Fiber Reinforced Polymer (FRP) Composites Rebar

FDOT
June 15, 2016

John P. Busel, VP, Composites Growth Initiative
ACMA

3033 Wilson Blvd., Ste. 420 Arlington, VA 22201
w: www.acmanet.org | t: 703.525.0511 | f: 703.525.0743 | e: jbusel@acmanet.org
Outline

• About ACMA and Rebar Council
• Installations Today
• Durability
• Standards & Specifications
• Invitation to collaborate with FDOT
About ACMA

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

- Manufacturers
- Material Suppliers & Distributors
- Industry Consultants
- Academia

**Composites Industry**
- 3000+ Companies
- 280,000+ employees
- North America
- **$30 Billion Industry**
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 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™)
Concrete FRP “Community”

- FRP-RMC
- Individual producers (fabricators)
- Material suppliers
- Academia (Univ Miami, Sherbrooke, WVU, ...)
- Colleagues in ACI 440
- International colleagues (academia, industry, suppliers)
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 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)
### FRP Rebar Use in USA

**67 Bridges – 27 States**

<table>
<thead>
<tr>
<th>State</th>
<th>Count</th>
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<tbody>
<tr>
<td>Colorado</td>
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<td>Connecticut</td>
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<td>Kentucky</td>
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<td>Maine</td>
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<td>Nebraska</td>
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<td>Ohio</td>
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<td>Oregon</td>
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<td>PA/NJ</td>
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<td>Texas</td>
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<td>Utah</td>
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<td>Vermont</td>
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<td>Virginia</td>
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<tr>
<td>West Virginia</td>
<td>9</td>
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<tr>
<td>Wisconsin</td>
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### Applications

<table>
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<tr>
<th>Deck only</th>
<th>Deck, parapet, barrier, enclosure, and/or sidewalk</th>
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<tr>
<td>54</td>
<td>8</td>
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<td>8</td>
<td>3</td>
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*not comprehensive*
## FRP Rebar Use in Canada

### 211 Bridges – 4 Provinces

<table>
<thead>
<tr>
<th>Rebar</th>
<th>Deck only</th>
<th>Deck, parapet, barrier, enclosure, and/or sidewalk</th>
<th>Parapet, barrier, enclosure, and/or sidewalk</th>
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<tbody>
<tr>
<td>Bridges in Canada</td>
<td>211</td>
<td>172</td>
<td>25</td>
</tr>
</tbody>
</table>
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 GangaRao, Constructed Facilities Center, WVU
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
GFRP in Marine & Waterfront Applications

Dry Dock rehabilitation  Pearl Harbor
2001 - Dry Dock rehabilitation  Pearl Harbor – Multiple Dry Docks !
2002 Sea Walls – Estee Lauder estate
Palm Beach
Seawall & Road Side Barrier - Maui, HI
Honoapiilani Highway – built in 2001 with steel

Courtesy of Hughes Brothers
Seawall - Honoapiilani Highway 2012

Courtesy of Hughes Brothers

American Composites Manufacturers Association
Retaining Wall Rebuild – Maui, HI (2013)

• One-sided form using GFRP Form Ties and placement of GFRP rebar

Courtesy of BP Composites
I-75- Tampa ~ Deck Replacement – NSM Stitching (repair / upgrade)

Courtesy of Hughes Bros.
Box Girder / Column
Structural Strengthening – Bridge Cantilever – Old Florida Keys Bridge

Underside Cast in place repair with GFRP & CFRP bars

ACMA
American Composites Manufacturers Association
Cast in place repair – CFRP & GFRP bars
Heavy Rail – Miami MetroRail – MIA

2.4 Miles of elevated rail

- Rail Plinths 100% reinforced with GFRP Bars
Durability - Canada

- 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
NO Degradation of GFRP bars found!

Additional studies are being performed on US bridges with service over 15 years – Preliminary results – the same
.....a closer look
Sierrita de la Cruz Creek Bridge, Amarillo, Texas Constructed in 2000

Material sampling following 15 years of use in 2015
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.
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
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].
Review – Standards & Specifications

Translating research into industry standards
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.
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
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.
ACI – FRP Rebar Materials Spec

- ACI 440.6-08, mandatory language (standard document)
- To be replaced by pending ASTM product specification
### ASTM D30 GFRP material specification

Table 1 – Geometric and mechanical property requirements

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diameter [mm [in.]]</td>
<td>Cross-Sectional Area [mm² [in.²]]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M6 [2]</td>
<td>6.3 [0.250]</td>
<td>32 [0.049]</td>
<td>30 [0.046]</td>
<td>55 [0.085]</td>
<td>27.3 [6.1]</td>
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<tr>
<td>M10 [3]</td>
<td>9.5 [0.375]</td>
<td>71 [0.11]</td>
<td>67 [0.104]</td>
<td>104 [0.161]</td>
<td>59.0 [13.2]</td>
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<tr>
<td>M13 [4]</td>
<td>12.7 [0.500]</td>
<td>129 [0.20]</td>
<td>119 [0.185]</td>
<td>169 [0.263]</td>
<td>96.1 [21.6]</td>
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<tr>
<td>M16 [5]</td>
<td>15.9 [0.625]</td>
<td>199 [0.31]</td>
<td>186 [0.288]</td>
<td>251 [0.388]</td>
<td>130 [29.1]</td>
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<tr>
<td>M19 [6]</td>
<td>19.1 [0.750]</td>
<td>284 [0.44]</td>
<td>268 [0.415]</td>
<td>347 [0.539]</td>
<td>182 [40.9]</td>
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<td>M22 [7]</td>
<td>22.2 [0.875]</td>
<td>387 [0.60]</td>
<td>365 [0.565]</td>
<td>460 [0.713]</td>
<td>241 [54.1]</td>
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<tr>
<td>M25 [8]</td>
<td>25.4 [1.000]</td>
<td>510 [0.79]</td>
<td>476 [0.738]</td>
<td>589 [0.913]</td>
<td>297 [66.8]</td>
</tr>
</tbody>
</table>

▶ Agreed upon table of properties for designers

![ACMA Logo](image)
### ASTM D30 GFRP material specification

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

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

• New FRP Rebar Design Code
  o In 2014, ACI TAC approved a new standard development

• Dependent Code
  o Aligned with the exact chapters and structure ACI 318-14
  o Only chapters that impact FRP will be re-tooled to reflect the properties, characteristics, etc.

• This is expected to be a 3 year effort
ACI Test methods – 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

American Concrete Institute®

Standards for the Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars

This standard is used under the fiscal designation D 7205/D 7205M, the number immediately following the designation indicates the year of original adoption or, in the case of revisions, 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 5033, and D 3034.

1.2 Linear elements used for reinforcing Portland cement concrete are referred to as bars, rebars, 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 particulate that promotes 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, anchorages 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 strengths 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 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:

A 615/A 615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement

D 702 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

D 3039 Terminology Relating to Plastics

D 3033 Test Method for Tensile Properties of Polymer Matrix Composite Materials

D 3171 Test Methods for Constituent Content of Composite Materials

D 3978 Terminology for Composite Materials

D 3816 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 Practice for Force Verification of Testing Machines

E 16 Terminology Relating to Methods of Mechanical Testing

E 83 Practice for Verification and Classification of Extensometer Systems

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 1013 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 Polymer Matrix Composites in Databases

E 1471 Guide for Identification of Fiber, Fillers, and Core
Rebar Test Methods

• ACI 440.3R-12
• ASTM D30

<table>
<thead>
<tr>
<th>ACI Test Method</th>
<th>ASTM Standard</th>
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<tbody>
<tr>
<td>B.1. Bar Cross-Section</td>
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<td>B.2. Bar Tension</td>
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<tr>
<td>App. A. Bar Anchors</td>
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<td>B.3 Concentric Bar Pullout</td>
<td>D7913</td>
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<td>B.4. Bar Transverse Shear</td>
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<td>B.5. Bar Strength at Bends</td>
<td>D7914</td>
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<td>B.6. Bar Alkaline Tension</td>
<td>D7705</td>
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<td>B.8. Bar Creep Rupture</td>
<td>D7337</td>
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</table>

• ASTM Under development – Spec for GFRP Bars

American Composites Manufacturers Association
Next steps

Areas of Collaboration
Invitation to collaborate with FDOT

1. Standards development
2. Sharing of technical reports and research information
3. New joint research on Florida’s most critical applications
FRP Community collaboration with Florida DOT

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
FRP Community collaboration with Florida DOT

Prove durability in marine splash zone

• Core some structures with 15 years service
  • Full suite of analysis.. SEM, EDS as in TxDOT cores

• Put test beams in tidal zone
  • Pre-cracked beams under stress
  • Compare to steel reinforced
FRP Community collaboration with Florida DOT

Test / Validate 6 concrete standard elements with most benefit to FDOT

• Substructure elements identified by FDOT
  • FDOT supplies section geometries / structural analysis /design
  • FRP community proposes economical detailing / implementation

• FRP Community tests full scale members at end of service life using $C_e=0.70$ or 70% of rebar to simulate theoretical 75 to 100 year end of service life

• Furnish drawings of economical detailing for given standard elements such as bulkhead caps
Thank You

John P. Busel
Vice President, Composites Growth Initiative
American Composites Manufacturers Association (ACMA)
P: 914-961-8007
E: jbusel@acmanet.org
www.compositesinfrastructure.org/frp-rebar