Fiber Reinforced Polymer (FRP) Composites

2014 Design Training Expo

Gevin McDaniel, P.E.

Roadway Design Standards Administrator

&

Chase Knight, PhD

Composite Materials Research Specialist

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

FRP Overview: Fibers

- 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?

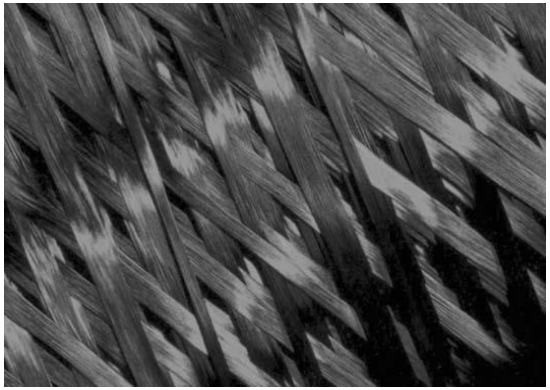
FRP Overview: Fibers

- Used in many different forms:


Short Fibers


Chopped Fibers


Long Fibers


Woven Fibers

2014 Design Training Expo

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; <u>Can't</u> 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; <u>Can</u> 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

FRP Overview: Resins

- **Vinyl esters**
  - Advantages:
    - Very high chemical/environmental resistance
    - Higher mechanical properties than polyesters
  - Disadvantages:
    - Sensitive to heat
    - Higher cost than polyesters

FRP Overview: Resins

- **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)

FRP Overview: Resins

- **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

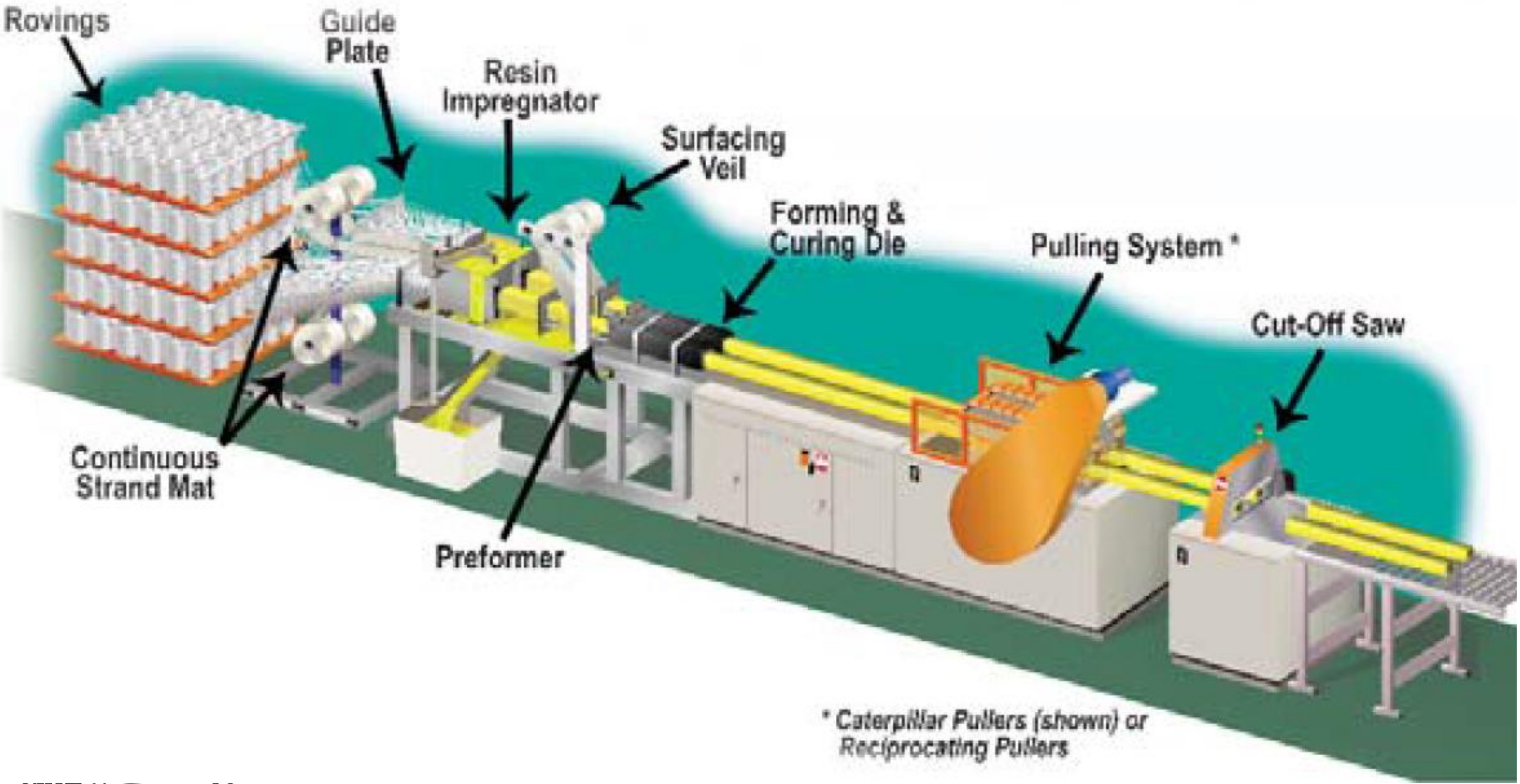
- Manufacturing Processes
  - ✓ Predominate Processes
    - Pultrusion
    - Vacuum Infusion
  - ✓ Other Processes

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

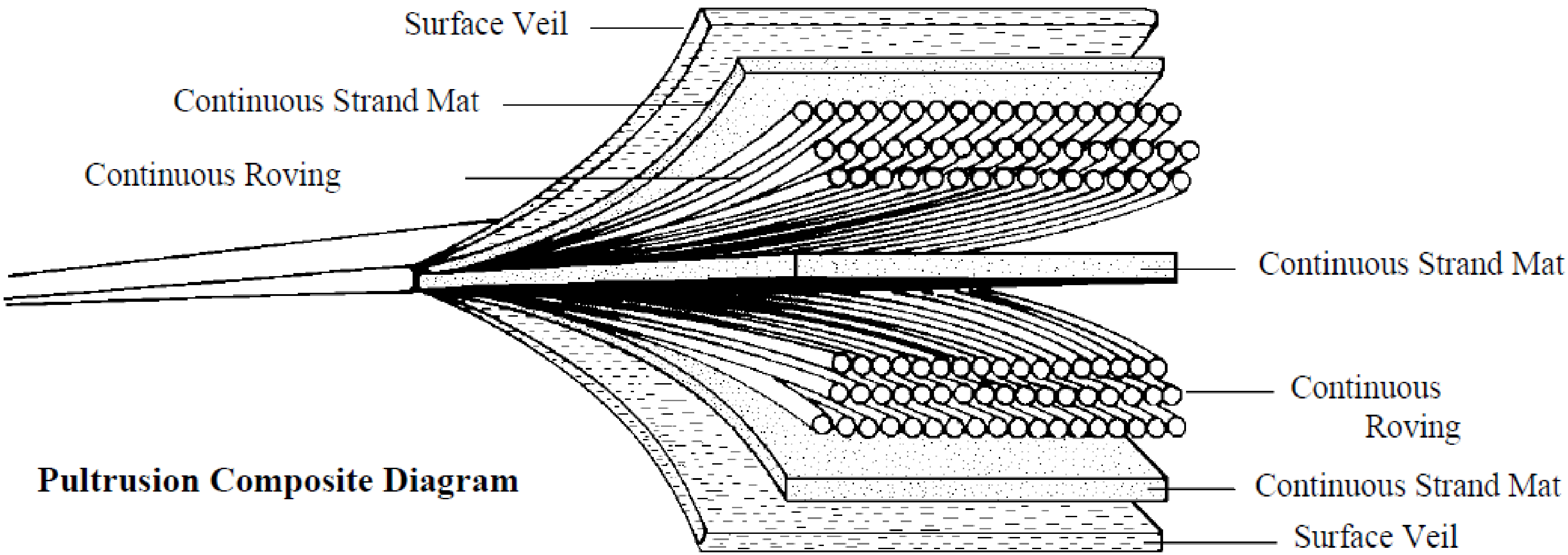
FRP Overview: Processes

- Pultrusion Processing:



FRP Overview: Processes

- Pultrusion Processing:



Pultrusion Composite Diagram

Courtesy of: Creative Pultrusions, Inc.

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

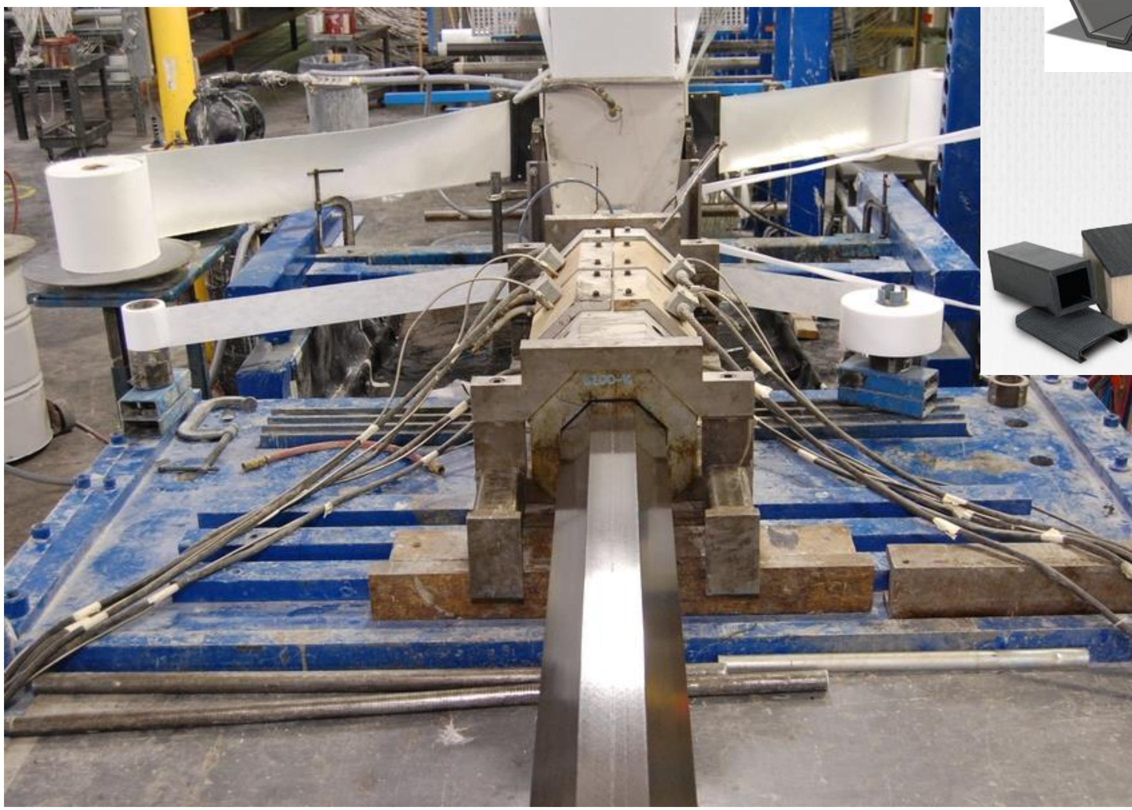
FRP Overview: Processes

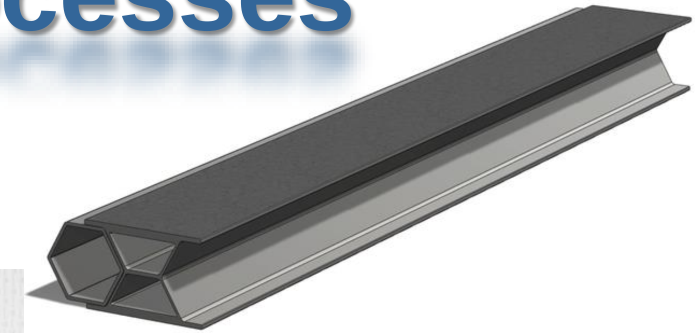
- Pultruded hollow piles

Courtesy of: Creative Pultrusions, Inc.

FRP Overview: Processes

- Various Pultruded Structural Shapes





Courtesy of: Creative Pultrusions, Inc.

2014 Design Training Expo

FRP Overview: Processes

- Pultruded GFRP/CFRP reinforcing bars and dowels

GFRP = Glass FRP

CFRP = Carbon FRP

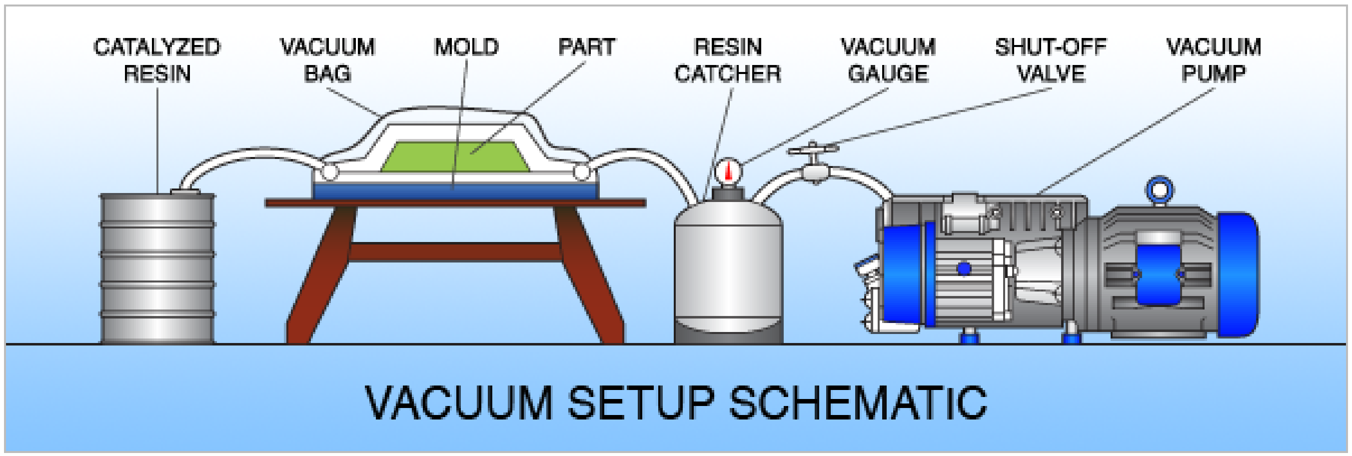
FRP Overview: Processes

- 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

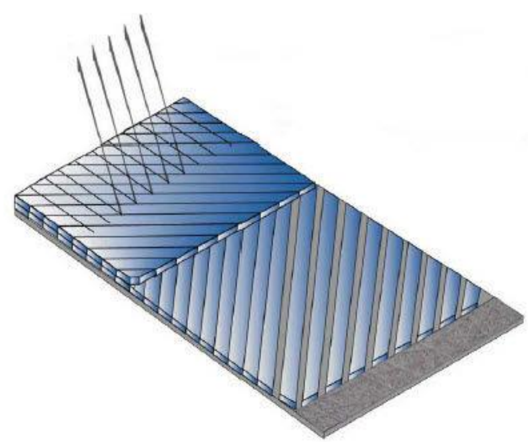
2014 Design Training Expo

FRP Overview: Processes

- Vacuum Infusion (VIP)



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



FRP Overview: Processes

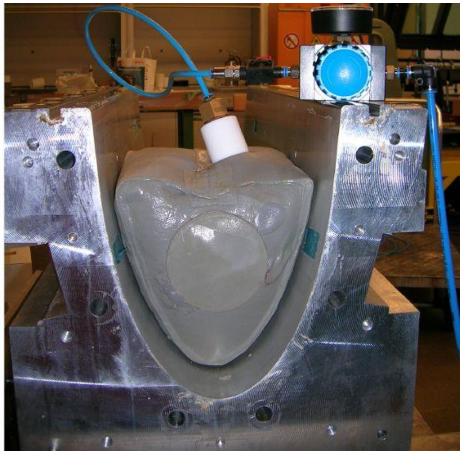
- Variable shape and size of VIP structural members

2014 Design Training Expo

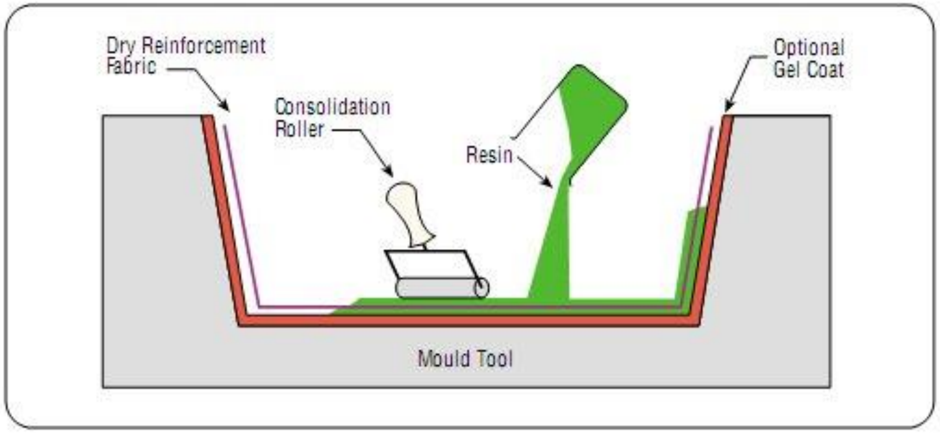
HarborTechnologies, LLC

FRP Overview: Processes

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



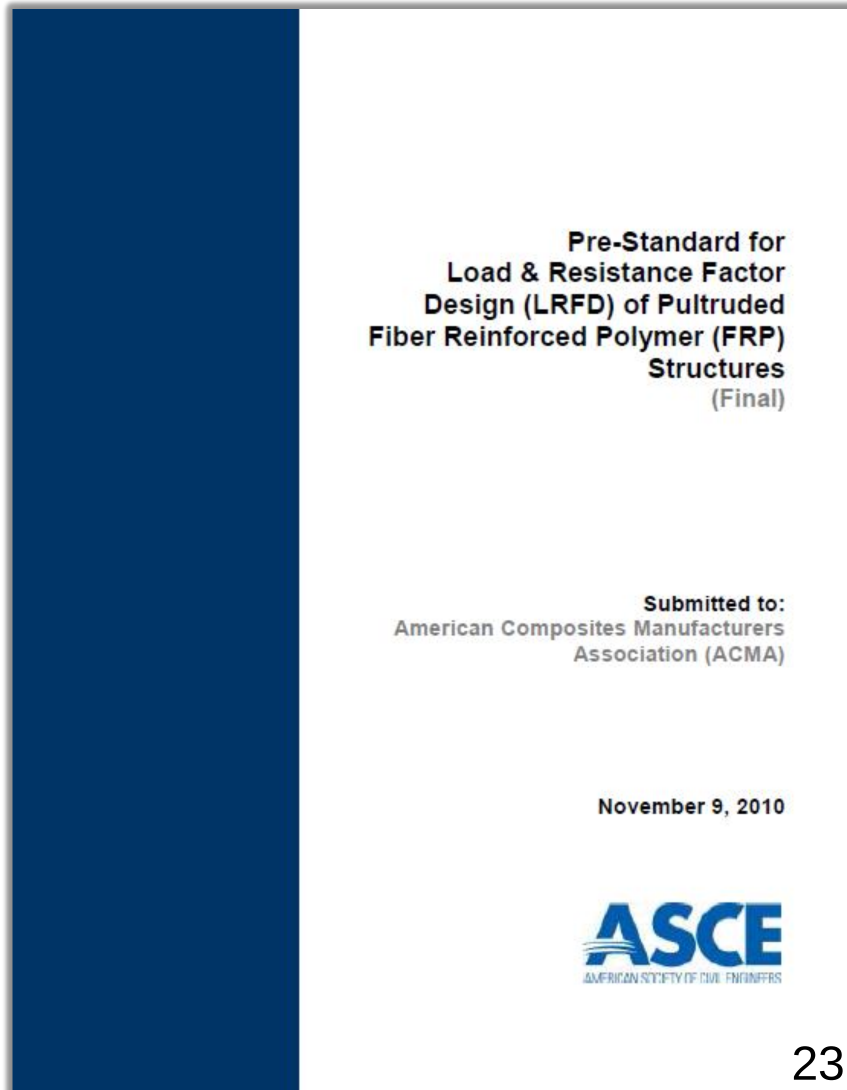
Bladder Molding



Wet Layup

National Specifications

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



Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures
(Final)

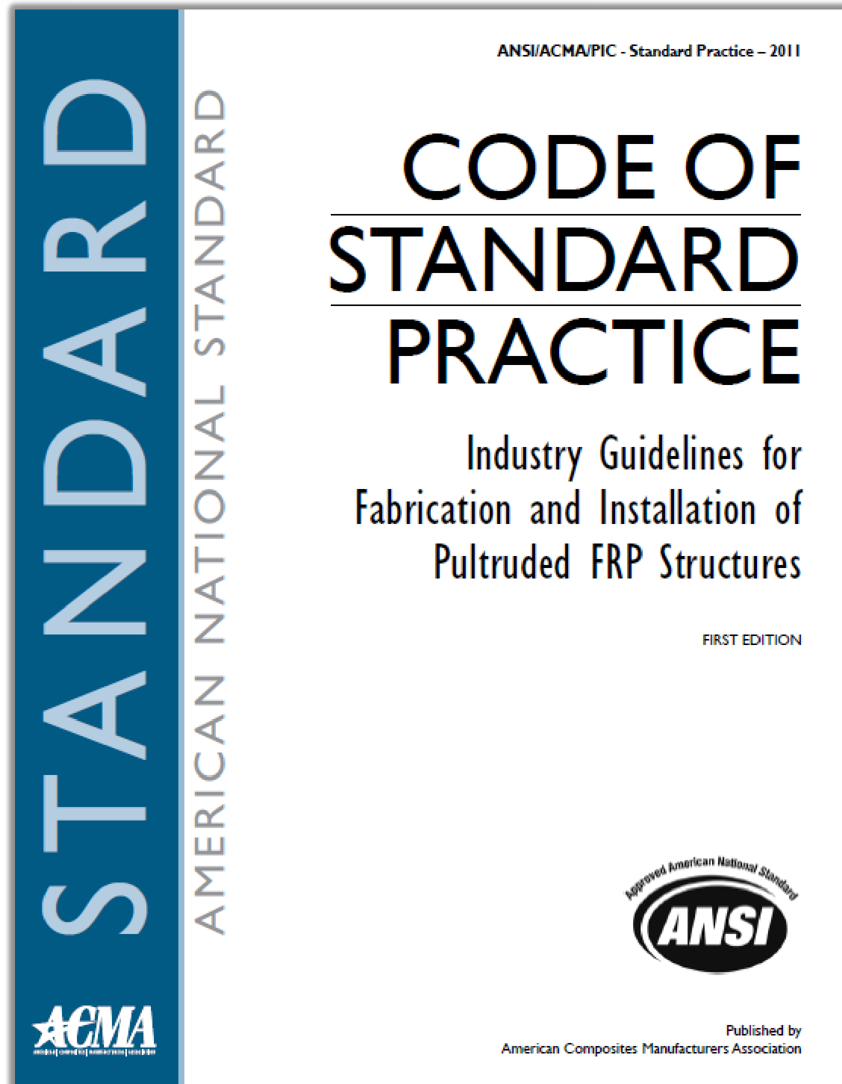
Submitted to:
American Composites Manufacturers Association (ACMA)

November 9, 2010

ASCE
AMERICAN SOCIETY OF CIVIL ENGINEERS

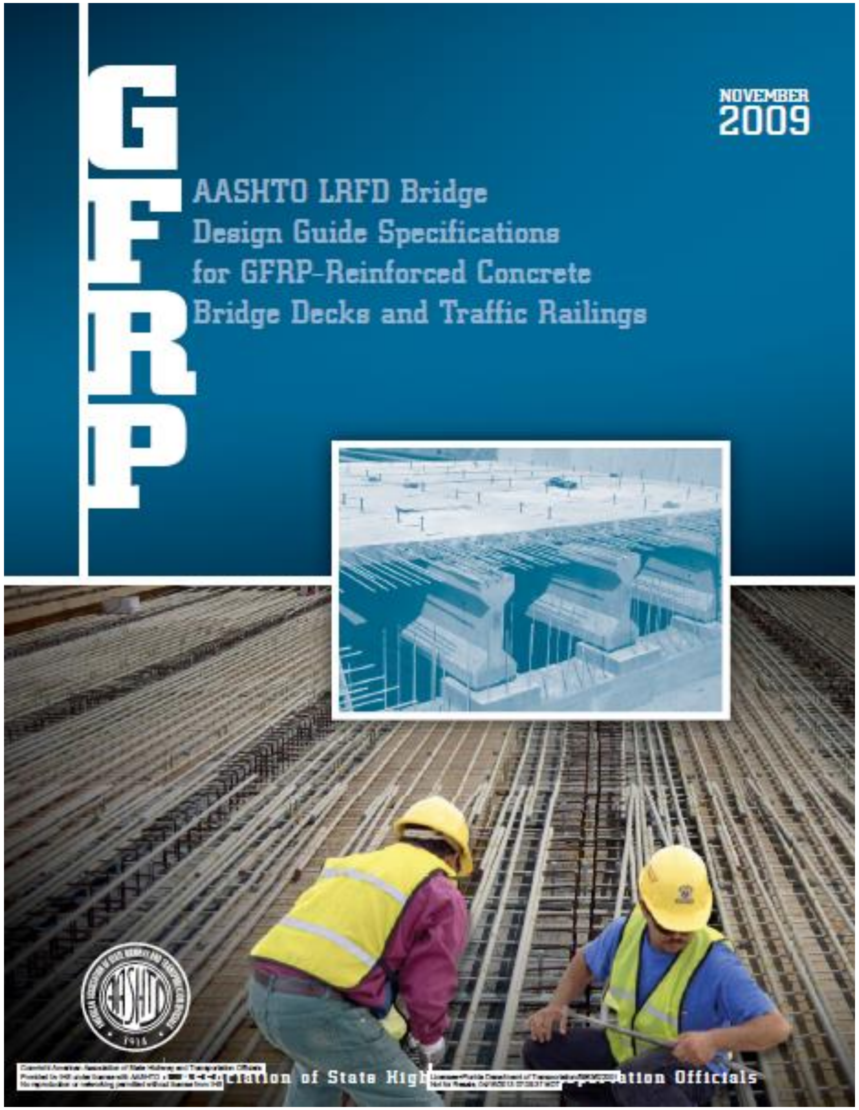
National Specifications

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



National Specifications

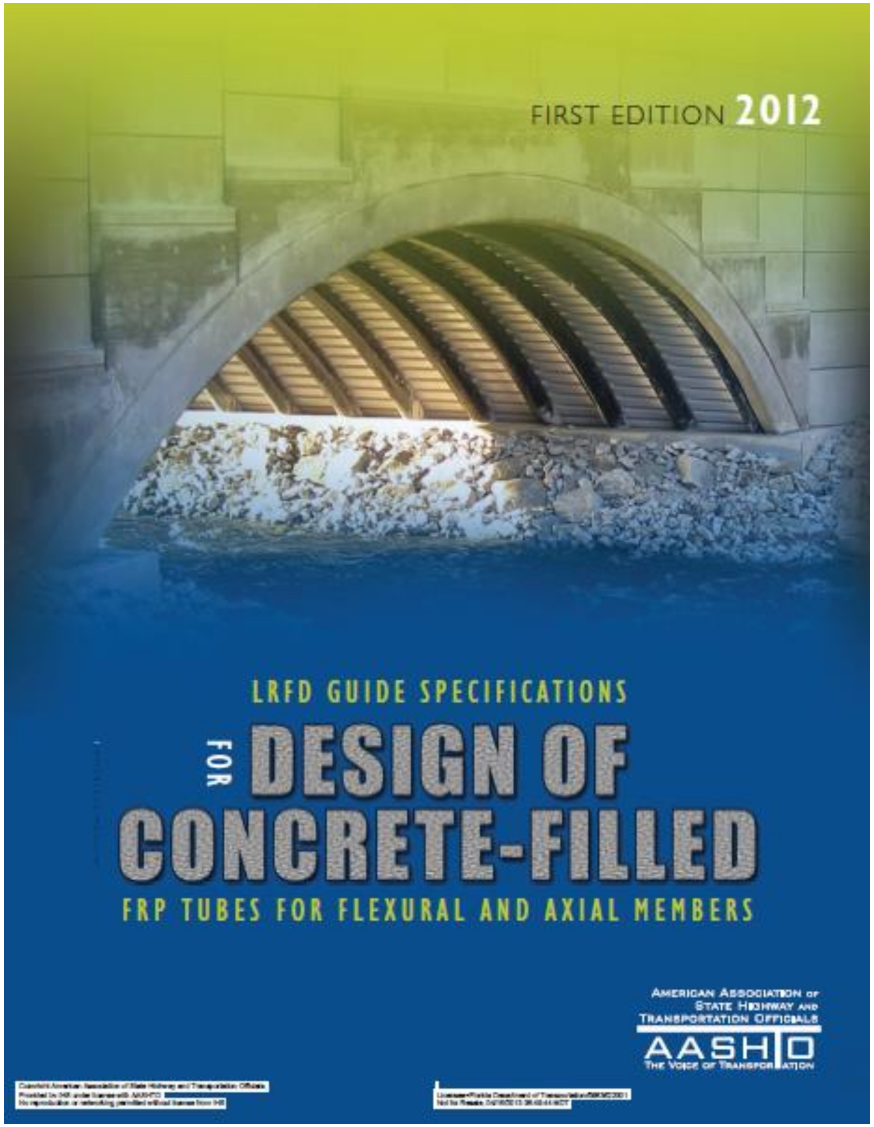
- For the design and construction of concrete bridge decks and railings reinforced with GFRP reinforcing bars.
- For GFRP bars only:
  - ✓ Deformed or Sand Coated only
  - ✓ See additional limitations



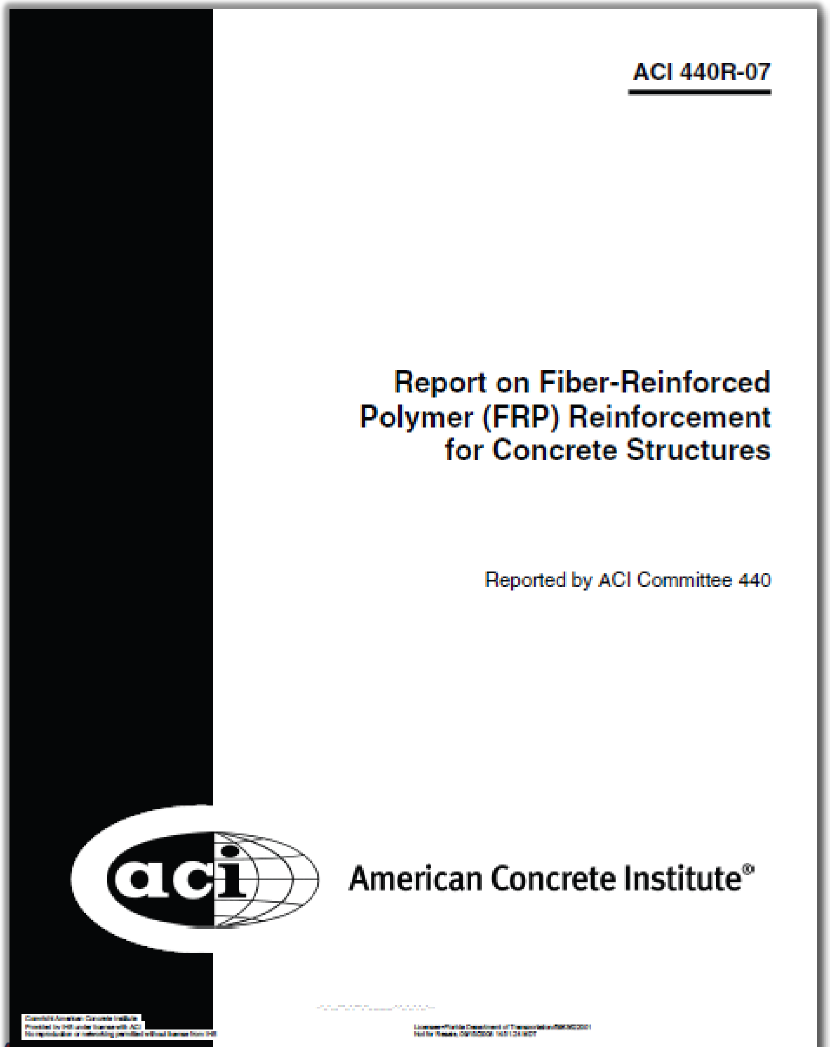
2014 Design Training Expo

National Specifications

- 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 440R-07

Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures

Reported by ACI Committee 440

American Concrete Institute®

ASTM

- 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 Design Criteria & Specifications

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

2014 Design Training Expo

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 incompliance with the latest draft of the ASTM. Will reference the new ASTM once ACI 440 is replaced.

FDOT Design Criteria & Specifications

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

FDOT Design Criteria & 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

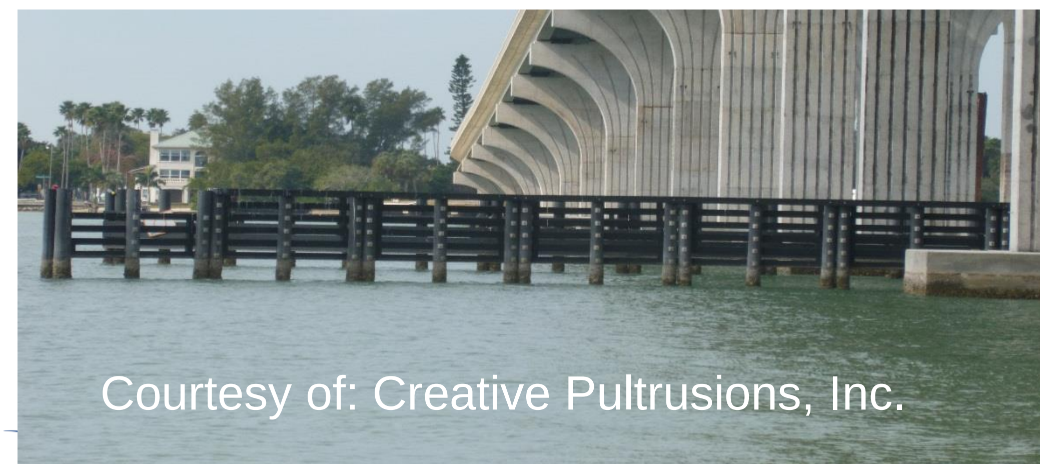
- Global Applications
  - Marine transportation components
  - Architectural Cladding components
  - Aerospace transportation and weapons components
  - Automotive components
  - Energy Sector components(wind turbines)
  - Static Structural Components(Buildings/Bridges)

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)

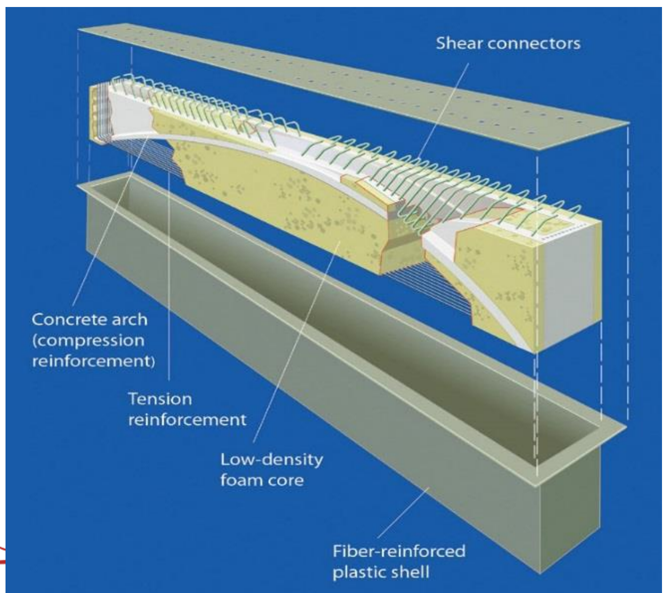
FDOT FRP Initiatives:

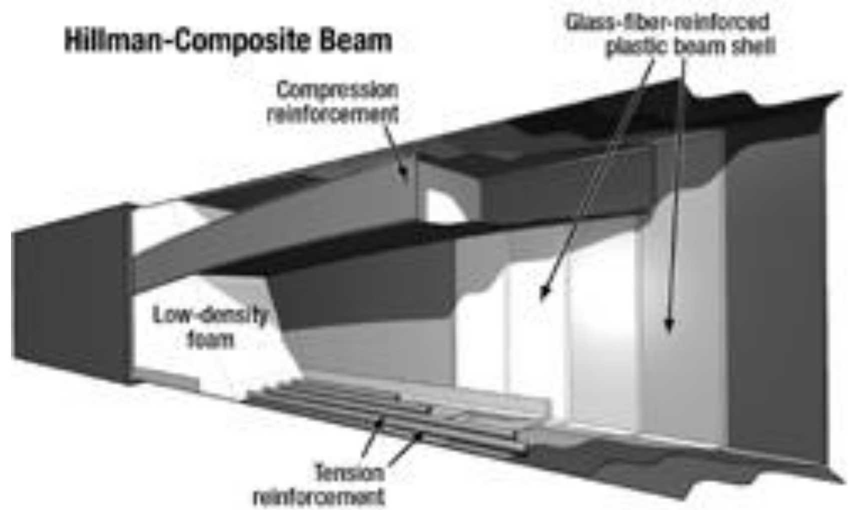
- Fender System Piles and Wales
  - ✓ FDOT 471 & 973 spec.
  - ✓ New Approved Fabricators List requirements through MM 12.1 (July 2014)
  - ✓ Revised SDG Section 3.14 (Jan 2015)
  - ✓ New Structure Detailing Manual Chapter 24 (Jan 2015)



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)

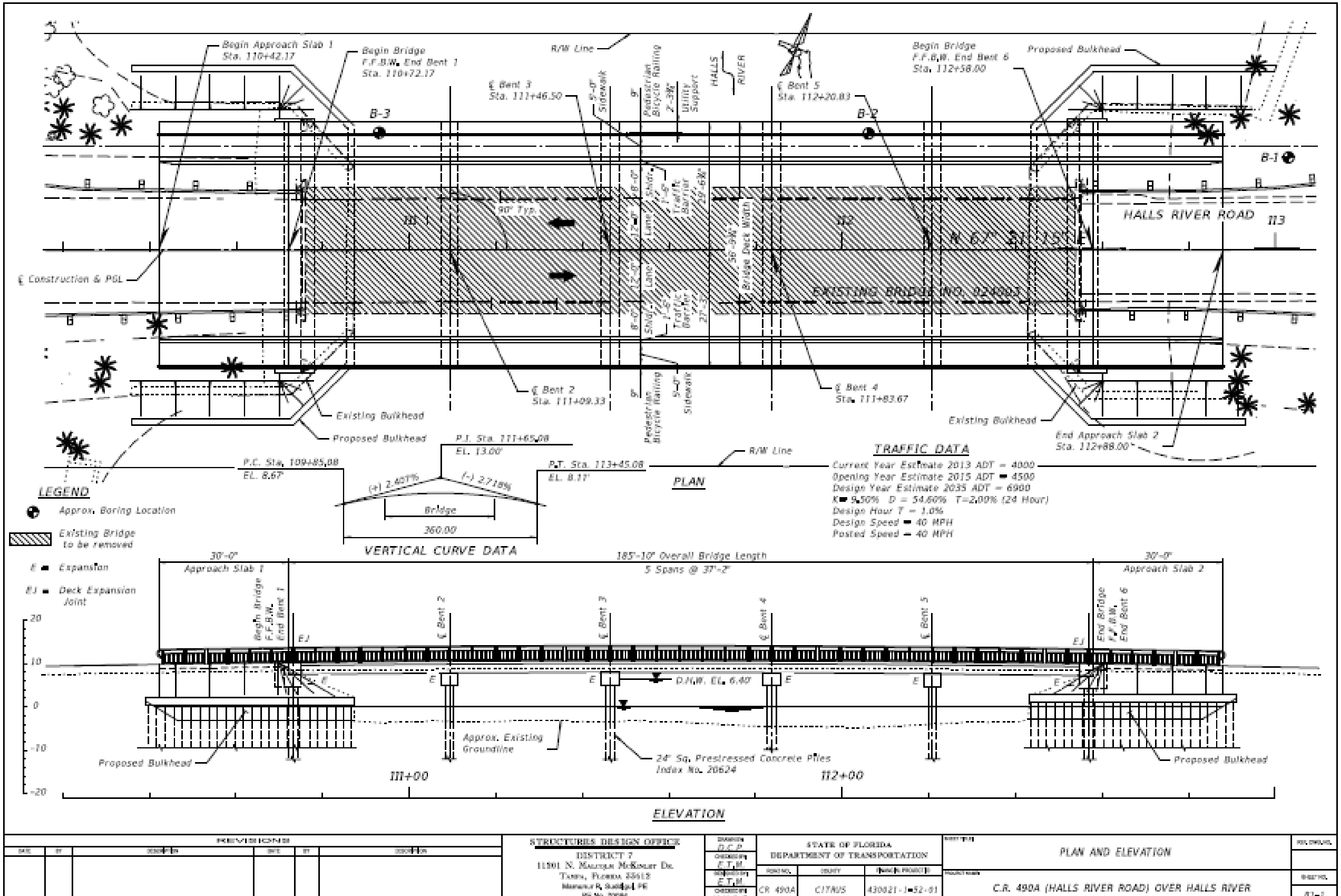




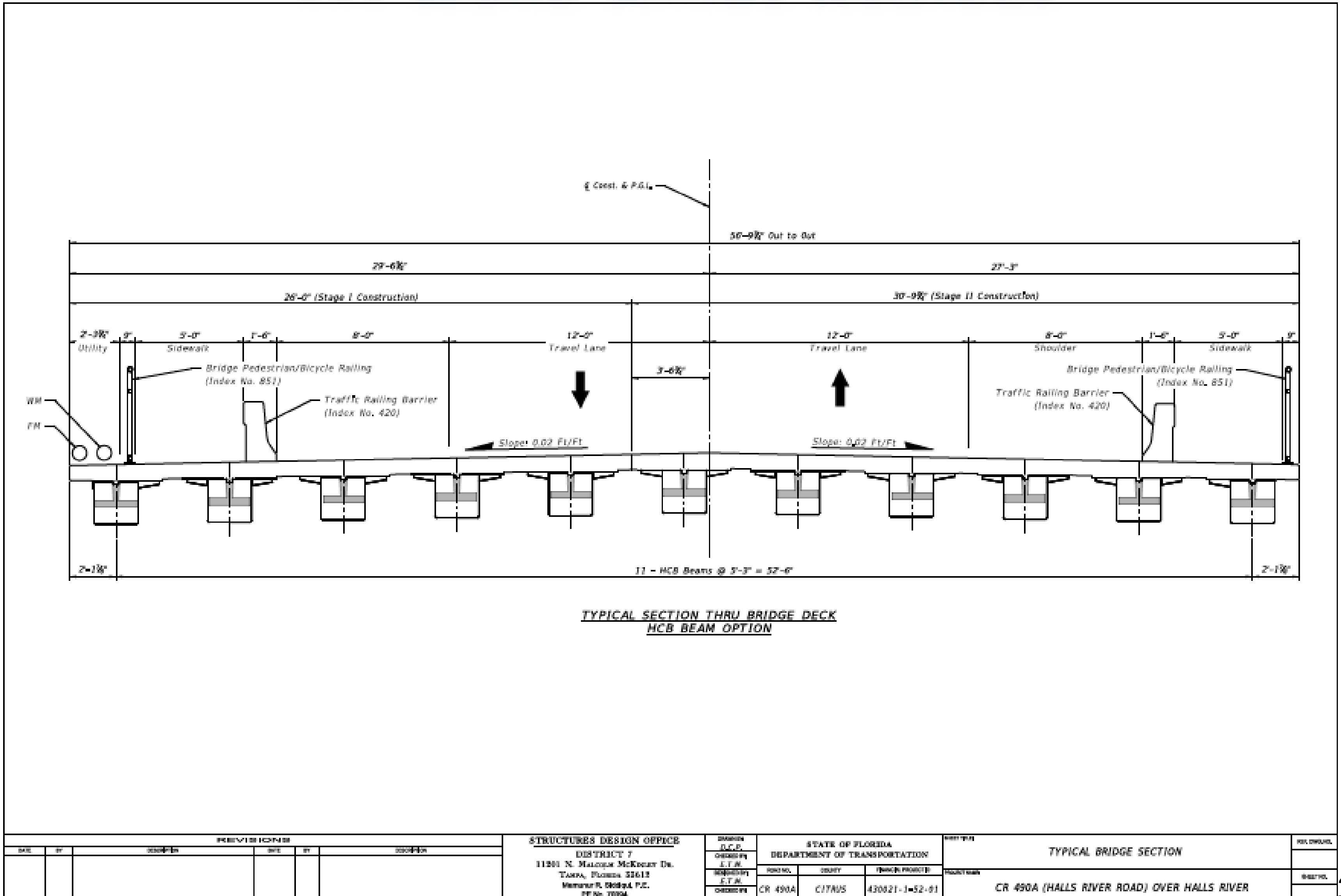
D7 Halls River Project

- 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



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

FDOT FRP Initiatives:

INVITATION TO
INNOVATION

Fiber Reinforced Polymer (FRP)
Reinforcing Bars and Strands

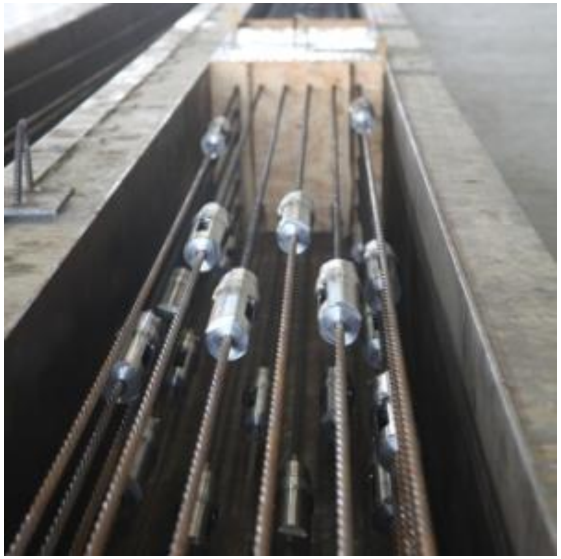
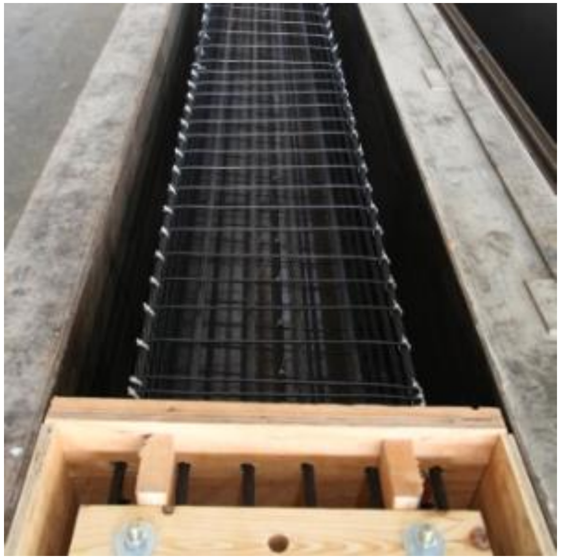
FDOT FRP Initiatives:

- 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**

2014 Design Training Expo

FDOT FRP Initiatives:

- Concrete Pretensioning
  - ✓ Pre-stressing strands(CFRP)
    - Pre-stressed Concrete Piles (with CFRP spirals)
    - Pre-stressed Concrete Sheet Piles

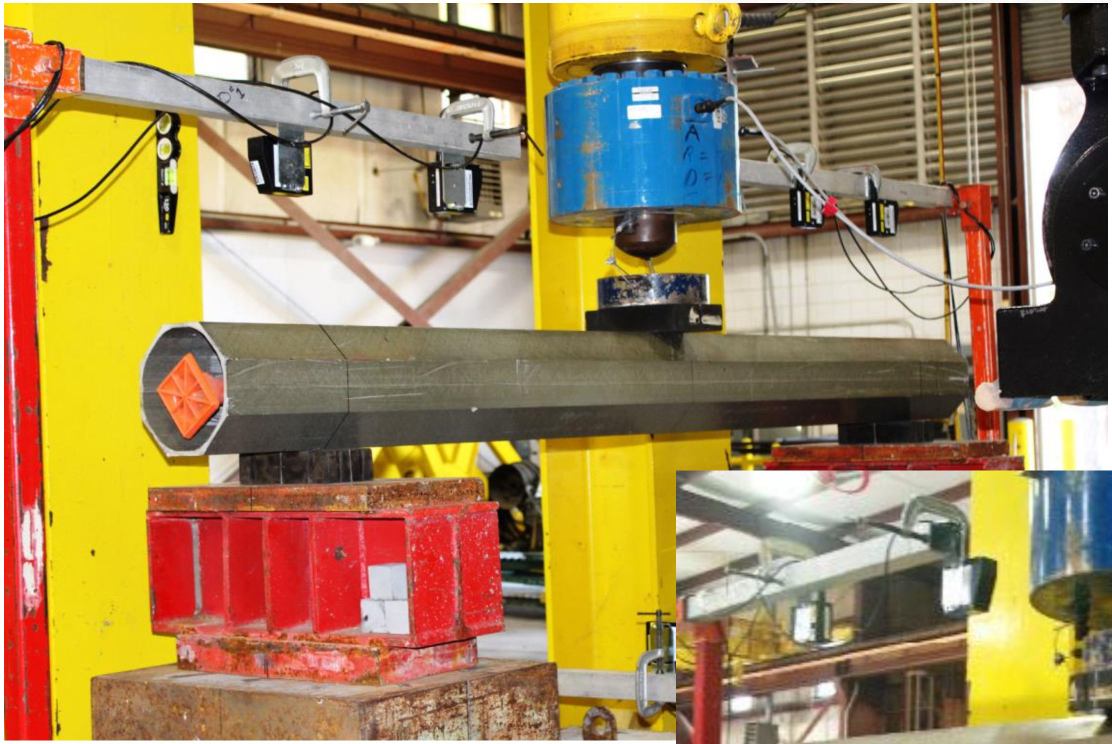



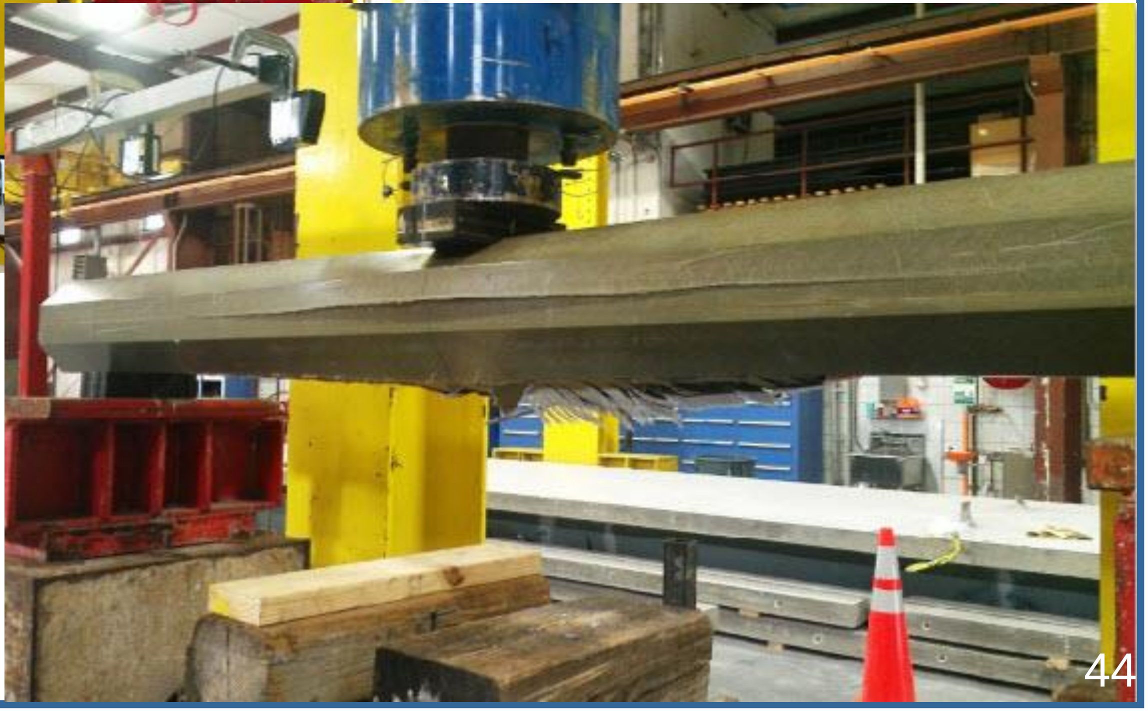

Research

M.H. Ansley Structures Research Center

- 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 Wraping

Research





Research

2014 Design Training Expo

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)

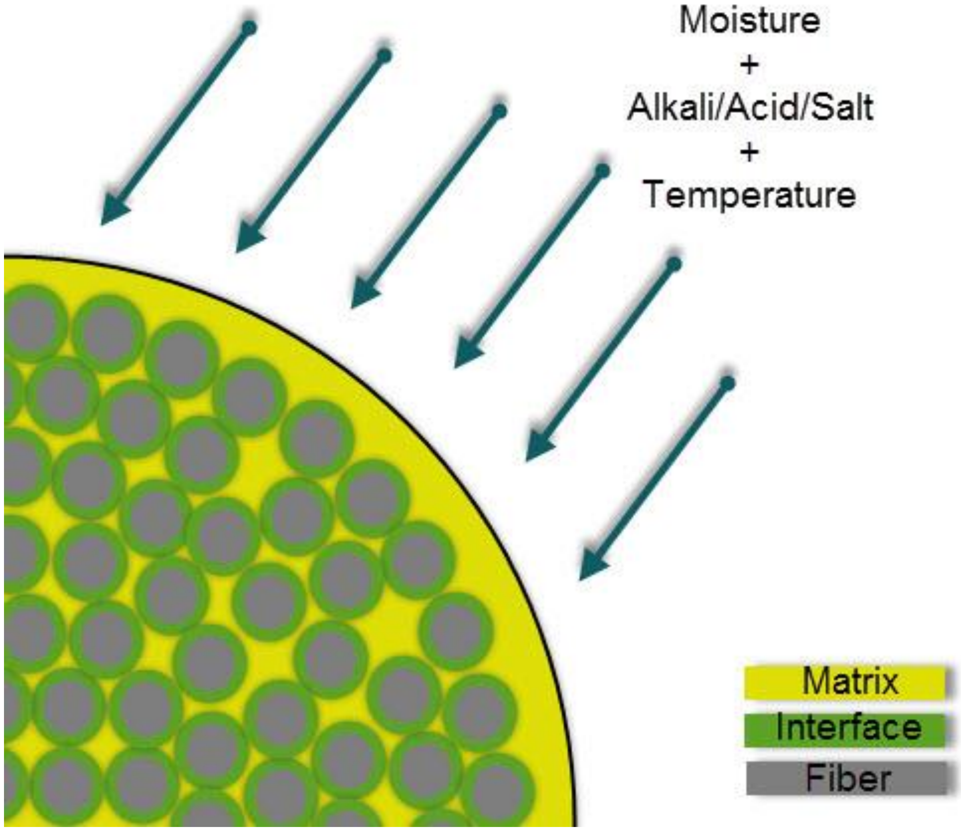
2014 Design Training Expo

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

Usage (Characteristics/Durability)

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



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”

GangaRao et al. Reinf. concr. des. with compos. CRC Press (2007)

Usage (Characteristics/Durability)

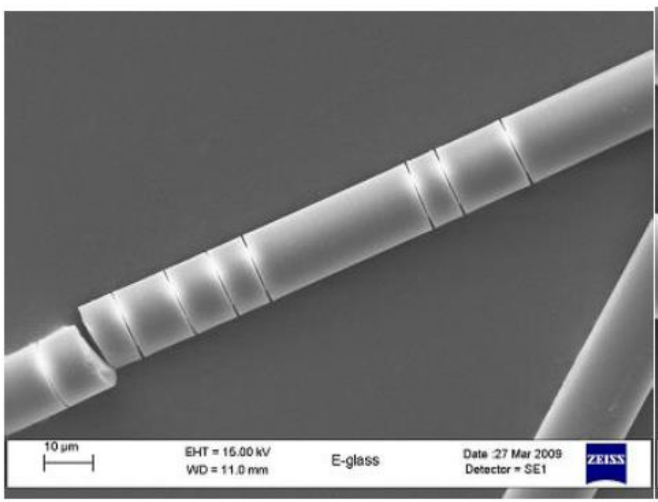
- Degradation factors
  - ✓ Acids
    - Hydrogen replaces alkali and other positive mobile ions in glass – “leaching”
  - ✓ Salts
    - Similar to acids
  - ✓ Temperature
    - Affects rate of moisture absorption and chemical reactions

GangaRao et al. Reinf. concr. des. with compos. CRC Press (2007)

Usage (Characteristics/Durability)

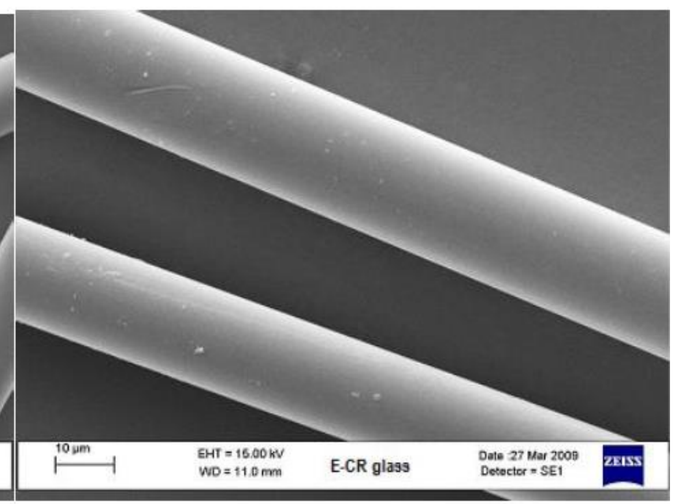
- Materials and processing
  - ✓ Improvements made in material selection
    - Polyester to Vinyl Ester (less moisture absorption)
    - E glass to E-CR glass fibers (less leaching)

E-glass



4 hours in 5%HCl @ 95°C

Boron-free E- CR glass

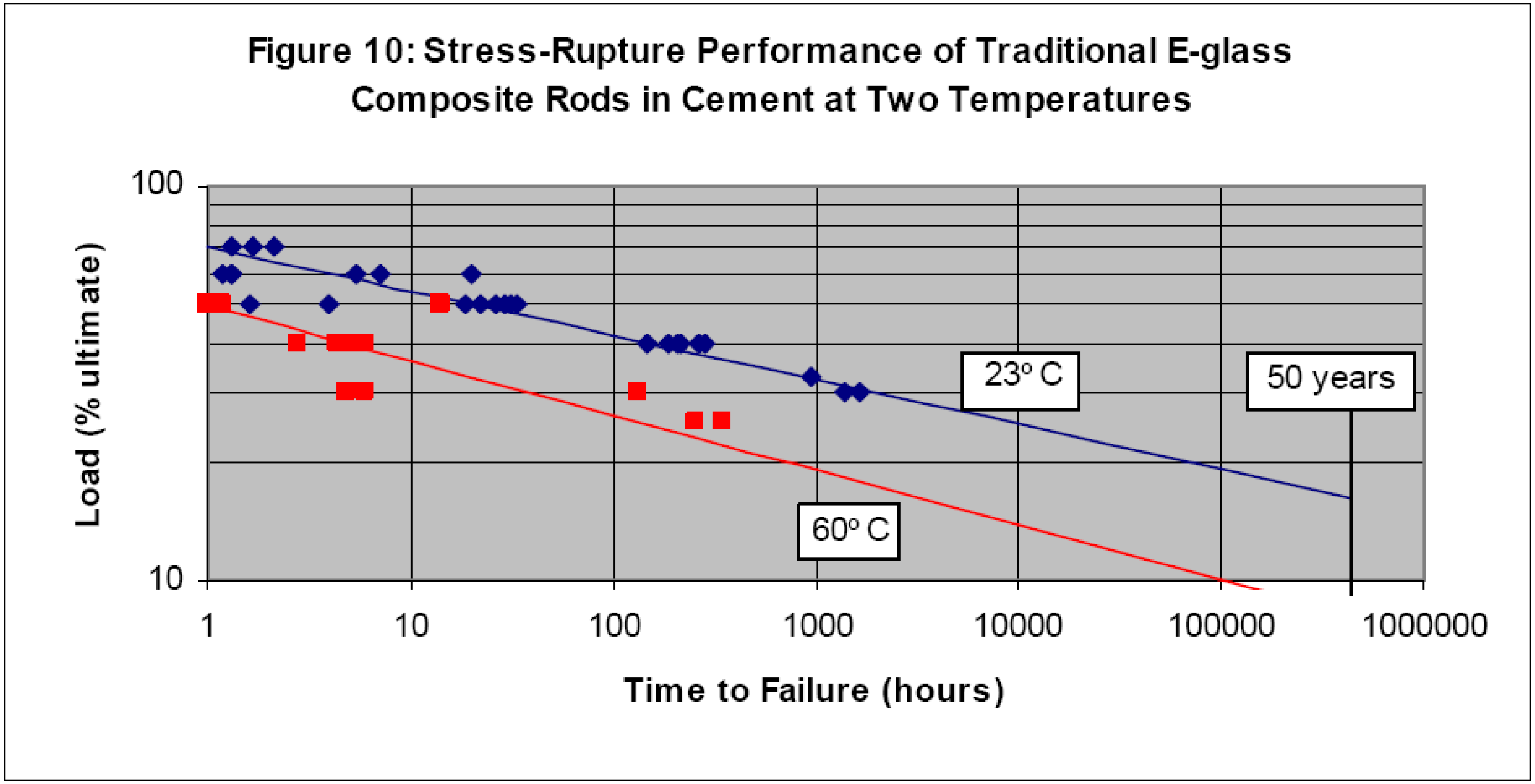


4 hours in 5% HCl @ 95°C

Spoo, ACMA Chemical Processing Symposium (2013)

Usage (Characteristics/Durability)

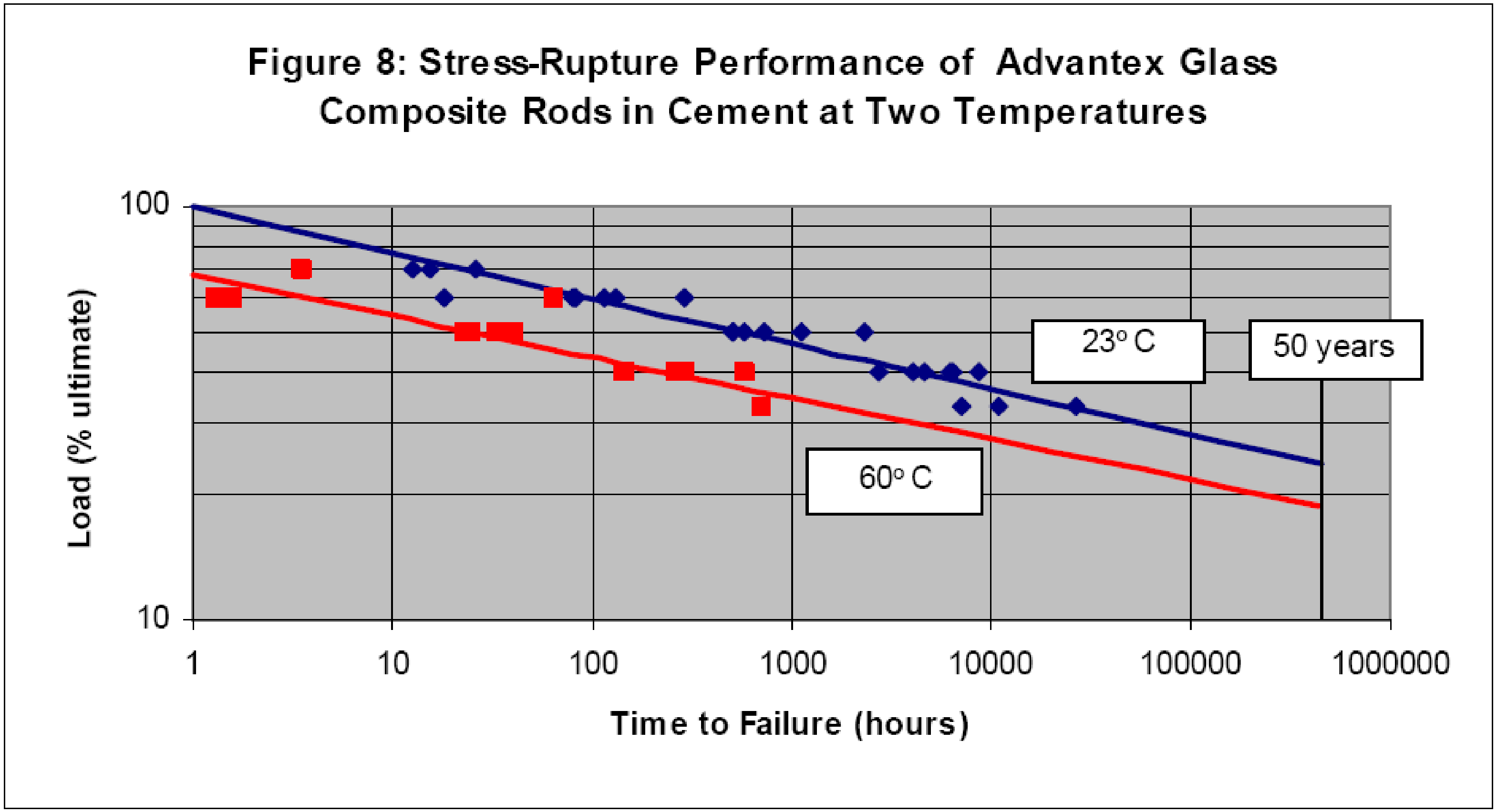
- E glass fiber composite



Greenwood. Pultruded composites durability. Owens Corning (2001)

Usage (Characteristics/Durability)

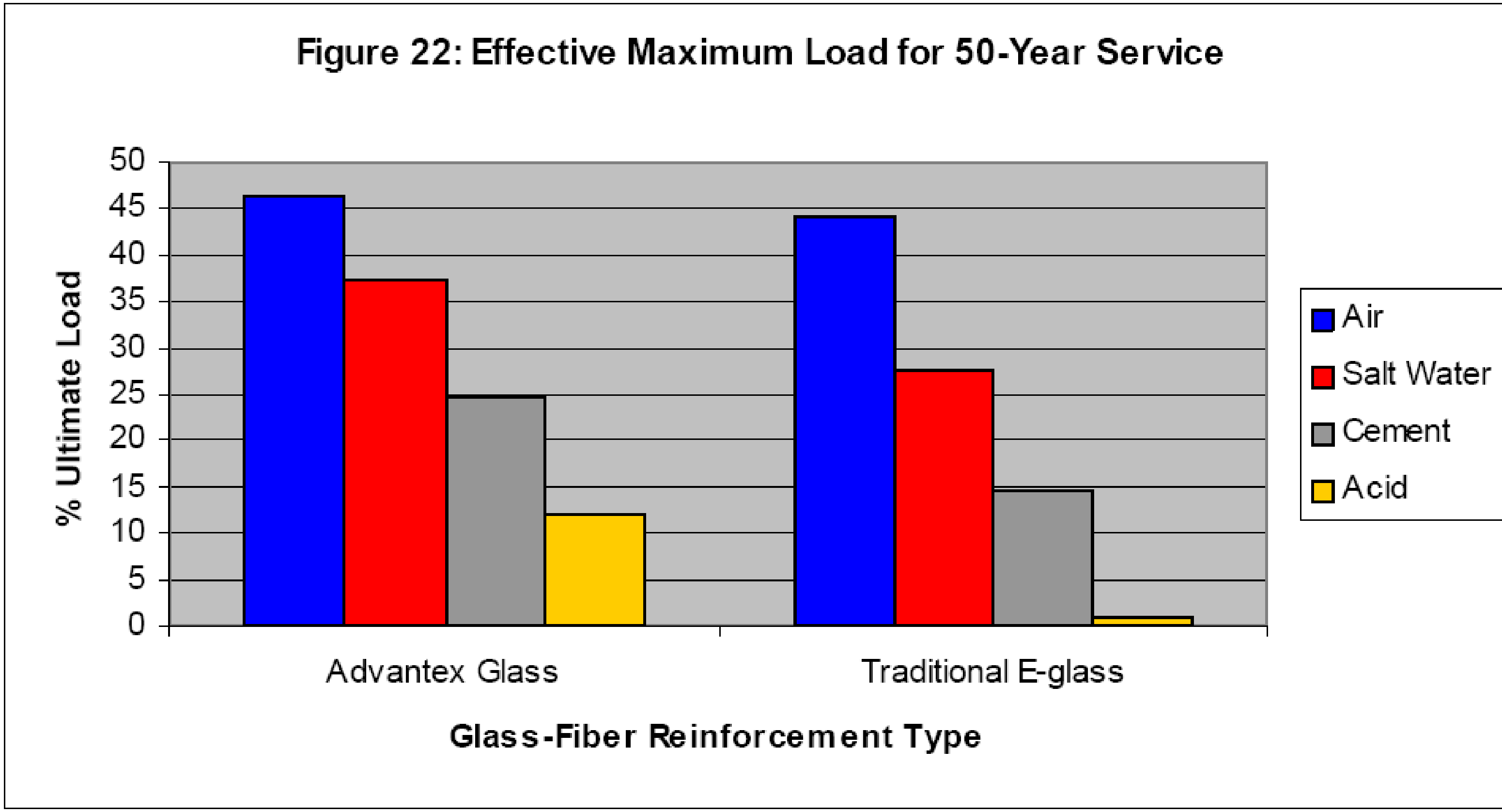
- E-CR glass fiber composite



Greenwood. Pultruded composites durability. Owens Corning (2001)

Usage (Characteristics/Durability)

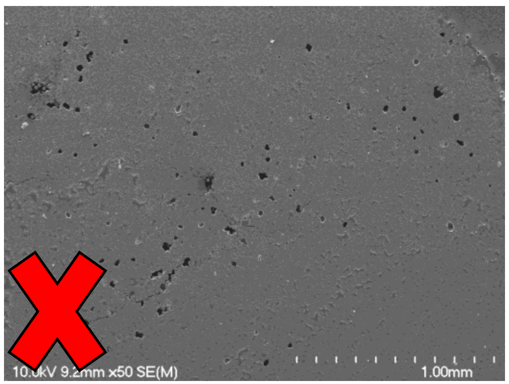
- E vs E-CR glass fiber composites

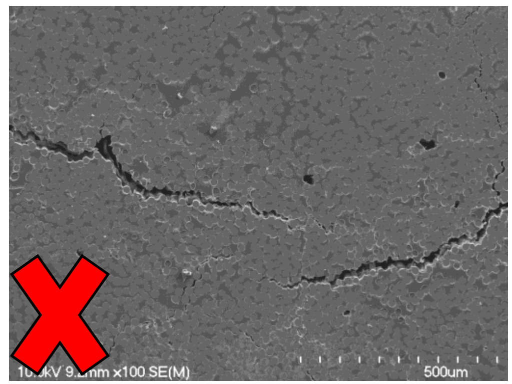


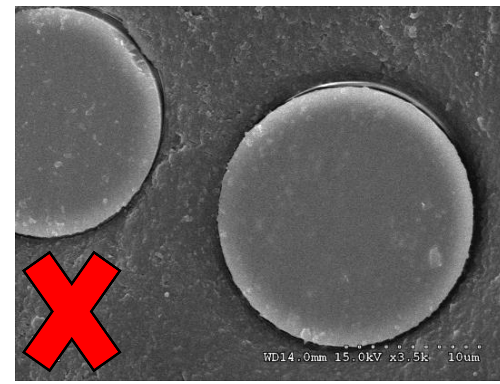
Greenwood. Pultruded composites durability. Owens Corning (2001)

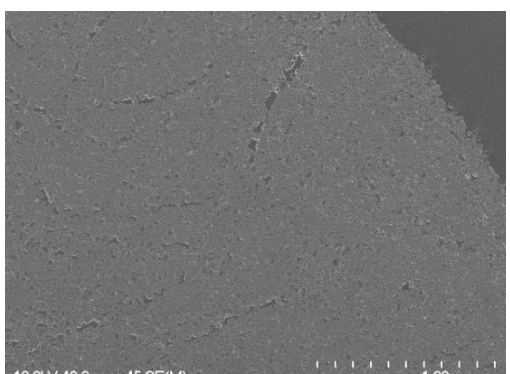
Usage (Characteristics/Durability)

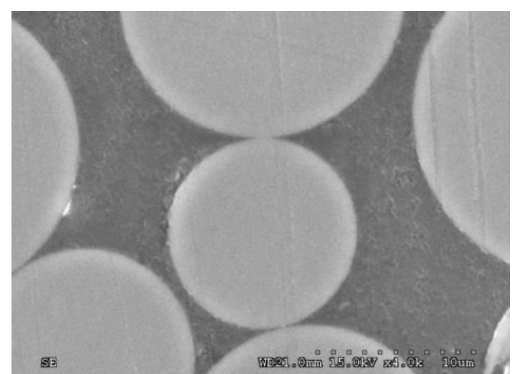
- Materials and processing
  - ✓ Quality of finished composite affects durability
    - Look for minimal defects and fully cured resin





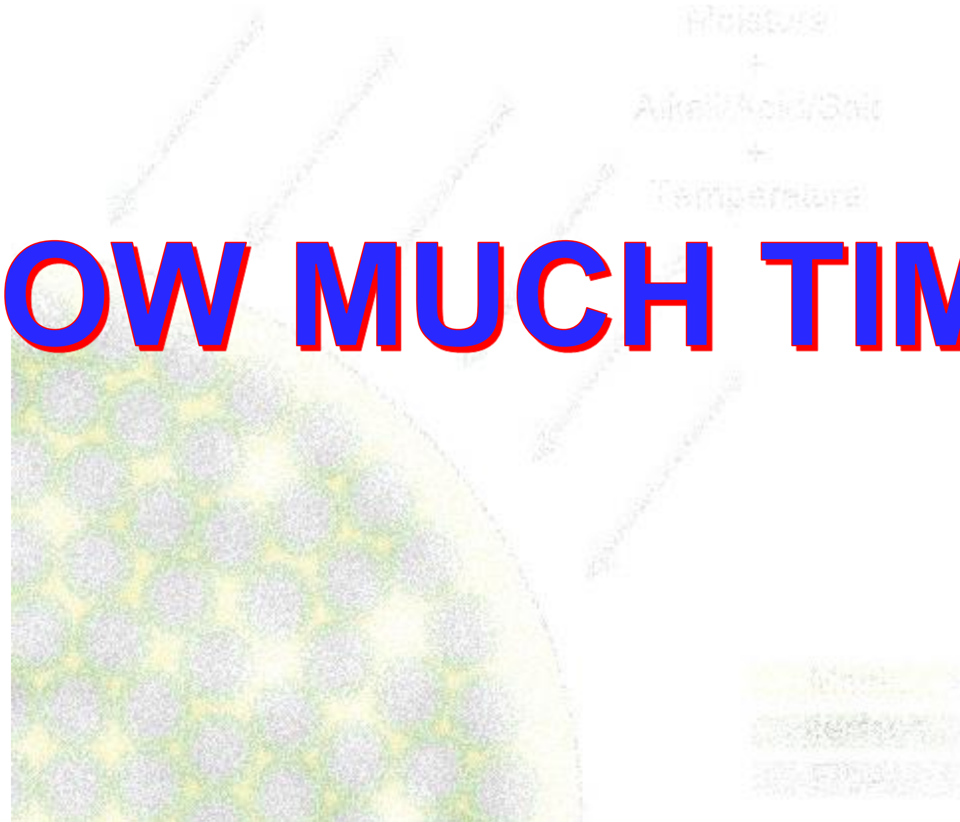






Usage (Characteristics/Durability)

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



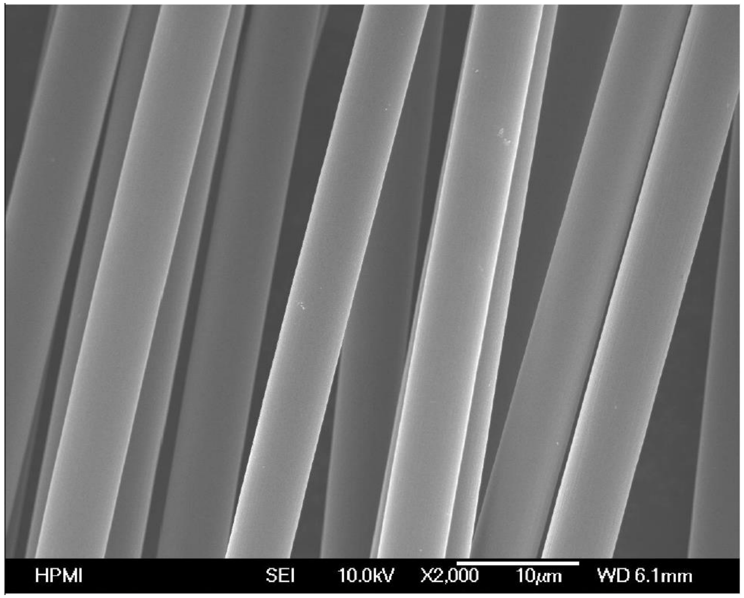
HOW MUCH TIME?

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)

Usage (Characteristics/Durability)

- 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

Knight et al. Environmental Technology 33, 639-644 (2012)

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

ACMA
American Composites Manufacturers Association

SAMPE
Society for the Advancement of Material and Process Engineering

2014 Design Training Expo

Questions?