GFRP Rebar for a Longer Lasting Infrastructure

Doug Gremel

Director, Non-metallic Reinforcing Hughes Bros

Co-Chair, FRP Rebar Mfgrs Council

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Outline

- Why GFRP Rebar
- FRP Rebar Manufacturers Council
- Experience with GFRP bar
- Performance after 20 years in use
- Standards & Specifications
- What is needed

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

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Service life of Bridges – Greatly reduced by corrosion

- Failure mechanism is often corrosion of the steel reinforcing
- Chlorides from de-icing salts penetrate to steel
  - Via cracks in deck
  - Permeation through concrete
- Inevitably concrete cracks

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“State of the Practice”

- Corrosion mitigation efforts center on keeping chlorides from getting to the reinforcing steel or simply delaying the time to corrosion.
- Structure fails from the inside

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Traditional Approach to Corrosion Problems:

- Reduce, Eliminate, or Negate the Current Flow of the Electrochemical Corrosion Cell Inherent With Steel Reinforced Concrete
  - Admixtures
  - Increase Concrete Cover
  - Efforts to reduce permeability & mitigate cracking - HPC
  - Alter Concrete Mix
  - Membranes & Overlays
  - Epoxy coated steel
  - Cathodic protection
  - Sacrificial anodes
  - etc, etc- inherent in current "State of the Practice"

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Instead of Mitigation Why Not Eliminate?

Use rebar that will never corrode

Simplest Solution to get many additional years of Service Life

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.*

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GFRP Rebar is NOT a proprietary product

- Owners can get bids from multiple bidders
- Use existing bid letting process
- Designed by same methods, but with minor variations based on authoritative consensus standards
- Properties validated by ASTM standards
- Installed by existing contractors

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FRP-RMC Manufacturers

- BP Composites (TUFF-Bar)
- C1 Pultrusions, LLC (XBar™)
- Composite Rebar Technologies, Inc. (HollowBar)
- Hughes Brothers, Inc. (AslanFRP)
- Marshall Composite Technologies, Inc. (C-Bar™)
- Pultrall, Inc. (V-ROD)
- Raw Energy Materials Corporation (RockRebar™)

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Concrete FRP "Community"

- FRP-RMC
- Individual producers (fabricators)
- Composites suppliers
- Academia
- Colleagues in ACI 440
- International colleagues (academia, industry, suppliers)

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Applications: Transportation

- Cast in place bridge decks
- Precast deck panels
- Box Girders
- Barriers, parapets, sidewalks
- Box Culverts
- Rail (electrical mitigation)
- Tunneling / Soft-eye (SR99 Alaska Way)
- Structural strengthening of existing infrastructure
- Sea Walls, bulkhead caps,

FRP Rebar Use in USA
65 Bridges – 27 States

not comprehensive

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

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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

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McKinleyville, WV (1996)

1st Bridge with FRP Rebar

Courtesy of West Virginia Univ. CFC

McKinleyville, WV Bridge Installed 1996

The McKinleyville bridge was the first vehicular bridge in the U.S. to be constructed with a concrete deck reinforced with FRP rebar. The bridge is 177 feet long by 30 feet wide and accommodates two lanes of traffic. Original surface, no repairs required in 20 years

Photos courtesy of Dr. Hota GangaRoa
Constructed Facilities Center WVU

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Floodway Bridge Winnipeg

One of the largest uses of GFRP bars

150 tons of GFRP = 1.2 million lbs of steel rebar or 30 truckloads
Largest “steel free deck”
Largest FRP reinforced bridge
8 truckloads of GFRP bar

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GFRP in Marine & Waterfront Applications

Dry Dock rehabilitation Pearl Harbor

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2001 - Dry Dock rehabilitation Pearl Harbor – Multiple Dry Docks !

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2002 Sea Walls – Estee Lauder estate Palm Beach

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Seawall - Honoapiilani Highway 2012

Courtesy of Hughes Brothers

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Under water sculptures ~ Jason deCaires Taylor

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

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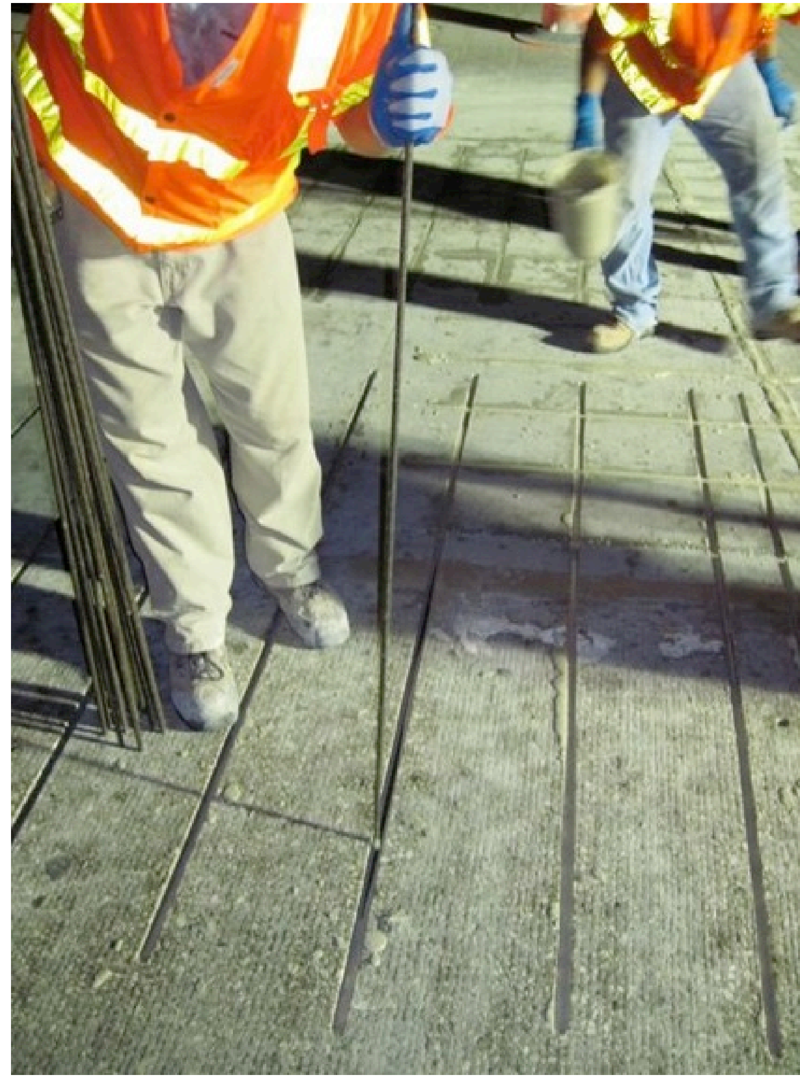

New Precast deck panels , NSM stitched at night leaving bridge open to traffic during high volume use in daytime.

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Structural Strengthening – Bridge Cantilever – Old Florida Keys Bridge

Underside Cast in place repair with GFRP & CFRP bars

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Cast in place repair – CFRP & GFRP bars

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Heavy Rail – Miami MetroRail – MIA
2.4 Miles of elevated rail

- Rail Plinths 100% reinforced with GFRP Bars

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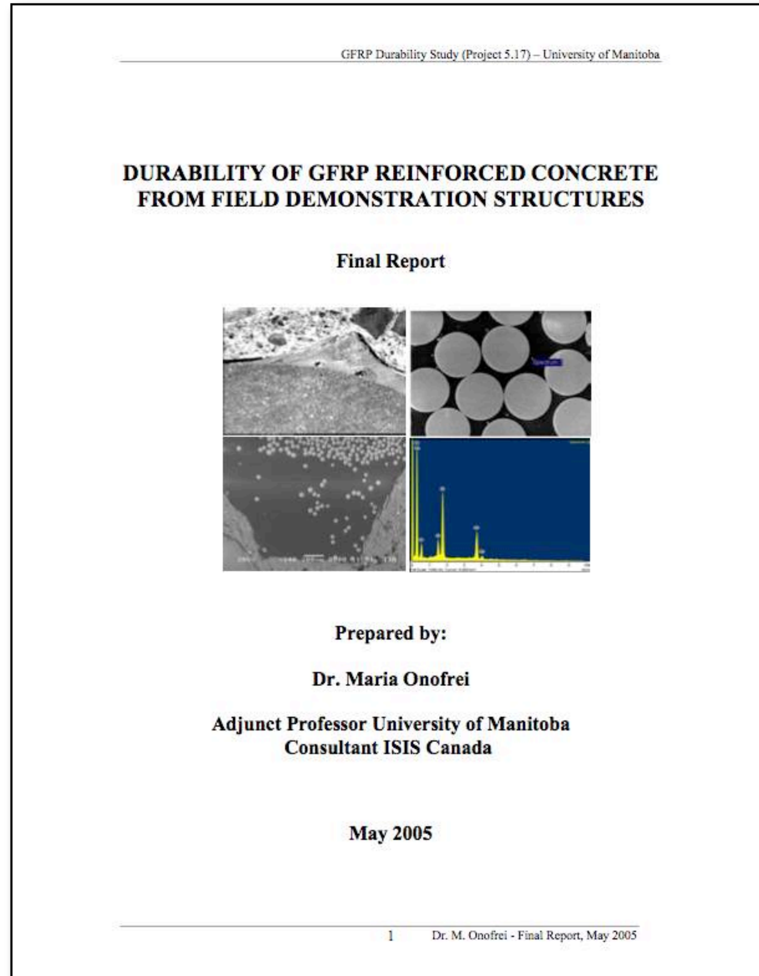
Durability

- ISIS Canada reports on Durability performance of GFRP bars in Bridge Decks in Service for 8-10 years
- Multiple reports from several institutions
- Follow-up reports after 15 years



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

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NO Degradation of GFRP bars found !

Additional studies are being performed on US bridges with service over 15 years – Preliminary results – the same

Composites in Construction 2005 – Third International Conference, Hamelin et al (eds) © 2005 ISBN xxxxx

Lyon, France, July 11 – 13, 2005

REPORT ON THE STUDIES OF GFRP DURABILITY IN CONCRETE FROM FIELD DEMONSTRATION STRUCTURES

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ABSTRACT: In 2004, ISIS Canada studied the durability of GFRP in concrete by removing concrete cores containing GFRP from five Canadian field demonstration structures built during the last 5 to 8 years. Three teams working independently at several Canadian universities used a variety of analytical methods to (a) investigate whether or not the GFRP in concrete field structures had been attacked by alkali, and (b) compare the composition of GFRP removed from in-service structures to that of control specimens, which were saved from the projects and not exposed to the concrete environment. The analytical results have confirmed that the GFRP in concrete has not suffered any discernible damage during the last five to eight years. As a result of this study, the Technical Subcommittee of Fibre Reinforced Structures of the CHBDC has recommended that GFRP can now be used as primary reinforcement and prestressing tendons in concrete structures. The paper reports on the findings of the durability study conducted by the ISIS Canada Research Network.

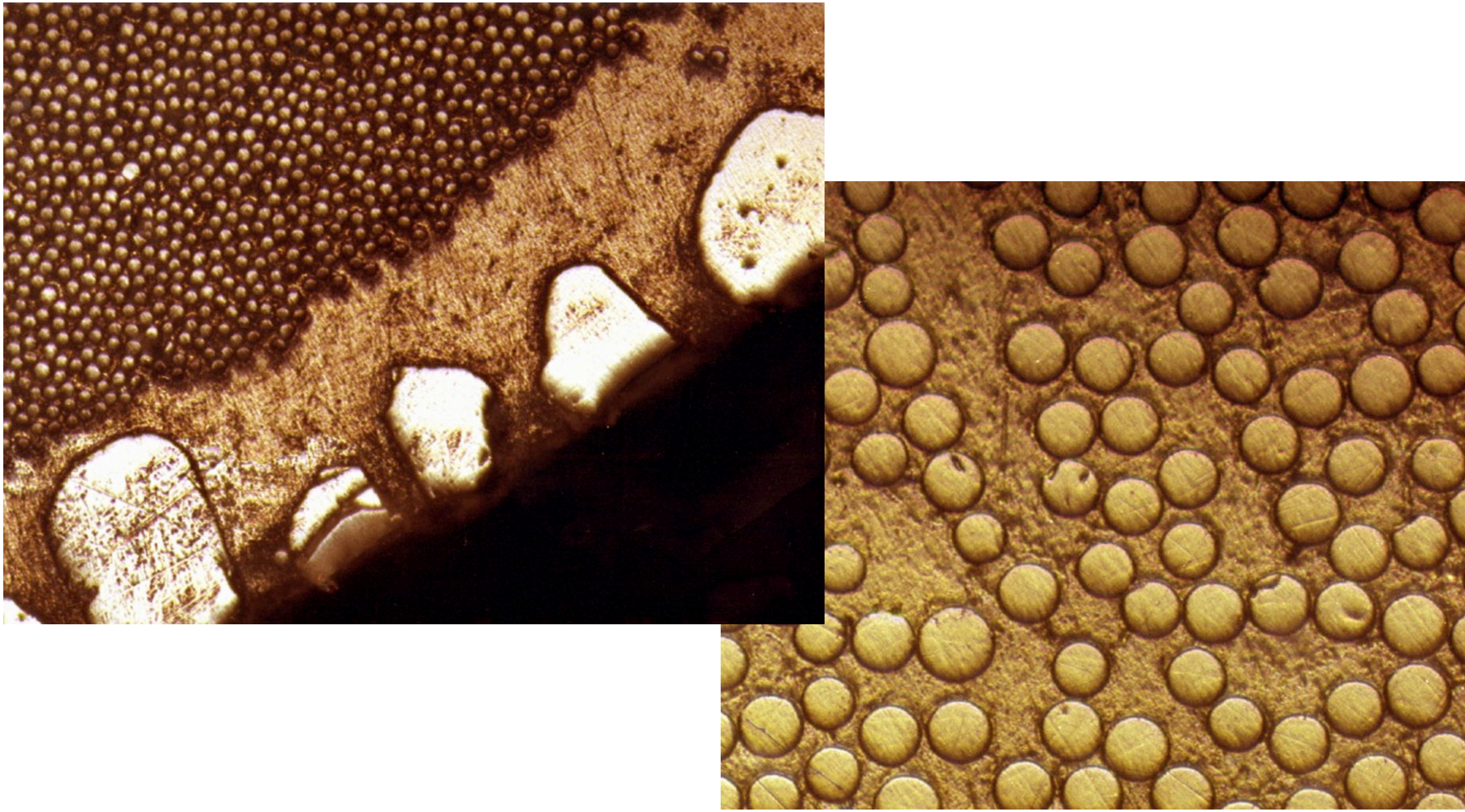
1. INTRODUCTION

Recently, Professor U. Meier reviewed the activities of ISIS Canada [1]; he recommended that Canada, having invested significantly in innovative concrete structures with GFRP, should study the durability of GFRP in concrete. Following his advice, ISIS Canada initiated in 2004 a project, in which concrete cores containing GFRP were removed from five Canadian structures, and analyzed the GFRP for its composition at a micro level. Since previous simulated studies of the durability of GFRP in concrete [e.g., 2,3] had indicated that GFRP is not stable in the alkaline environment of concrete, the Canadian Highway Bridge Design Code (CHBDC) [4] restricted the use of GFRP as only secondary reinforcement. It has been argued in [5] that the simulated tests, whether accelerated or non-accelerated, were conducted in an alkaline environment, which is likely to be different from the concrete environment found in field structures. The objective of the study described in this paper was to provide data on the performance of GFRP in several Canadian concrete demonstration structures built during the past five to eight years. The paper reports on the findings of the durability study conducted by the ISIS Canada Research Network. The names of the authors are those of the project team that conducted the study with the President of the ISIS Canada Research Network as the project leader.

2. ANALYTICAL STUDIES

Five field demonstration projects were chosen for the study under consideration, these being the Hall's Harbor Wharf, the Joffre Bridge, the Chatham Bridge, the Crowchild Trail Bridge, and the Waterloo Creek Bridge; these structures, exposed to a wide range of environmental conditions, are well

…..a closer look



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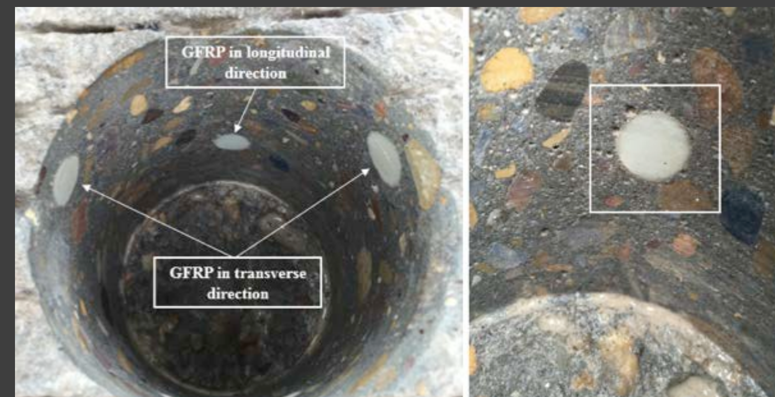
Durability - US

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

Material sampling following 15 years of use in 2015



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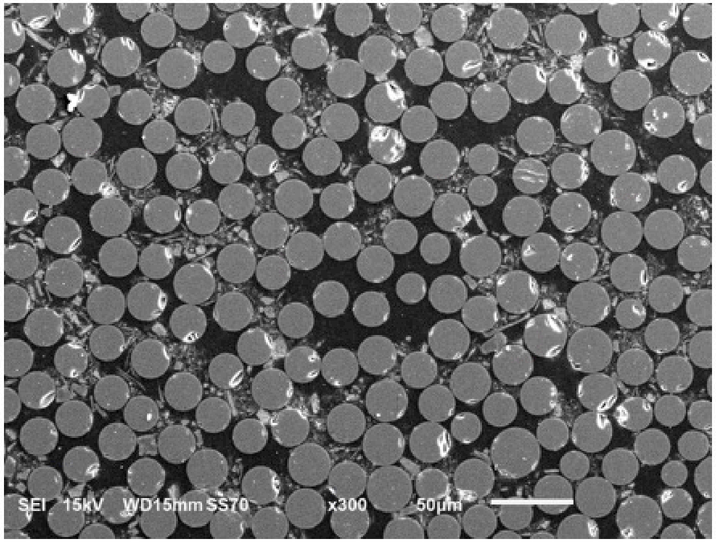
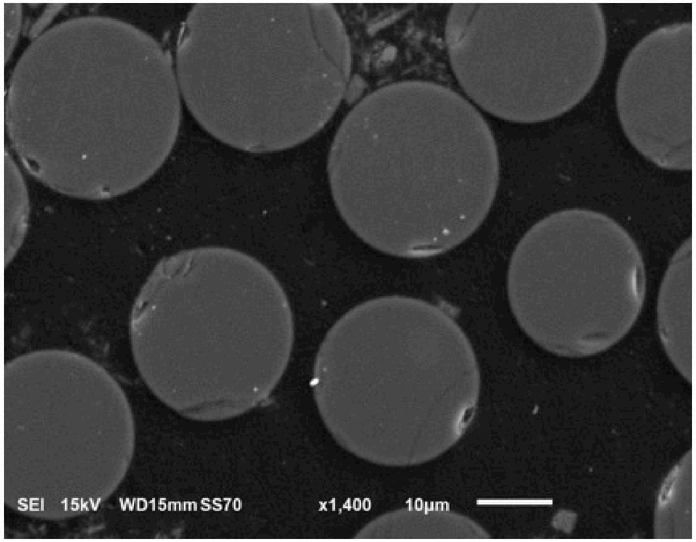
Durability - US





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.

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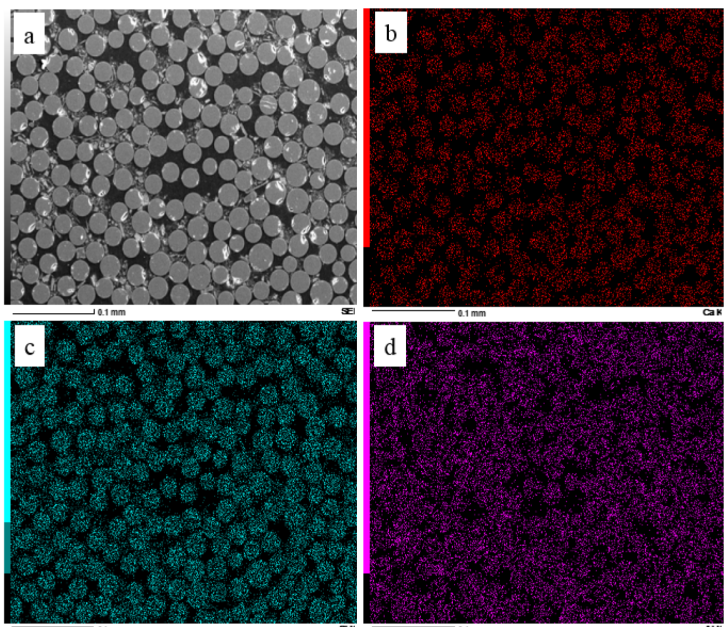
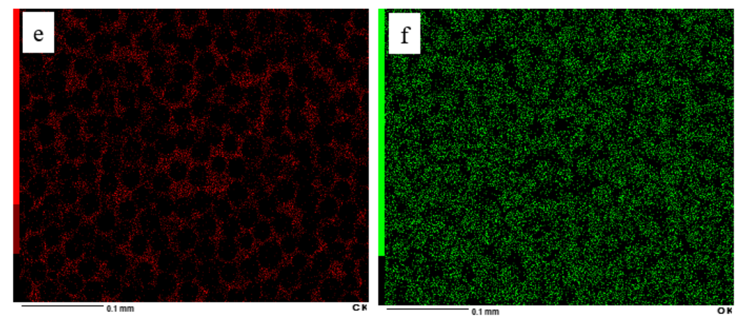
Durability - US

Energy Dispersive X-Ray Spectroscopy or EDS 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

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]
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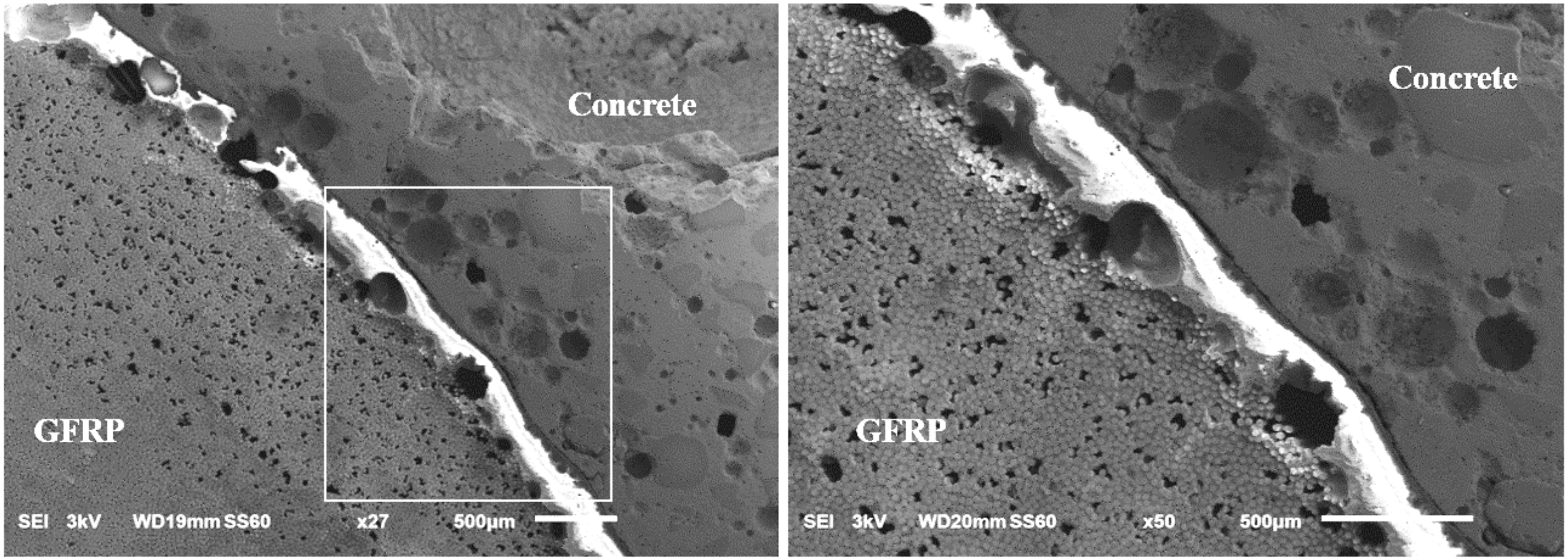
Durability - US



The GFRP to concrete interfacial bond was maintained properly and no sign of bond degradation nor loss of contact was observed after 15 years. The visible interfacial damage may be the result of sample preparation and drying in the SEM chamber [3].

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]
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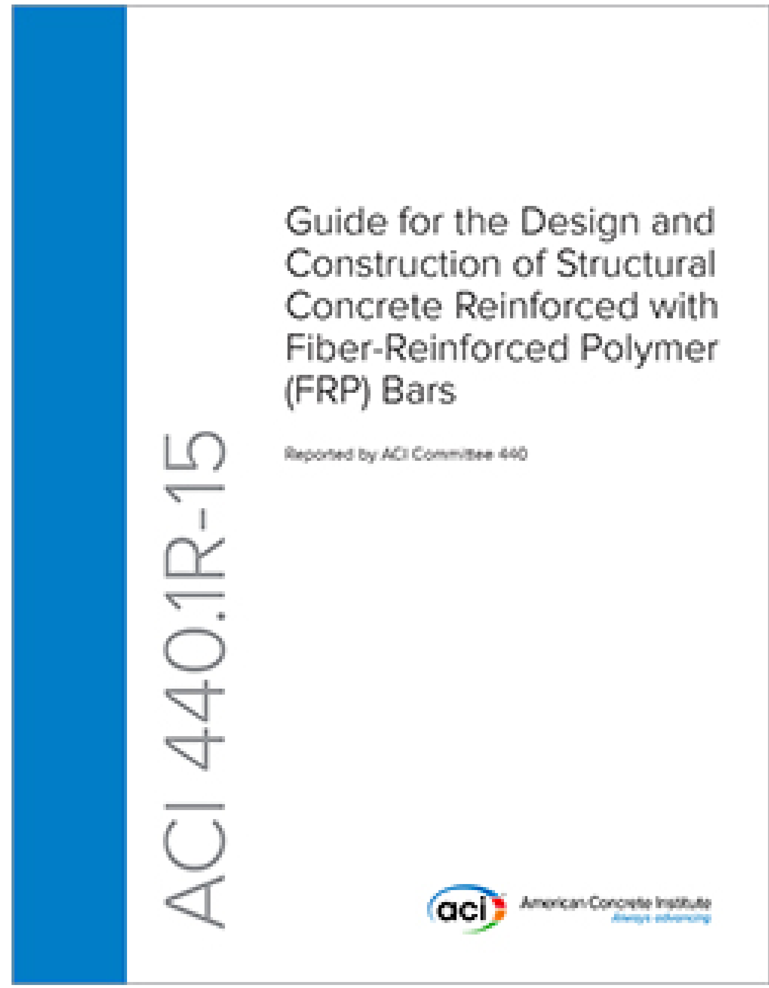
ACI – rebar design guideline

- Design principles well established through extensive research
- <u>Non-mandatory language</u>
- ACI 440.1R-15
  - 4th update to document
  - Current research added
  - Added direction on high temperature and fire effects
  - Design examples enhanced and reorganized.


ACI 440.1R-15

Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-Reinforced Polymer (FRP) Bars

Reported by ACI Committee 440

aci American Concrete Institute

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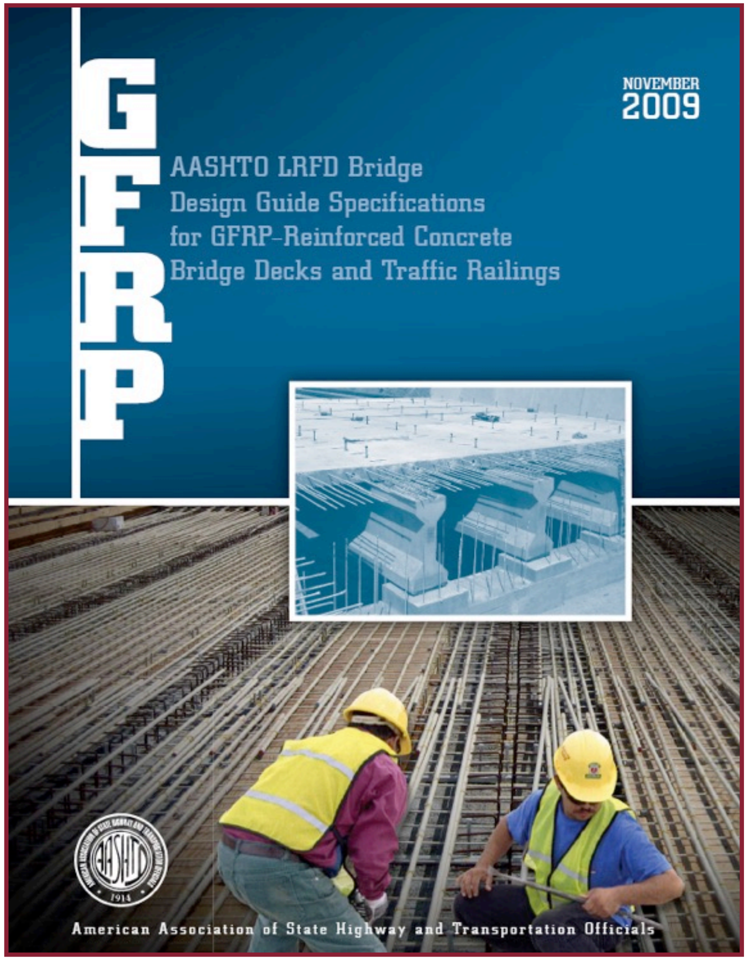
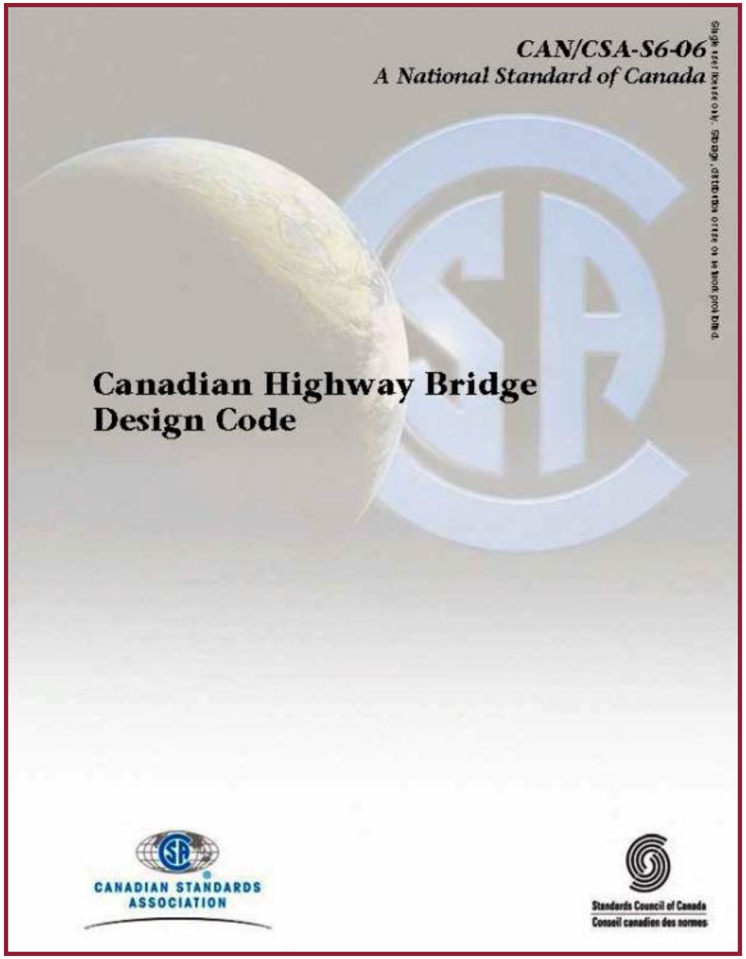
AASHTO design guide



- New AASHTO LRFD design guide specifications published 11/2009
- Bridge decks and traffic railings, glass FRP (GFRP) bars
- Specific properties of GFRP reinforcement, design algorithms and resistance factors, detailing, material and construction specifications

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

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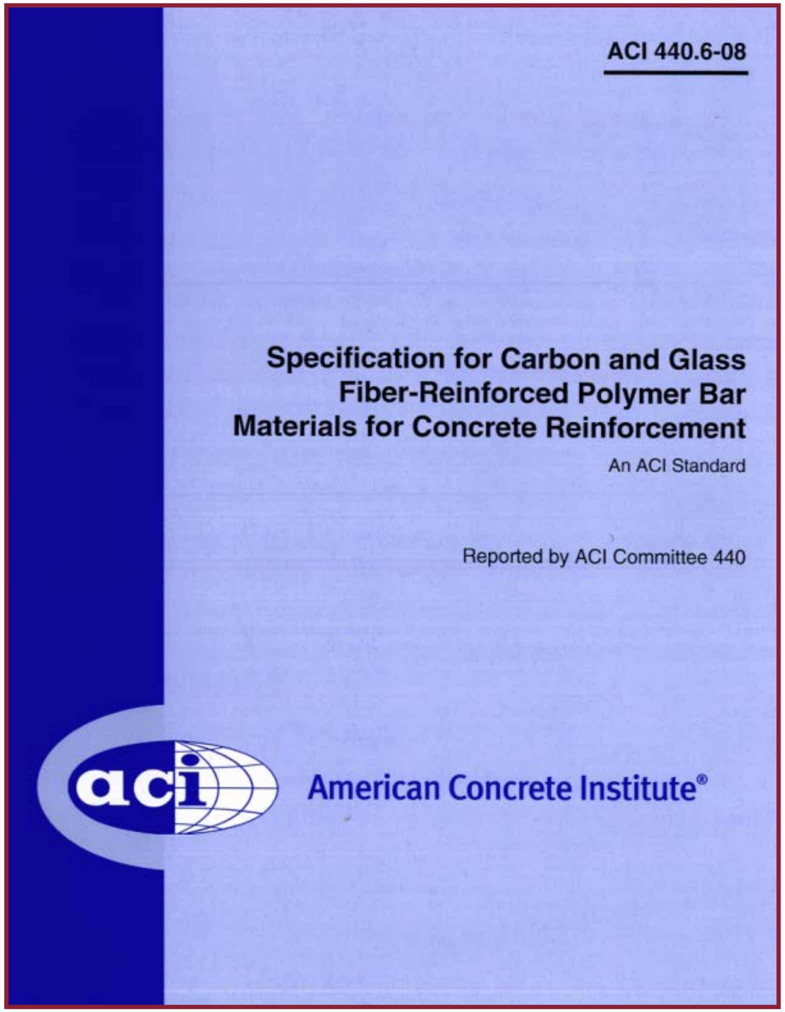
ACI – FRP Rebar Materials Spec

- ACI 440.6-08, **mandatory language** (standard document)
- To be replaced by pending ASTM product specification


ACI 440.6-08

Specification for Carbon and Glass Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement

An ACI Standard

Reported by ACI Committee 440

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ASTM D30 GFRP material specification

Table 1 – Geometric and mechanical property requirements

Bar Designation No.	Nominal Dimensions		Measured Cross-Sectional Area Limits mm² [in.²]		Minimum Guaranteed Ultimate Tensile Force kN [kip]
	Diameter mm [in.]	Cross-Sectional Area mm² [in.²]	Minimum	Maximum	
M6 [2]	6.3 [0.250]	32 [0.049]	30 [0.046]	55 [0.085]	27.3 [6.1]
M10 [3]	9.5 [0.375]	71 [0.11]	67 [0.104]	104 [0.161]	59.0 [13.2]
M13 [4]	12.7 [0.500]	129 [0.20]	119 [0.185]	169 [0.263]	96.1 [21.6]
M16 [5]	15.9 [0.625]	199 [0.31]	186 [0.288]	251 [0.388]	130 [29.1]
M19 [6]	19.1 [0.750]	284 [0.44]	268 [0.415]	347 [0.539]	182 [40.9]
M22 [7]	22.2 [0.875]	387 [0.60]	365 [0.565]	460 [0.713]	241 [54.1]
M25 [8]	25.4 [1.000]	510 [0.79]	476 [0.738]	589 [0.913]	297 [66.8]
M29 [9]	28.7 [1.128]	645 [1.00]	603 [0.934]	733 [1.137]	365 [82.0]
M32 [10]	32.3 [1.270]	819 [1.27]	744 [1.154]	894 [1.385]	437 [98.2]

- Agreed upon table of properties for designers

ASTM D30 GFRP material specification

- Agreed upon industry criteria for limits, testing for QC and Characterization & Qualification

Table 3 - Physical property limits, test methods, and test purpose.

Property	Limit	Test Method	Purpose
Fiber Content	≥ 55% - volume ≥ 70% - mass	ASTM D2584 ASTM D3171	QA / QC
Glass Transition Temperature	≥ 100°C [212°F]	ASTM E1356 - DSC, or ASTM E1640 – DMA	Characterization / Qualification
Bar Size	Table 1	Measured Cross Sectional Area per ASTM D7205 paragraph 11.2.5.1	Qualification and QA / QC
Ultimate Tensile Force	Table 1	ASTM D7205	Characterization / Qualification and QA / QC
Mean Tensile Modulus of Elasticity	≥ 44,800 MPa [6,500,000 psi]	ASTM D7205	Characterization / Qualification and QA / QC
Mean Ultimate Tensile Strain	≥ 1.2%	ASTM D7205	Characterization / Qualification and QA / QC
Guaranteed Transverse Shear Strength	≥ 131 MPa [19,000 psi]	ASTM D7617	Characterization / Qualification
Guaranteed Bond Strength	≥ 7.6 MPa [1,100 psi]	ASTM D7913	Characterization / Qualification
Moisture Absorption in 24 hours	≤ 0.25% in 24 hours at 50°C [122°F]	ASTM D570, Section 7.4, or ASTM D5229 BWEP	QA / QC
Moisture Absorption to Saturation	≤ 0.75% to saturation at 50°C [122°F]	ASTM D570, Section 7.4, or ASTM D5229 BWEP	Characterization / Qualification
Alkaline Resistance	≥ 80% of initial mean ultimate tensile force following 90 days at 60°C [140°F]	ASTM D7705 Procedure A	Characterization / Qualification
Cracks and Voids	No continuous crack or void on both ends of more than three of seven consecutive 25 mm [1 in.] bar segments	Visual inspection	QA / QC
Guaranteed Ultimate Tensile Force of Bent Portion of Bar	≥ 60% of guaranteed ultimate tensile force of straight bars as listed in Table 1	ASTM D7914	Characterization / Qualification
Ultimate Tensile Force of Straight Portion of Bent Bar	Table 1	ASTM D7205	QA / QC

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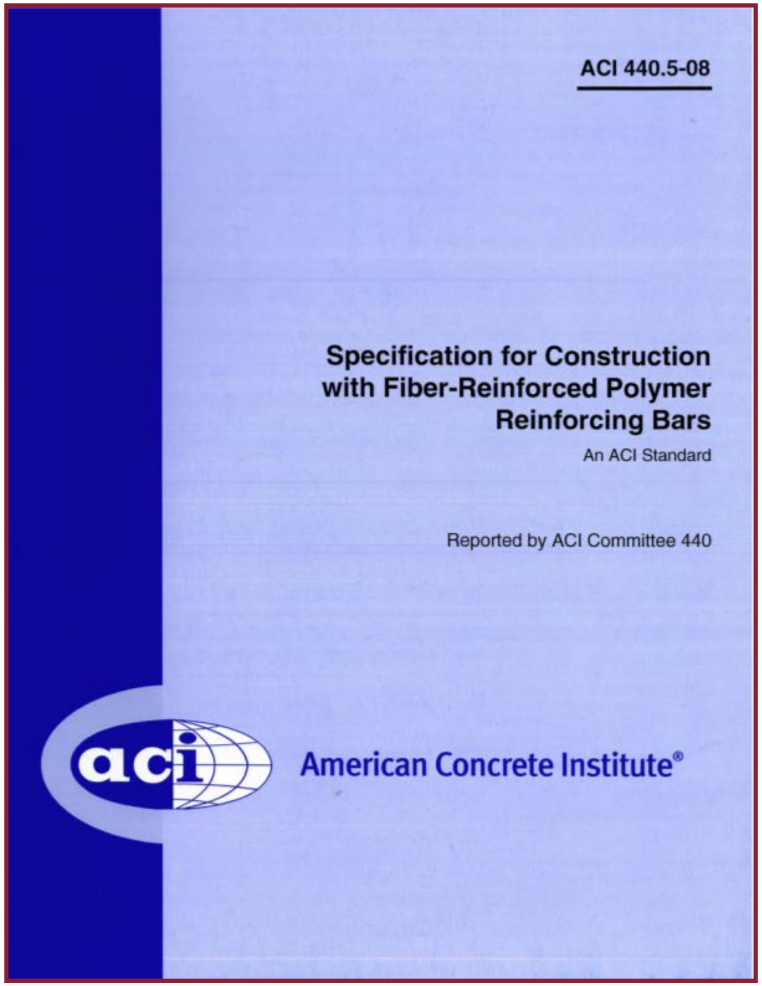
ACI – FRP Rebar Construction Spec

- ACI 440.5-08
  - **mandatory language** (standard document)
- GFRP bar
  - preparation,
  - placement (including cover requirements, reinforcement supports),
  - repair, and field cutting



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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.
- This is expected to be a 3 year effort

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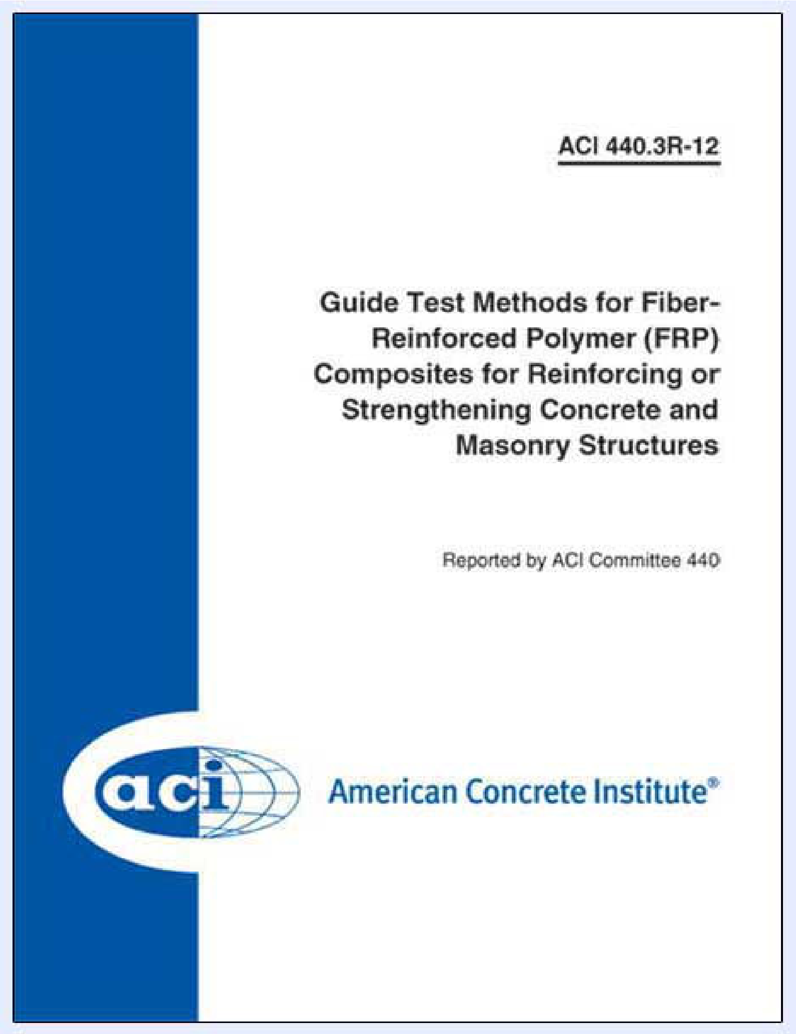
ACI Test methods – 440.3R-12



ACI 440.3R-12

Guide Test Methods for Fiber-Reinforced Polymer (FRP) Composites for Reinforcing or Strengthening Concrete and Masonry Structures

Reported by ACI Committee 440

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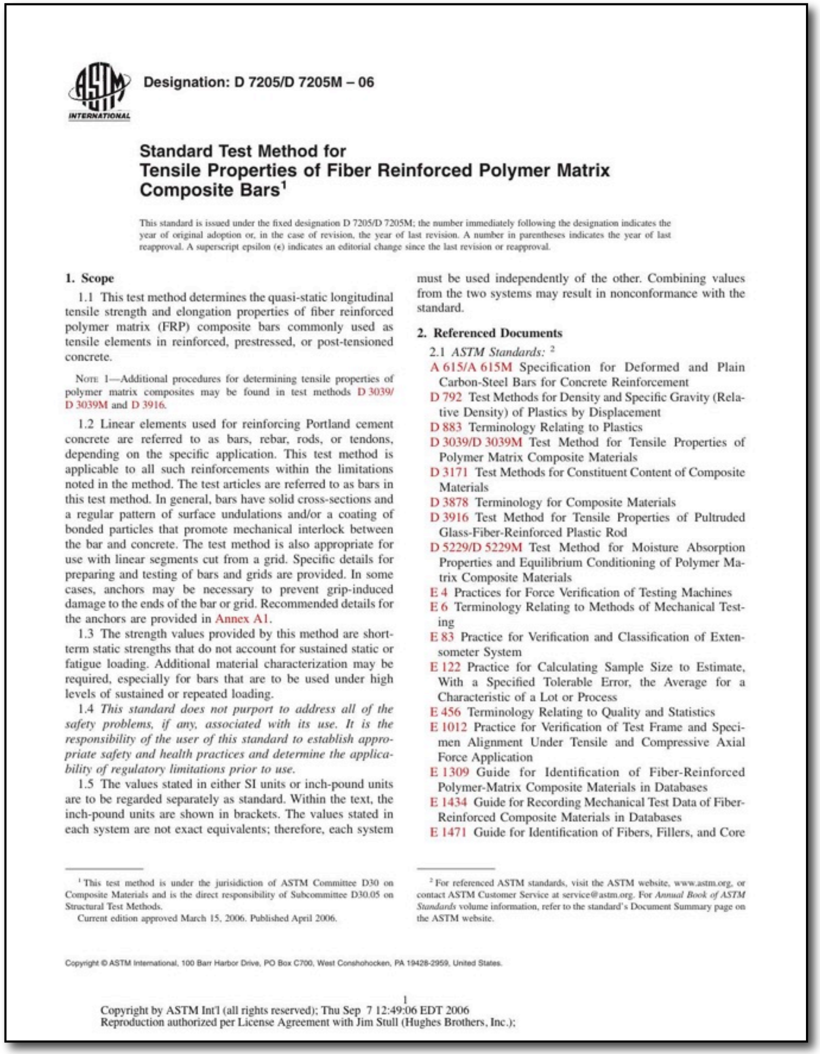

Designation: D 7205/D 7205M – 06

Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars[1]

This standard is issued under the fixed designation D 7205/D 7205M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method determines the quasi-static longitudinal tensile strength and elongation properties of fiber reinforced polymer matrix (FRP) composite bars commonly used as tensile elements in reinforced, prestressed, or post-tensioned concrete.

NOTE 1—Additional procedures for determining tensile properties of polymer matrix composites may be found in test methods D 3039/D 3039M and D 3916.

1.2 Linear elements used for reinforcing Portland cement concrete are referred to as bars, rebar, rods, or tendons, depending on the specific application. This test method is applicable to all such reinforcements within the limitations noted in the method. The test articles are referred to as bars in this test method. In general, bars have solid cross-sections and a regular pattern of surface undulations and/or a coating of bonded particles that promote mechanical interlock between the bar and concrete. The test method is also appropriate for use with linear segments cut from a grid. Specific details for preparing and testing of bars and grids are provided. In some cases, anchors may be necessary to prevent grip-induced damage to the ends of the bar or grid. Recommended details for the anchors are provided in Annex A1.

1.3 The strength values provided by this method are short-term static strengths that do not account for sustained static or fatigue loading. Additional material characterization may be required, especially for bars that are to be used under high levels of sustained or repeated loading.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.5 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 615/A 615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
D 792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D 883 Terminology Relating to Plastics
D 3039/D 3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials
D 3171 Test Methods for Constituent Content of Composite Materials
D 3878 Terminology for Composite Materials
D 3916 Test Method for Tensile Properties of Pultruded Glass-Fiber-Reinforced Plastic Rod
D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
E 4 Practices for Force Verification of Testing Machines
E 6 Terminology Relating to Methods of Mechanical Testing
E 83 Practice for Verification and Classification of Extensometer System
E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process
E 456 Terminology Relating to Quality and Statistics
E 1012 Practice for Verification of Test Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application
E 1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases
E 1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases
E 1471 Guide for Identification of Fibers, Fillers, and Core

[1] This test method is under the jurisidiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.05 on Structural Test Methods.

Current edition approved March 15, 2006. Published April 2006.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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Rebar Test Methods

- ACI 440.3R-12
- ASTM D30

ACI Test Method	ASTM Standard
B.1. Bar Cross-Section	D7205
B.2. Bar Tension	
App. A. Bar Anchors	
B.3 Concentric Bar Pullout	D7913
B.4. Bar Transverse Shear	D7617
B.5. Bar Strength at Bends	D7914
B.6. Bar Alkaline Tension	D7705
B.8. Bar Creep Rupture	D7337

- ***ASTM Under development*** – Spec for GFRP Bars

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What is needed

Standards development

- Iterate AASHTO LRFD design guide
  - Bring up to speed with 440.1R
  - Include more economical implementation (less conservatism i.e. unit strip design)
  - Include substructure and other elements besides decks & railings
- Task Group of T-6
  - FRP community to do heavy lifting
  - Florida DOT Will Potter to be liaison of task group to T-6

Educate & Inform DOT's

- DOT's need to learn about composites
- New materials mean
  - Different testing
  - Different spec's
  - Things for inspectors to look for
- Awareness of FRP's is very very low by DOT engineers

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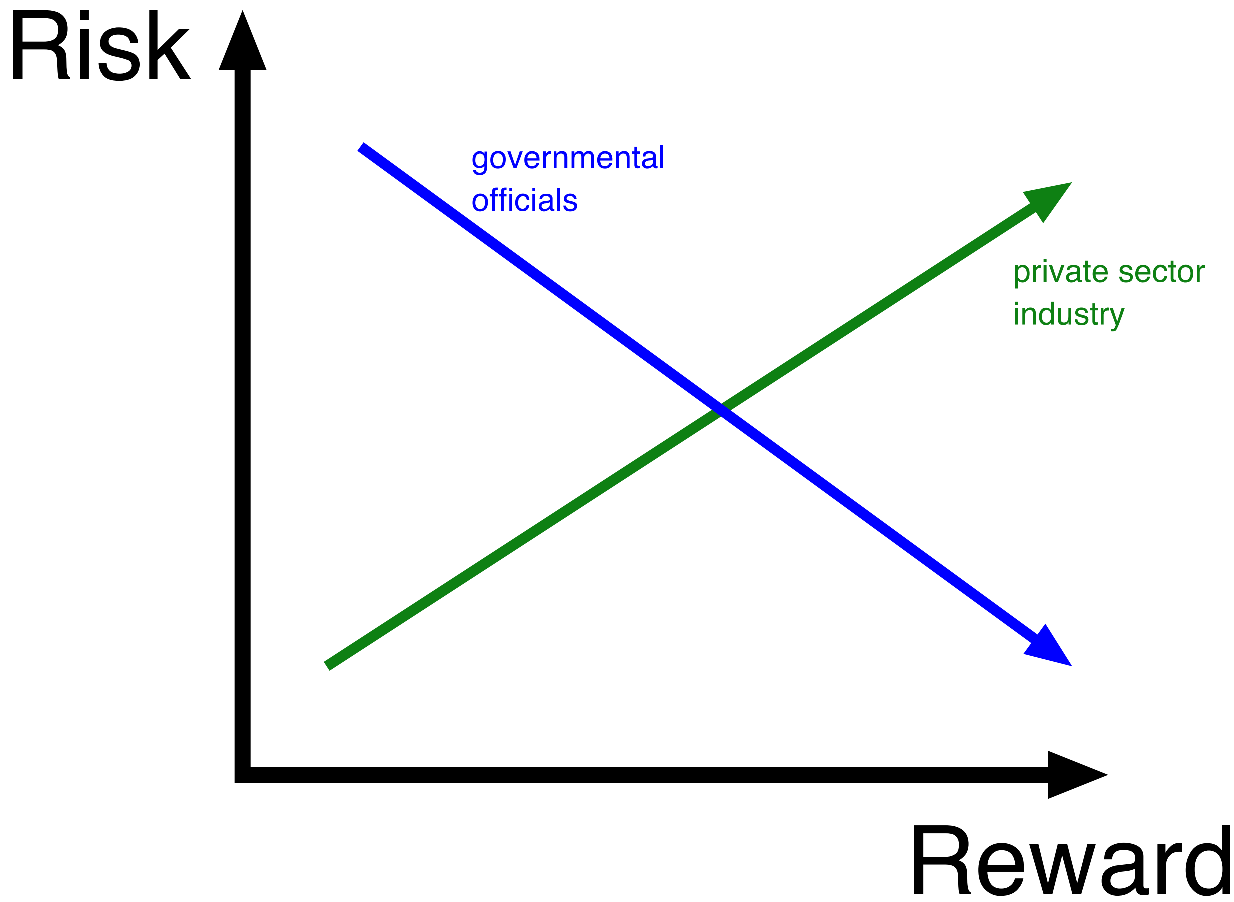
Willingness to Change



- Why isn’t GFRP rebar being adopted more quickly?

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Conclusions

- GFRP Rebar is ready for wide spread use
- Will help infrastructure last longer
- First cost to install less than 5% of bridge cost
  - 5% more to achieve 75 or 100 year service life
- Many Successful Projects Completed
- Traditional Design, Procurement & Construction Methods used
- Multiple vendors to bid GFRP Rebar

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