Introduction to Fiber Reinforced Polymer (FRP) Composites In Infrastructure

Rhode Island DOT
July 21, 2016

John P. Busel, VP, Composites Growth Initiative
ACMA
Outline

• About ACMA
• FRP Materials
• Products Used Today
• Installations Today
• Durability
• Standards & Specifications
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 Councils

• Transportation Structures Council (TSC)

• FRP Rebar Manufacturers Council (FRP-RMC)

• Members represent the supply chain: material suppliers, manufacturers, distributors, consultants, and academia.
TSC Manufacturers

• Composite Advantage
• Creative Pultrusions, Inc.
• Kenway Corporation
• Gordon Composites, Inc.
• Marshall Composite Technologies, LLC
• Sika Corporation
• Strongwell
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™)
FRP Materials

Why are composites different?
**FRP Materials**

**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

Fibers and matrix both play critical roles in the composites material...
Factors Affecting Material Characteristics in Composites

• Type of fiber
• Fiber volume
• Type of resin
• Fiber orientation
• Quality control procedures during manufacturing
• Rate of curing
• Void content
• Service temperature
Tensile Stress-Strain Characteristics of Reinforcement Fibers

- **FRP Composite Types**
  - CFRP
  - AFRP
  - GFRP

- **Typical Steel Rebar**
  - Linear elastic behavior to failure
  - No yielding
  - Higher Ultimate Strength
  - Lower Strain at Failure

**Graph:**
- Tensile Stress (ksi) vs. Tensile Strain (%)
- FRP Composite Types:
  - CFRP: Red line
  - AFRP: Orange line
  - GFRP: Blue line

**Note:**
- 0 MPa to 2000 MPa
- 0% to 3% strain range
- ACMA logo and text at the bottom
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
Products Used Today

Historical and new
From the beginning...infrastructure

- 1st FRP rebar – early 1970’s - USA
  - 2nd company, more R&D – early 1980’s
  - Bridges – 1980’s – Japan
- 1st FRP dowel bar - concrete pavements – USA – 1977
- 1st FRP Vehicular Bridge – China – 1982
- 1st FRP Pedestrian Bridge – China – 1986
- 1st FRP tendon, prestressing – Germany - 1986
- 1st CFRP tendon – Canada -1991
- 1st FRP Glulam beams – USA – early 1990’s
More firsts...

- 1st FRP Strengthening System
  - Experimental work, 1978, Germany
  - 1st application, RC columns, 1980’s, Japan
  - 1st application, flexural strengthening of RC bridges, 1987
- 1st Bridge “Wind Fairing” – USA – 2003
- Movable bridges
- Long spans.....
- ...and more to come
FRP Products Used in Infrastructure

- Vehicular & Pedestrian Bridge Decks
- Deck Superstructures
- FRP Rebar
- Girders
- Concrete Strengthening Systems (blast mitigation)
  - Thousands of installations (column, bent, slab, girder)
  - Blast hardening of cables
- Marine Piles (fender, bearing, sheet)
- Cables, tendons (carbon fiber)
- Other: Parapets, Sidewalks, Guardrails, Bridge Enclosures / Fairings, drainage pipe
Composites Products for Prefabricated Bridge Elements & Systems (PBES)

- FRP composites deck panel systems
  - Sandwich construction, vacuum infusion (foam/structural reinforcement)
  - Full thickness, pultruded, 1-piece, bonded panel joints

- FRP composites deck superstructure systems
  - Sandwich construction (foam/structural reinforcement)

- Girders
  - Pultruded structural shape
  - Vacuum infused box systems
Composites Products for Prefabricated Bridge Elements & Systems (PBES)

- FRP rebar - reinforced precast concrete deck panels
- FRP grid - reinforced concrete structural stay-in-place deck panel systems
FRP Composites Benefits

- Prefabrication of deck panels
  - Manufacturing in a plant to ensure quality
  - Minimizes installation on site

- High strength
  - Design loads are tailored to meet the requirements of the job/application

- Lightweight
  - Reduces installation time
  - Reduces the number of trucks to carry products to site as more products can be transported per truck
  - Lighter duty equipment needed to lift and place panels
  - Increases the live load capacity of weight restricted bridges with FRP deck replacements.
FRP Composites Benefits

• Corrosion resistance
  • Long durable life

• Design flexibility
  • Infinite shapes and sizes can be designed to meet the requirements of the job

• Color matching
  • Meet needs of blending into surrounding environment

• Enhanced Safety
  • Solid surface for traction
  • Non-skid surface for safety of pedestrian traffic
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)
Installations Today
North American Bridge Installations

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

Source: ACMA, 2016
# FRP Products Used in North American Installations

<table>
<thead>
<tr>
<th>Product Applications</th>
<th>Number of Installations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>USA</td>
</tr>
<tr>
<td>Deck Panel System</td>
<td>70</td>
</tr>
<tr>
<td>Deck Superstructure</td>
<td>49</td>
</tr>
<tr>
<td>Girder/Beam</td>
<td>54</td>
</tr>
<tr>
<td>Concrete Deck with rebar/grid</td>
<td>65</td>
</tr>
<tr>
<td>Tendon/Cable</td>
<td>13</td>
</tr>
<tr>
<td>Panel</td>
<td>18</td>
</tr>
<tr>
<td>Abutment / Footing</td>
<td>3</td>
</tr>
<tr>
<td>Parapet, Barrier, Enclosure, sidewalk</td>
<td>9</td>
</tr>
<tr>
<td>Piling / Column</td>
<td>3</td>
</tr>
<tr>
<td>Pier (Column) Fendering Systems</td>
<td>14</td>
</tr>
<tr>
<td>FRP / Glulam Beam</td>
<td>9</td>
</tr>
<tr>
<td>Carbon Fiber/Glass Concrete Filled Arch</td>
<td>17</td>
</tr>
</tbody>
</table>

Source: ACMA, 2016

*Note: Does not include repair/strengthening*
## FRP Rebar Use in USA

### 65 Bridges – 27 States

<table>
<thead>
<tr>
<th>State</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado</td>
<td>2</td>
</tr>
<tr>
<td>Connecticut</td>
<td>1</td>
</tr>
<tr>
<td>Florida</td>
<td>8</td>
</tr>
<tr>
<td>Georgia</td>
<td>2</td>
</tr>
<tr>
<td>Indiana</td>
<td>1</td>
</tr>
<tr>
<td>Iowa</td>
<td>2</td>
</tr>
<tr>
<td>Kansas</td>
<td>1</td>
</tr>
<tr>
<td>Kentucky</td>
<td>2</td>
</tr>
<tr>
<td>Mass</td>
<td>1</td>
</tr>
<tr>
<td>Maine</td>
<td>4</td>
</tr>
<tr>
<td>Michigan</td>
<td>2</td>
</tr>
<tr>
<td>Minnesota</td>
<td>1</td>
</tr>
<tr>
<td>Missouri</td>
<td>6</td>
</tr>
<tr>
<td>Nebraska</td>
<td>1</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>1</td>
</tr>
<tr>
<td>New York</td>
<td>3</td>
</tr>
<tr>
<td>North Carolina</td>
<td>1</td>
</tr>
<tr>
<td>Ohio</td>
<td>4</td>
</tr>
<tr>
<td>Oregon</td>
<td>1</td>
</tr>
<tr>
<td>PA/NJ</td>
<td>1</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>1</td>
</tr>
<tr>
<td>Texas</td>
<td>3</td>
</tr>
<tr>
<td>Utah</td>
<td>2</td>
</tr>
<tr>
<td>Vermont</td>
<td>1</td>
</tr>
<tr>
<td>Virginia</td>
<td>1</td>
</tr>
<tr>
<td>West Virginia</td>
<td>9</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>3</td>
</tr>
</tbody>
</table>

### Applications

<table>
<thead>
<tr>
<th>Deck only</th>
<th>Deck, parapet, barrier, enclosure, and/or sidewalk</th>
</tr>
</thead>
<tbody>
<tr>
<td>56</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: ACMA, 2016
FRP Rebar Use in Canada

**202 Bridges – 4 Provinces**

<table>
<thead>
<tr>
<th></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>
</tr>
</thead>
<tbody>
<tr>
<td>Bridges in Canada</td>
<td>202</td>
<td>167</td>
<td>23</td>
<td>12</td>
</tr>
</tbody>
</table>

Source: ACMA, 2016
Installations by State

• Several States have many installations which range in size, ADT, and complexity

• States like Ohio and West Virginia made commitments to integrating composites technology

<table>
<thead>
<tr>
<th>Installations by State</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME</td>
<td>43</td>
</tr>
<tr>
<td>WV</td>
<td>35</td>
</tr>
<tr>
<td>OH</td>
<td>34</td>
</tr>
<tr>
<td>NY</td>
<td>20</td>
</tr>
<tr>
<td>MO</td>
<td>18</td>
</tr>
<tr>
<td>FL</td>
<td>10</td>
</tr>
<tr>
<td>VA</td>
<td>9</td>
</tr>
<tr>
<td>NJ</td>
<td>8</td>
</tr>
<tr>
<td>OR</td>
<td>8</td>
</tr>
<tr>
<td>PA</td>
<td>7</td>
</tr>
<tr>
<td>KS</td>
<td>6</td>
</tr>
<tr>
<td>KY</td>
<td>6</td>
</tr>
<tr>
<td>MA</td>
<td>6</td>
</tr>
<tr>
<td>DE</td>
<td>5</td>
</tr>
<tr>
<td>IA</td>
<td>5</td>
</tr>
</tbody>
</table>

Source: ACMA
Bridge Tour
Beddington Trail Bridge, Canada

Calgary, Alberta

Opened 1993

2 spans (22.8 and 19.2 meter)

First Bulb-Tee bridge girder pretensioned with CFRP tendons, CFRP stirrups, and monitored by FBG sensors
McKinleyville, WV (1996)

1st Bridge with FRP Rebar

Courtesy of West Virginia Univ. CFC
Smith Road, Tech21

- All Composite Short Span Bridge

- 1997 - Tech21 - Butler County Ohio
Smith Road, Tech21

- All Composite Short Span Bridge

- 1997 - Tech21 - Butler County Ohio
FRP Tendons: Cable-Stayed Bridges

Wintertur, Switzerland

Stork bridge (124 m span, 2 lanes)

241 wires (each 0.2 in)
ultimate load: 2700 kips
Pierce Street over Ottawa River (1999)
- Concrete reinforcement

• Pierce Street over the Ottawa River - Lima Ohio
  - Glass fiber reinforcing bars

ACMA
American Composites Manufacturers Association
Bridge Street Bridge, USA

Bonded and unbonded CFRP Tendons in both Longitudinal and Transverse Directions

Southfield, Michigan

Opened 2001

2 parallel independent bridges (A and B)

3-spans (21.3, 20.4 and 21.4 meters)

2-lanes

ACMA

American Composites Manufacturers Association
Bridge Street Bridge

- Two parallel independent bridges:
  - **Structure A**: 5 conventional AASHTO-I beams
  - **Structure B**: 12 beams (each prestressed using pretensioned CFRP Leadline tendons and post-tensioned in the longitudinal and transverse directions using CFCC strands)

Erection of 12 CFRP Pretensioned and Post-tensioned DT Beams, (Courtesy of LTU)
<table>
<thead>
<tr>
<th><strong>Fairgrounds Road over Little Miami River</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Installation: 2002  Span Length: 221’</td>
</tr>
<tr>
<td>• Location: Greene County</td>
</tr>
<tr>
<td>• Bridge Owner: Greene County</td>
</tr>
<tr>
<td>• Designer: LJB</td>
</tr>
<tr>
<td>• FRP Application: FRP Deck – DuraSpan™</td>
</tr>
<tr>
<td>• FRP Manufacturer: Martin Marietta Composites</td>
</tr>
<tr>
<td>• Performance History:</td>
</tr>
<tr>
<td>• Live load tests in 2002 and 2004, FRP deck performing properly</td>
</tr>
<tr>
<td>• Of Interest:</td>
</tr>
<tr>
<td>High Volume Rural – average daily traffic 15,200</td>
</tr>
<tr>
<td>7,072 sq. ft. of FRP deck installed in under three days</td>
</tr>
</tbody>
</table>
Fairgrounds Road, Greene County
Installation Pictures
Morristown Bridge Vermont 2002

Concrete cast-in-place
May 2002

Bridge opened to traffic
July 2002

Courtesy of Pultrall, Inc.
Bronx-Whitestone Bridge – Wind Fairings – 2,300 ft span
Bridge deck - Broadway Bridge, 2005

- Located in the heart of the Portland harbor
- 30,000 vehicles per day
- Bascule bridge
- Vital to all types of traffic
  - Vehicular
  - Pedestrian
  - Marine (4 shifts)
Decorative architectural composites for bridge applications

Source: DEC Architectural Composites
Wolf Trap National Park
Vienna, Virginia

- Pedestrian bridge connecting parts of the park
- Crosses main access to Dulles Airport
  - Ten lanes of highway and one passenger rail line
- Safe access to amphitheater from one parking lot
- Visitors were walking on vehicle bridge with minimal sidewalk
FRP Deck Enables Accelerated Construction of Truss Bridges

- Enabled fully assembled spans to be erected with minimal road closure
  - No deck installation over the road
  - Precast concrete would have added 74,000 lb to the 132,000 lb lift

- 15 minutes in the middle of the night is Minimal

- FRP Benefits
  - Prefabricated Elements
  - Ease of installation - Light Weight

ACMA
American Composites Manufacturers Association
Penobscot Narrows Cable Stayed Bridge (2007/08)
Prefabricated FRP stay-in-place panels

Double-layer stay-in-place (SIP) reinforcing panels pre-assembled using off-the-shelf pultruded GFRP components

- 1.5” I-bars (4” o.c. perpendicular to traffic)
- 1/8” thick epoxy bonded form plate
- Three-part cross rods (4” o.c. parallel to traffic)
- Vertical connectors

Prefabricated FRP stay-in-place panels
Deck construction, Missouri

- Setting Panels of Reinforcement
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
Seawall - Honoapiilani Highway 2012

Courtesy of Hughes Brothers
Box Girder / Column
Four 70 ft. Beams – One Truck
Bridge in a Backpack

- Carbon Fiber shell, prefabricated in the plant
- Shipped to site – installed – lightweight, carried by workers - concrete poured
- Finished with composites panels
Historic Powder Point Bridge (Duxbury, MA)
Nipigon River Cable-Stayed Bridge (2012-2017)

Canada’s First Deck Slab Reinforced with GFRP Bars in Cable Stayed Bridge: Nipigon River Bridge
Traditional Looking Pedestrian Bridge
Innovative Pedestrian Bridge – Internal Structure
Innovative Pedestrian Bridge
Exterior Finishing
Innovative Pedestrian Bridge
Lifting into place
Pont y Ddraig, Wales, 2013
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

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 five to eight 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 controls. Both sets of data were compared to data from laboratory test 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
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.
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 retooled to reflect the properties, characteristics, etc.

• This is expected to be a 3 year effort
AASHTO

• Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements, 1st Edition

• AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings, First Edition
AASHTO


• AASHTO LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes, 1st Edition
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.
Summary

• Engineered systems
• Prefabricated components, factory built, quality controlled
• Reduces the need for large, heavy, expensive equipment during installation
• Increases safety on site
• Lighter Weight for Reduced Shipping, Handling and Erection Time and Costs (Accelerated Bridge Construction)
• Reduced Carbon Footprint
• Greater Corrosion Resistance than Conventional Materials Providing Service Lives Beyond 100 Years

• LOWER OVERALL BRIDGE COST!!
4 – Eyes

• Composites inspire *innovation* with different designs using similar materials
• Composites encourage *ingenuity* because it allows you to think outside the box
• Composites facilitates *invention* by making existing techniques, systems, methods better
• Composites propels *imagination* into new frontiers to make an engineers or contractors vision a reality
Thank You

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