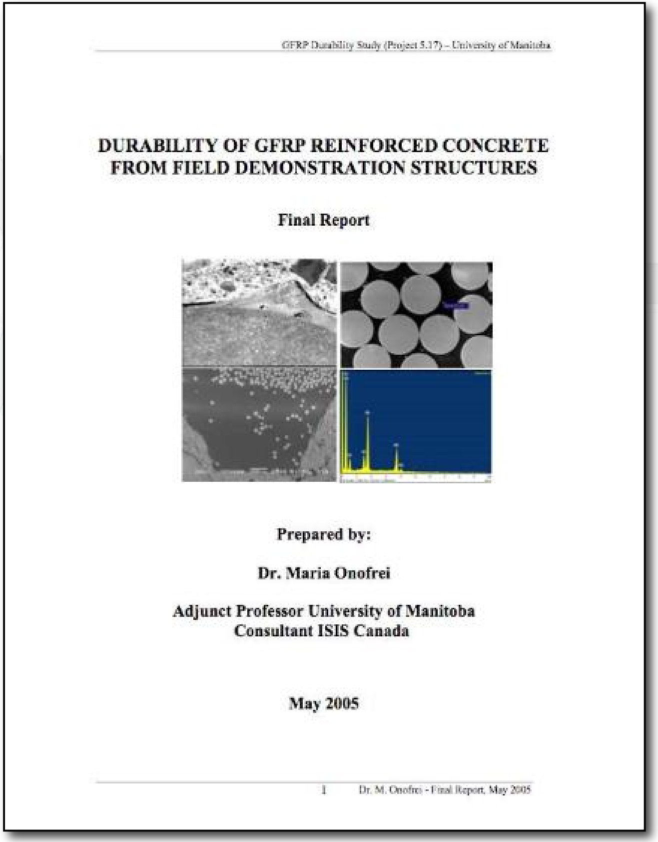
D7205-06(2016)	Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars
D7290-06(R17)	Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications
D7337-12	Standard Test Method for Tensile Creep Rupture of Fiber Reinforced Polymer Matrix Composite Bars
D7522-15	Standard Test Method for Pull-Off Strength for FRP Laminate Systems Bonded to Concrete Substrate
D7565-10(2017)	Standard Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures
D7616-11(R17)	Standard Test Method for Determining Apparent Overlap Splice Shear Strength Properties of Wet Lay-Up Fiber-Reinforced Polymer Matrix Composites Used for Strengthening Civil Structures
D7617-11(R17)	Standard Test Method for Transverse Shear Strength of Fiber-reinforced Polymer Matrix Composite Bars
D7705-12	Standard Test Method for Alkali Resistance of Fiber Reinforced Polymer (FRP) Matrix Composite Bars used in Concrete Construction
D7913-14	Standard Test Method for Bond Strength of Fiber-Reinforced Polymer Matrix Composite Bars to Concrete by Pullout Testing
D7914-14	Standard Test Method for Strength of Fiber Reinforced Polymer (FRP) Bent Bars in Bend Locations
D7958-17	Standard Test Method for Evaluation of Performance for FRP Composite Bonded to Concrete Substrate using Beam Test
D7957-17	**Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement**

Canadian Standards

- CSA S807–09
- Qualification and QA criteria

Durability

- Canadian report on Durability of GFRP bars in Bridge Decks in Service for 8-10 years
- Multiple reports from several institutions
- *NO Degradation of GFRP bars found !*
- Follow-up reports after 15 years


GFRP Durability Study (Project 5.17) – University of Manitoba

DURABILITY OF GFRP REINFORCED CONCRETE FROM FIELD DEMONSTRATION STRUCTURES

Final Report

Prepared by:

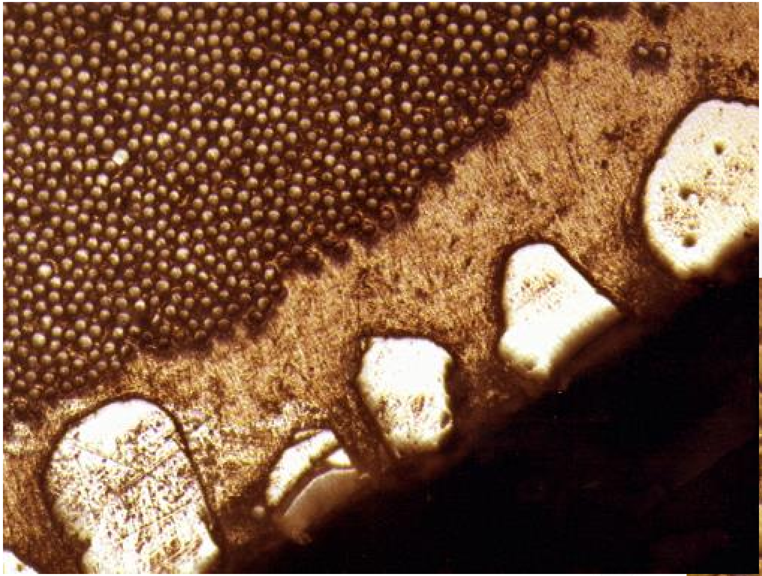
Dr. Maria Onofrei

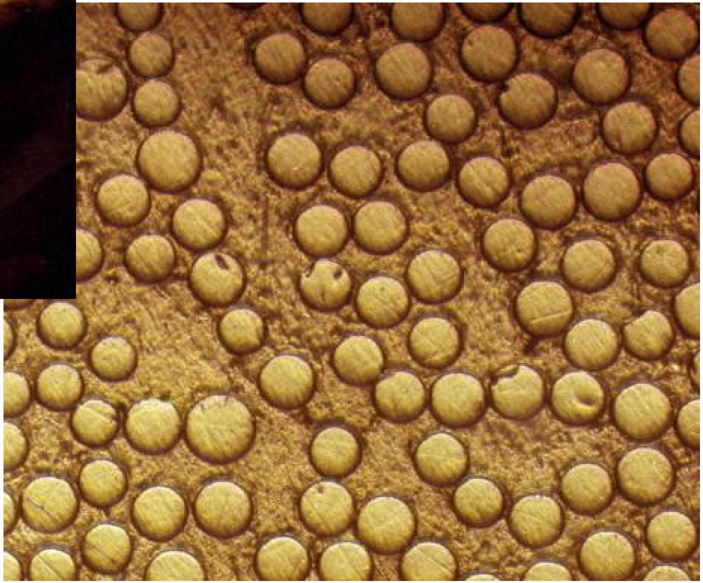
Adjunct Professor University of Manitoba
Consultant ISIS Canada

May 2005

1 Dr. M. Onofrei - Final Report, May 2005

.....a closer look



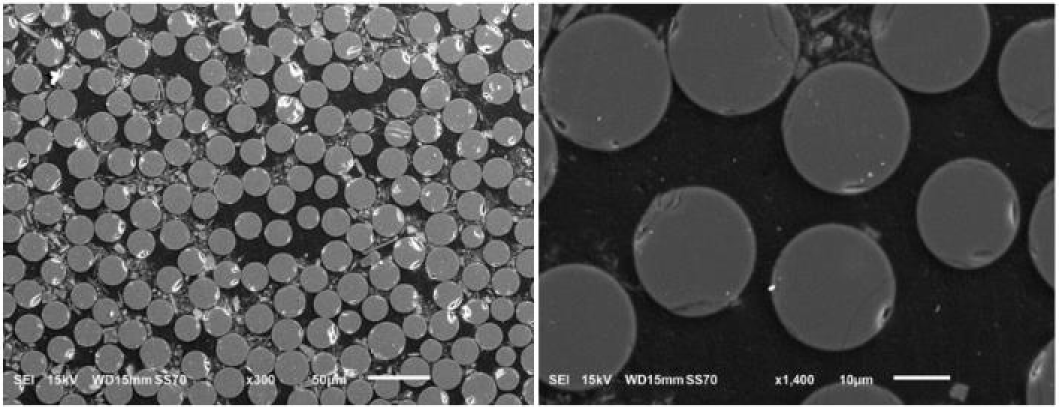


Durability – USA

Sierrita de la Cruz Creek Bridge, Amarillo, Texas Constructed in 2000

Material sampling following 15 years of use in 2015

Durability - USA

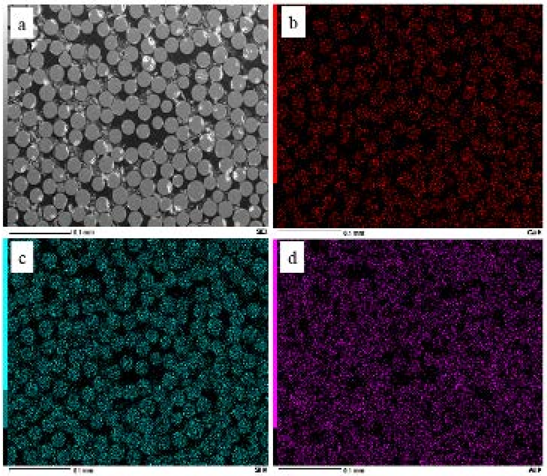


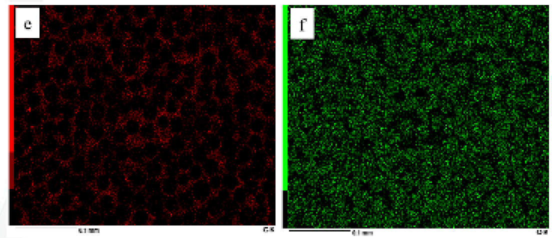
SEM analysis confirmed that there was **no sign of deterioration** in the GFRP coupons. Glass fibers were intact **without loss of any cross-sectional areas**. Fibers were surrounded by the resin matrix and **no gap nor sign indicating the loss of bond between resin and fibers**, was observed.

Long-term Durability of GFRP Reinforcement in Concrete: A Case Study after 15 Years of Service - O. Gooranorimi[1], **E. Dauer**[2], **J. Myers**[3], **A. Nanni**[4]
[1, 4] Dept., Civil, Architectural and Environmental Engineering, [2] Dept., Biomedical Engineering, University of Miami, Coral Gables, 33146, Florida, USA.
[3] Dept., Civil, Architecture and Environmental Engineering, Missouri University of Science and Technology, Rolla, 65409, Missouri, USA.

Durability - USA

Elemental scatter in GFRP bars after 15 years of service at magnification level of 300x: SEM image of GFRP (a) and elemental distributions of: Ca (b), Si (c), Al (d), C (e), and O (f)





- Comparing the result of EDS analysis performed on the in-service and control samples confirmed that no change in chemical composition of fiber and matrix occurred after 15 years of service
- Silica was not dissolved in the alkaline environment of concrete

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Applications: *Concrete Exposed to De-Icing Chlorides*

- Bridge Decks & Railings
- Median Barriers
- Approach Slabs
- Salt Storage Facilities
- Continuously Reinforced Concrete Paving
- Parking Structures
- Precast Elements including Manhole Covers, Culverts, Rail Grade Crossings, Full-Depth Bridge Deck Panels

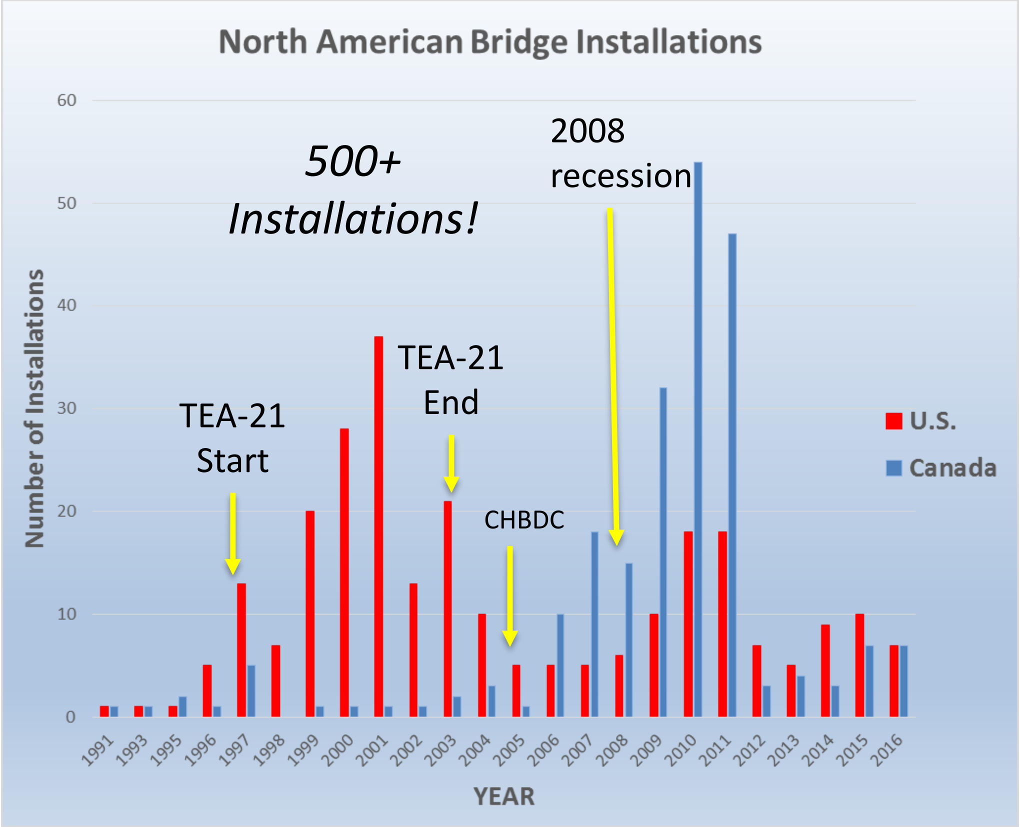
Applications: *Concrete Exposed to Marine Chlorides*

- Sea Walls, Wharfs, Quays & Dry Docks
- Coastal Construction exposed to Salt Fog
- Desalinization intakes
- Port Aprons

Overview of Installations

Vehicular Bridge Installations

Bridge Installations	Canada	U.S.
1991	1	1
1993	1	1
1995	2	1
1996	1	5
1997	5	13
1998	0	7
1999	1	20
2000	1	28
2001	1	37
2002	1	13
2003	2	21
2004	3	10
2005	1	5
2006	10	5
2007	18	5
2008	15	6
2009	32	10
2010	54	18
2011	47	18
2012	3	7
2013	4	5
2014	3	9
2015	7	10
2016	7	7
	220	**262**



Source: ACMA, 2016

FRP Products Used in North American Installations

Product Applications	Number of Installations	
	USA	Canada
Deck Panel System	70	2*
Deck Superstructure	49	0
Girder/Beam	54	9
Concrete Deck with rebar/grid	65	202
Tendon/Cable	13	7
Panel	18	1
Abutment / Footing	3	4
Parapet, Barrier, Enclosure, sidewalk	9	41
Piling / Column	3	1
Pier (Column) Fendering Systems	14	0
FRP / Glulam Beam	9	0
Carbon Fiber/Glass Concrete Filled Arch	17	0

Source: ACMA, 2016

Note: Does not include repair/strengthening

FRP Rebar Use in USA

65 Bridges – 27 States

Colorado	2
Connecticut	1
Florida	8
Georgia	2
Indiana	1
Iowa	2
Kansas	1
Kentucky	2
Mass	1
Maine	4
Michigan	2
Minnesota	1
Missouri	6
Nebraska	1

New Hampshire	1
New York	3
North Carolina	1
Ohio	4
Oregon	1
PA/NJ	1
Pennsylvania	1
Texas	3
Utah	2
Vermont	1
Virginia	1
West Virginia	9
Wisconson	3

Applications		
Deck only	Deck, parapet, barrier, enclosure, and/or sidewalk	Parapet, barrier, enclosure, and/or sidewalk
56	5	4

Source: ACMA, 2016

FRP Rebar Use in Canada

202 Bridges – 4 Provinces

	Rebar	Deck only	Deck, parapet, barrier, enclosure, and/or sidewalk	Parapet, barrier, enclosure, and/or sidewalk
Bridges in Canada	202	167	23	12

Source: ACMA, 2016

McKinleyville, WV (1996) – *21+ years service*

1st Bridge with FRP Rebar

Inspected in 2013

Courtesy of West Virginia Univ. CFC

Nipigon River Cable-Stayed Bridge

The First Deck Slab Reinforced with GFRP Bars in **Cable Stayed Bridge**

Nipigon River Cable-Stayed Bridge

- 2012-2017
- ~827 ft. (252m) in length
- two-span, four lanes
- 480 precast concrete panels (10 ft. x 23 ft.)
- High Performance concrete
- Panel joint filled with UHPFRC
- Many partners

Halls River Bridge Replacement

Halls River Bridge Replacement

- **Under Construction – Homosassa, FL (north of Tampa)**
- **~186 ft. overall bridge length, 58 ft. wide**
- **5 spans (37 ft.), continuous deck, simple span beams**
- **Owner: Citrus County, Designer: FDOT, Funding: FHWA**
- **Experimental Project with Innovative Materials – First in Florida**
  - <u>Superstructure</u>: Hybrid Composite Beams; GFRP Bars: Deck, Barriers & Approach Slabs
  - <u>Substructure</u>: CFRP Pre-stressed Piles; Bent Caps: GFRP Bars
  - <u>Sheet Pile Walls</u>: CFRP Sheet Piles; Wall Cap: GFRP Bars
- **Contractor Bid Cost - $6.016 Million (Structures = $4.06 Million)**
  - Bridge Cost = **$218 / sq. ft.** (Conventional Construction = **$166 / sq. ft.**)

– **Accelerated Construction**
  - Lighter Materials – Beams and Rebar
  - Faster Transportation and Delivery – reduced construction time

Fort Knox Bridge

- 2012
- Two 40’ spans
- Concrete abutments and central pier
- Span 1 – Hybrid Composite Beams with SAFPLANK® SIP forms and uncoated steel reinforced concrete deck
- Span 2 – Steel beams with concrete deck using GRIDFORM™ SIP form and reinforcement

- **USACOE Conclusions**
  - Load tests confirm that both spans meet the design requirements
  - GRIDFORM™ reduced installation time by 80% and labor costs by more than 75%
  - FRP reinforcing elements will be included in Unified Facilities Criteria

Kansas City – I-635 over State Ave

- **Oct/Nov 2013**
- **First Interstate Highway**
- **Bridge dimensions**
  - 32 ft x 232 ft
- **Bridge construction**
  - cast in place concrete on steel girders
- **FRP rebar**
  - top/bottom mat
- **Cost**
  - Bids were same for installed cost of epoxy coated & GFRP

Innovation Bridge – Univ. of Miami

- May 2016 installed
- 70 ft x 14 ft pedestrian bridge
- Combines BFRP, CFRP, GFRP
- Concrete elements:
  - foundation auger-cast piles (40 ft)
  - precast prestressed girders (66 ft)
  - cast-in-place pile caps
  - side blocks
  - back walls
  - deck topping and curbs
- closed continuous stirrups and preassembled pile cages

Innovation Bridge

Seawall & Road Side Barrier - Maui, HI Honoapiilani Highway – built in 2001

Courtesy of Hughes Brothers

Seawall - Honoapiilani Highway under Construction (2012)

Courtesy of Hughes Brothers

Seawall - Honoapiilani Highway (2012)

Courtesy of Hughes Brothers

53rd Ave Bridge Bettendorf, IA (2001)

Courtesy of Hughes Bros.

Morristown Bridge Vermont 2002

Concrete cast-in-place
May 2002

Bridge opened to traffic
July 2002

Courtesy of Pultrall, Inc.

Emma Park Bridge, Pleasant Grove, Utah DOT (2009)

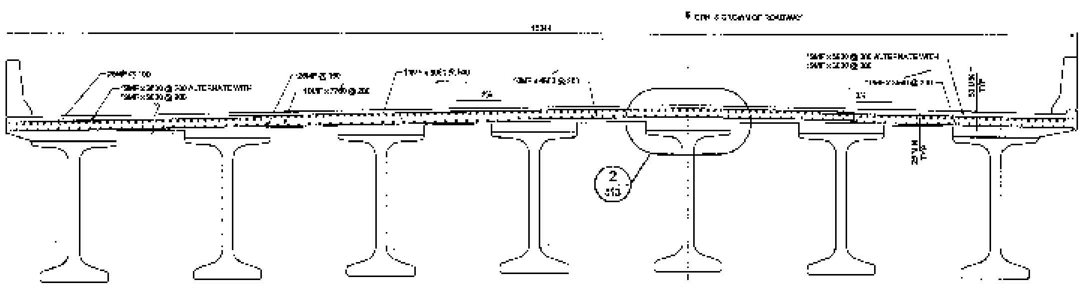
Courtesy of Hughes Brothers, Inc.

Emma Park Bridge

- **Full Depth Precast – top & bottom mat**
- **Cost premium in 2009 to use GFRP over Epoxy bar**
  - 14% greater deck cost – due in large part to additional girders
  - On a 1:1 basis, GFRP bars equal in unit price to epoxy steel

Floodway Bridge, Manitoba, Canada (2005)

- 2 Bridges 8 spans each
- 2 Lanes Each Bridge
- 142 feet typical span
- 1136 feet total length (1/5 mile)
- 50 foot Wide
- 9 inch thick Deck Slab, 8 feet Girder Spacing



Floodway Bridge, Manitoba, Canada

- Largest Steel Free Deck Project
- Largest FRP reinforced bridge in the world
- 8 Truckloads of GFRP Rebar
- 150 Tons of GFRP = 1.2 million lbs of steel rebar (30 truckloads)
  - Primarily #8 and #3 Longitudinal
  - #6 Transverse
- 3200 CY concrete (6400 tons)

Floodway Bridge, Manitoba, Canada

Courtesy of Hughes Bros.

Noden Causeway, Ontario, Canada

- **Prestressed/precast deck**

Courtesy of Pultrall, Inc.

I-75- Tampa ~ Deck Replacement – NSM Stitching (repair / upgrade)

Courtesy of Hughes Bros.

Canada - Eagle River Bridge, box girder

Courtesy of Pultrall, Inc.

Summary

- Complete set of guides, test methods and standards are available for FRP bars
- Many bridges built with FRP bars and performing well
- Non-proprietary solution, traditional supply chain acquisition & installation in place
- Extended service life of FRP reinforced decks is expected
- Many practices adopted for corrosion protection are not necessary with FRP bars
- Holistic view of bridge deck construction makes FRP bars the best value proposition

Thank You

John P. Busel, FACI

Vice President, Composites Growth Initiative

American Composites Manufacturers Association (ACMA)

P: 914-961-8007

E: jbusel@acmanet.org