Fiber Reinforced Polymer (FRP) Composites

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&

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Topics Covered

- Overview of FRP Composites
- Currently Available National Specifications
- FDOT Design Criteria and Specifications
- Acceptable FDOT Applications
- Research on FRP Composites
- District 7 Demonstration Project
- Chase Knight, PhD - Usage (Characteristics/Durability)
- Questions
FRP Overview: What is FRP?

- General Composition

Fiber [Carbon, Glass, Etc.] + Resin [Polymer] = Fiber Reinforced Polymer
Common Fiber Types:

- Aramid
  - Extremely sensitive to environmental conditions
- Glass (Most Widely Used)
  - Subject to creep under high sustained loading
  - Subject to degradation in alkaline environment
- Carbon
  - Premium Cost
- Basalt
  - The future of FRP fibers?
FRP Overview: Fibers

- Used in many different forms:

  - Short Fibers
  - Chopped Fibers
  - Long Fibers
  - Woven Fibers
FRP Overview: Resins

- Two Categories:
  - Thermoset Resins (most common for structural uses)
    - Liquid state at room temperature prior to curing
    - Impregnated into reinforcing fibers prior to heating
    - Chemical reaction occurs during heating/curing
    - Solid after heating/curing; Can’t be reversed/reformed
  - Thermoplastic Resins
    - Solid at room temperature (recycled plastic pellets)
    - Heated to liquid state and pressurized to impregnate reinforcing fibers
    - Cooled under pressure; Can be reversed/reformed
FRP Overview: Resins

- Common Thermoset Resin Types
  - Polyester
    - Lowest Cost
  - Vinyl ester
    - Industry Standard
  - Polyurethane
    - Premium Cost
  - Epoxy
    - Highest Cost
    - Commonly used in aerospace applications
FRP Overview: Resins

Polyesters

✓ Advantages:
  - Easy to use
  - Lowest cost of resins available

✓ Disadvantages:
  - Sensitive to UV degradation
  - Only moderate mechanical properties
✓ Vinyl esters

✅ Advantages:
- Very high chemical/environmental resistance
- Higher mechanical properties than polyesters

✅ Disadvantages:
- Sensitive to heat
- Higher cost than polyesters
Polyurethanes

Advantages:
- Higher strength and flexibility than vinyl esters
- Very high chemical/environmental resistance
- Higher mechanical properties than vinyl esters

Disadvantages:
- Higher cost than vinyl esters (about 1.5 x)
Epoxies

- Advantages:
  - High mechanical and thermal properties
  - High moisture resistance
  - Long working times available
  - High temperature resistance

- Disadvantages:
  - More expensive than polyurethanes
  - Critical mixing/Consistency
  - Corrosive handling
FRP Overview: Processes

- Manufacturing Processes
  - Predominate Processes
    - Pultrusion
    - Vacuum Infusion
  - Other Processes
FRP Overview: Processes

- Pultrusion Processing:
  - Linear, continuous process
  - Reinforcing (Roving & Mats) saturated with resin
  - Pulled through heated die
  - Chemical reaction occurs as it cures (Polymerization)
  - The resin saturated reinforcements exit the die in a solid state and in the form of the cross section of the die.
  - Types of products produced:
    - Structural shapes w/ constant cross-sections
    - GFRP/CFRP reinforcing bars & CFRP prestressing bars
FRP Overview: Processes

- Pultrusion Processing:

![Diagram of Pultrusion Process](image-url)
FRP Overview: Processes

- Pultrusion Processing:

  - Surface Veil
  - Continuous Strand Mat
  - Continuous Roving

Pultrusion Composite Diagram

Continuous Strand Mats: Reinforcements in any direction; consistent along the length of the member.
FRP Overview: Processes

• Pultruded hollow piles

 Courtesy of: Creative Pultrusions, Inc.
FRP Overview: Processes

- Various Pultruded Structural Shapes

Courtesy of: Creative Pultrusions, Inc.
FRP Overview: Processes

- Pultruded GFRP/CFRP reinforcing bars and dowels

GFRP = Glass FRP
CFRP = Carbon FRP
Vacuum Infusion (VIP)

- Reinforcing laid dry into the mold
- Vacuum is pulled before resin is introduced
- Resin is then sucked into the laminate via distributed tubing

Types of products:
- Structural shapes:
  - Uniform cross-sections
  - Non-uniform cross-sections
Vacuum Infusion (VIP)

Benefit of VIP:
Reinforcing fibers oriented in any direction at specific and targeted locations.
FRP Overview: Processes

- Variable shape and size of VIP structural members
FRP Overview: Processes

- Other Processes
  - Bladder Molding
  - Compression Molding
  - Thermoplastic Extrusion
  - Filament winding
  - Wet Layup
  - Others
National Specifications

- LRFD Design Specification for FRP Pultruded Structures
  - Structural shapes
  - Connections
  - Prefabricated building products
- Symmetric and balanced glass fiber reinforcing only
National Specifications

- ANSI Code of Standard Practice
- Pultruded FRP Structures
- Recommendations for:
  - Construction Contract Documents
  - Fabrication
  - Installation
National Specifications

- For the design and construction of concrete bridge decks and railings reinforced with GFRP reinforcing bars.

- For GFRP bars only:
  - Deformed or Sand Coated only
  - See additional limitations
For the analysis and design of concrete-filled FRP tubes (CFFT) for use as structural components in bridges

For CFFT use as:
- Beams
- Arches
- Columns
- Piles
National Specifications

- ACI 440 Series:
  - FRP Reinforcement for Concrete
  - Materials, Design and Construction Specifications
  - ASTM is currently being developed to replace the materials specifications for FRP reinforcing
FDOT Specifications

- **FRP Composite Structural Shapes:**
  - Current Section 973: “Structural Plastics”
  - Revised Section 973: FRP Composite Structural Shapes
    - Thermoset Pultruded Structural Shapes
    - Thermoset Vacuum Infusion Processed (VIP) Structural Shapes
    - Thermoplastic Structural Shapes
      - Unreinforced
      - Reinforced with GFRP Bars
FDOT Design Criteria & Specifications

FDOT Specifications

- FRP Composite Reinforcing:
  - Dev. 932: FRP Reinforcing Bar (2014)
  - Dev. 933: FRP Strand (2014)
  - Dev. 400, 415, 450, 105 for FRP Reinforcing (2014)

The draft versions currently reference ACI 440 and modifies it to be in compliance with the latest draft of the ASTM. Will reference the new ASTM once ACI 440 is replaced.
New Materials Manual Chapter 12

- Included in the July 2014 Workbook
- Requirements for Quality Control (QC) Programs for FRP Composite Producers
- Must obtain FRP Composites from a producer that is currently on the list of Producers with Accepted Quality Control (QC) Programs for Fiber Reinforced Polymer (FRP) Composites
- All FRP Composites must meet the minimum requirements of the applicable material specifications
New *Structure Manual, Volume 4*

- Scheduled for release with the 2015 Structures Manual
- Guidance on acceptable uses for FRP Composites
- Guidance on how to incorporate FRP Components into the Contract Documents
- Provides Design Guidelines and appropriate references to the applicable National Specifications
- Guidance for preparation of Specifications Package
FRP Overview: Applications

- Global Applications
  - Marine transportation components
  - Architectural Cladding components
  - Aerospace transportation and weapons components
  - Automotive components
  - Energy Sector components (wind turbines)
  - Static Structural Components (Buildings/Bridges)
FDOT FRP Initiatives:

- **Structural Shapes**
  - Fender System Piles, Wales, and Catwalks
  - Composite Beams
    - Hillman Beam - D7 Project

- **Concrete Reinforcing – Invitation to Innovation**
  - Reinforcing bars
  - Pre-stressing strands
  - External reinforcing (maintenance)
FDO FRP Initiatives:

- Fender System Piles and Wales
  - FDOT 471 & 973 spec.
  - New Approved Fabricators List requirements through MM 12.1 (July 2014)
  - Revised SDG Section 3.14 (Jan 2015)
  - New Structure Detailing Manual Chapter 24 (Jan 2015)
FDOT FRP Initiatives:

- **Composite Beams**

  - **Hillman Composite Beam**
    - constructed as a composite of three materials: steel strands, concrete, and fiber reinforced polymer
    - materials are arranged in a manner that the materials act as what would traditionally be separate structural elements
    - District 7 (Halls River Project)
Demonstration Project in District 7:

- CR490A bridge replacement over Halls River
- Bridge Length = 185’-10” total
- 5 spans @ 37’-2”
- Overall Bridge Width = 56’-9 3/4”
- Hybrid Composite Beams (Hillman Beam) = 11 beams @ 5’-3”
- 24” Prestressed concrete piles w/CFRP strands and spirals
- Concrete seawalls replacement using GFRP & CFRP reinforcement
- Phased construction
- Extremely aggressive environment for both superstructure & substructure
D7 Halls River Project
FDOT FRP Initiatives:

- Concrete Repair (Maintenance)
  - Extension of service life
  - Near Surface Reinforcing
    - Carbon Fiber Fabric Wraps
    - Near Surface Reinforcing Bars
Fiber Reinforced Polymer (FRP) Reinforcing Bars and Strands
FDOT FRP Initiatives:

- Concrete Reinforcing
  - Reinforcing Bars (GFRP and/or CFRP)
    - Approach Slabs
    - Bridge Decks and Bridge Deck overlays
    - **Cast-in-Place Flat Slab Superstructures**
    - Pile Bent Caps not in direct contact with water
    - Pier Columns and Caps not in direct contact with water
    - **Retaining Walls, Noise Walls, Perimeter Walls**
    - Pedestrian/Bicycle Railings
    - Bulkheads
    - **MSE Wall Panels**
    - **Wall Copings**
    - Drainage Structures
    - **Concrete Sheet Piles**
FDOT FRP Initiatives:

- Concrete Pretensioning
  - Pre-stressing strands (CFRP)
    - Pre-stressed Concrete Piles (with CFRP spirals)
    - Pre-stressed Concrete Sheet Piles
Recent Testing on FRP Composites

- GFRP Reinforced Thermoplastic Piles and Wales
- VIP Composite Bridge Decking
- Pultruded Light Poles
  - Breakaway Pole Bases
- Prestressed Concrete Piles using CFCC
- Post Tensioned Box Girder using CFCC
- Mast Arm/Light Pole repair using CFRP Wrapping
Research
Research
Leading Researcher on FRP Reinforcing and Prestressing

Dr. Brahim Benmokrane, P. Eng., FACI, FCSCE, FIIFC, FCAE, FEIC
- FRP-ACI Committee Member
- Professor of Civil Engineering-Fellow of the Royal Society of Canada
- Tier-1 Canada Research Chair in Advanced Composite Materials for Civil Structures
- NSERC/Industry Research Chair in Innovative FRP Reinforcement for Concrete Infrastructure
- Director, Quebec-FQRNT Research Centre on Concrete Infrastructure (CRIB)
**Usage (Characteristics/Durability)**

- **Characteristics**
  - **PROS**
    - It is highly resistant to chloride ion and chemical attack
    - Its tensile strength is greater than that of steel yet it weighs only one quarter as much
    - It is transparent to magnetic fields and radar frequencies
    - GFRP has low electrical and thermal conductivity
  - **CONS**
    - Due to its inelastic behavior design codes significantly reduce the allowable stress capacity
    - Due to the manufacturing processes the industry is undergoing progressive standardization
    - Storage and handling requirements for FRP reinforcing on the construction site can be more restrictive due to FRP's susceptibility to damage by overexposure to UV light, improper cutting or aggressive handling.
    - The initial cost of the FRP reinforcing is considerably higher than traditional steel reinforcing
Long term durability of GFRP

Materials are resistant to degradation, but over time…

Moisture + Alkali/Acid/Salt + Temperature

Matrix
Interface
Fiber
Usage (Characteristics/Durability)

- Degradation factors
  - Moisture
    - Diffusion through matrix
    - Flow through cracks or other flaws
    - Transportation medium for alkali/acid/salt
  - Alkali
    - Attacks silica network in glass – “etching and leaching”

Usage (Characteristics/Durability)

- Degradation factors
  - Acids
    - Hydrogen replaces alkali and other positive mobile ions in glass – “leaching”
  - Salts
    - Similar to acids
  - Temperature
    - Affects rate of moisture absorption and chemical reactions
Usage (Characteristics/Durability)

- Materials and processing
  
  ✓ Improvements made in material selection
    
    - Polyester to Vinyl Ester (less moisture absorption)
    
    - E glass to E-CR glass fibers (less leaching)

E-glass

Boron-free E-CR glass

4 hours in 5% HCl @ 95°C

Spoo, ACMA Chemical Processing Symposium (2013)
Usage (Characteristics/Durability)

- E glass fiber composite

Figure 10: Stress-Rupture Performance of Traditional E-glass Composite Rods in Cement at Two Temperatures

Usage (Characteristics/Durability)

- E-CR glass fiber composite

Figure 8: Stress-Rupture Performance of Advantex Glass Composite Rods in Cement at Two Temperatures

Usage (Characteristics/Durability)

- E vs E-CR glass fiber composites

Figure 22: Effective Maximum Load for 50-Year Service

Usage (Characteristics/Durability)

- Materials and processing
  - Quality of finished composite affects durability
    - Look for minimal defects and fully cured resin
Usage (Characteristics/Durability)

- Long term durability of GFRP
  - Materials are resistant to degradation, but over time...

HOW MUCH TIME?
Usage (Characteristics/Durability)

- Long term durability of GFRP
  - Establish model(s) to accurately describe the degradation of GFRP based on the synergistic effects of physical and chemical aging on fibers, matrix and interface
  - Establish protocol for service life prediction based on the model(s)
Durability of CFRP

Carbon fibers are highly stable, even in aggressive environments

Fibers from carbon/epoxy composite treated for 2 hours in 0.05 M KOH solution at 770°F, 4200 psi
Individual fibers maintained 100% tensile strength

FDOT Resources

◆ Structures Design Office:
  ✓ A. Jordan Thomas, P.E. (FDOT Policy/Standards)
  ✓ Gevin McDaniel, P.E. (FDOT Policy/Standards)
  ✓ Sam Fallaha, P.E. (FDOT Research/Testing)
  ✓ Will Potter, P.E. (FDOT Research/Testing)

◆ Materials Office:
  ✓ Chase Knight, PhD (Materials/Durability)
Composites and Advanced Materials Expo
October 13-16, 2014
Orange County Convention Center
Orlando, FL

www.thecamx.org
Questions?