GFRP Rebar for a Longer Lasting Infrastructure

Doug Gremel
Director, Non-metallic Reinforcing Hughes Bros
Co-Chair, FRP Rebar Mfgrs Council
Outline

➢ Why GFRP Rebar
➢ FRP Rebar Manufacturers Council
➢ Experience with GFRP bar
➢ Performance after 20 years in use
➢ Standards & Specifications
➢ What is needed
Seawall & Road Side Barrier - Maui, HI
Honoapiilani Highway – built in 2001 with steel
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
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
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”
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.*
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
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)
- Composites suppliers
- Academia
- 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 Rebar Use in USA
65 Bridges – 27 States

<table>
<thead>
<tr>
<th>State</th>
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<td>Virginia</td>
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<td>West Virginia</td>
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<td>Wisconsin</td>
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<th>Applications</th>
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<th>Parapet, barrier, enclosure, and/or sidewalk</th>
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<tr>
<td>Deck, parapet, barrier, enclosure, and/or sidewalk</td>
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*not comprehensive*
## FRP Rebar Use in Canada

### 202 Bridges – 4 Provinces

<table>
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<tr>
<th>Bridges in Canada</th>
<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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<td>202</td>
<td>167</td>
<td>23</td>
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</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 GangaRoa
Constructed Facilities Center WVU
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
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 - Honoapiilani Highway 2012

 Courtesy of Hughes Brothers
Under water sculptures ~ Jason deCaires Taylor
I-75- Tampa ~ Deck Replacement –
NSM Stitching (repair / upgrade)
New Precast deck panels, NSM stitched at night leaving bridge open to traffic during high volume use in daytime.
Structural Strengthening – Bridge Cantilever – Old Florida Keys Bridge

Underside Cast in place repair with GFRP & CFRP bars
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

- 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

GFRP witness bars

GFRP in longitudinal direction

GFRP in transverse direction

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

Material sampling following 15 years of use in 2015

GFRP witness bars

GFRP in longitudinal direction

GFRP in transverse direction
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, E. Dauer, J. Myers, A. Nanni

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 - 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. Gooranorimi¹, E. Dauer², J. Myers³, A. Nanni⁴

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.
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, E. Dauer, J. Myers, A. Nanni
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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>
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<tbody>
<tr>
<td></td>
<td>Diameter mm [in.]</td>
<td>Cross-Sectional Area mm² [in.²]</td>
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<td></td>
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<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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<tr>
<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
ASTM D30 GFRP material specification

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

<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; ≥ 70% - mass</td>
<td>ASTM D2584; ASTM D3171</td>
<td>QA / QC</td>
</tr>
<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>
</tr>
<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>
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<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>
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<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>
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<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>
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<tr>
<td>Guaranteed Ultimate Tensile Force of Best Portion of Bar</td>
<td>≥ 60% of guaranteed ultimate tensile force of straight bars as listed in Table 1</td>
<td>ASTM D7914</td>
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<tr>
<td>Ultimate Tensile Force of Straight Portion of Bent Bar</td>
<td>Table 1</td>
<td>ASTM D7205</td>
<td>QA / QC</td>
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</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
  - 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
ACI Test methods – 440.3R-12
# 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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<tr>
<td>B.2. Bar Tension</td>
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<td>App. A. Bar Anchors</td>
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<td>B.3 Concentric Bar Pullout</td>
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<td>B.4. Bar Transverse Shear</td>
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<tr>
<td>B.5. Bar Strength at Bends</td>
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<td>B.6. Bar Alkaline Tension</td>
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<td>B.8. Bar Creep Rupture</td>
<td>D7337</td>
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**ASTM Under development** – Spec for GFRP Bars

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**FRP-RMC**

FRP Rebar Manufacturers Council
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
Why isn’t GFRP rebar being adopted more quickly?
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