Florida Department of
TRANSPORTATION

Research Update: Fiber Reinforced Polymer (FRP) Reinforcing for Concrete

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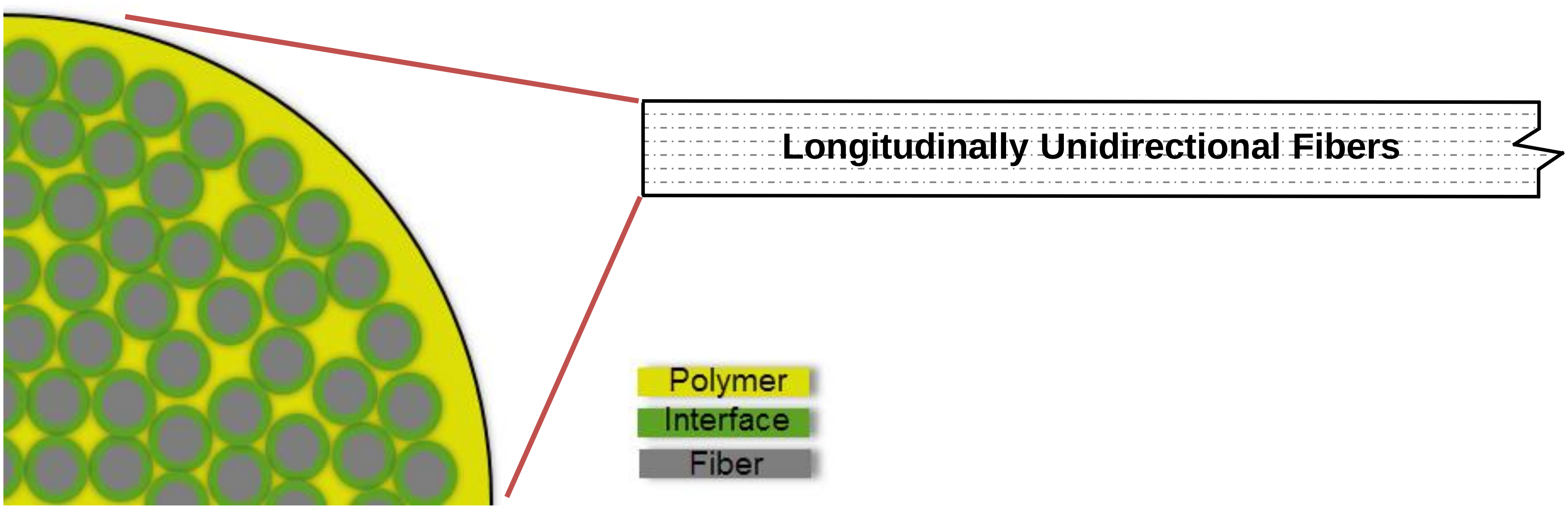
Outline

- Introduction – Fiber Reinforced Polymers (FRP) and FRP bars
- Glass Fiber Reinforced Polymer (GFRP) Bars
  - Performance evaluation of various surface treatments
  - Durability
- Carbon Fiber Reinforced Polymer (CFRP) Strands
  - Aging of CFRP strand in prestressed concrete
  - Durability of CFRP strand constituent materials
  - Alkali resistance of CFRP strands

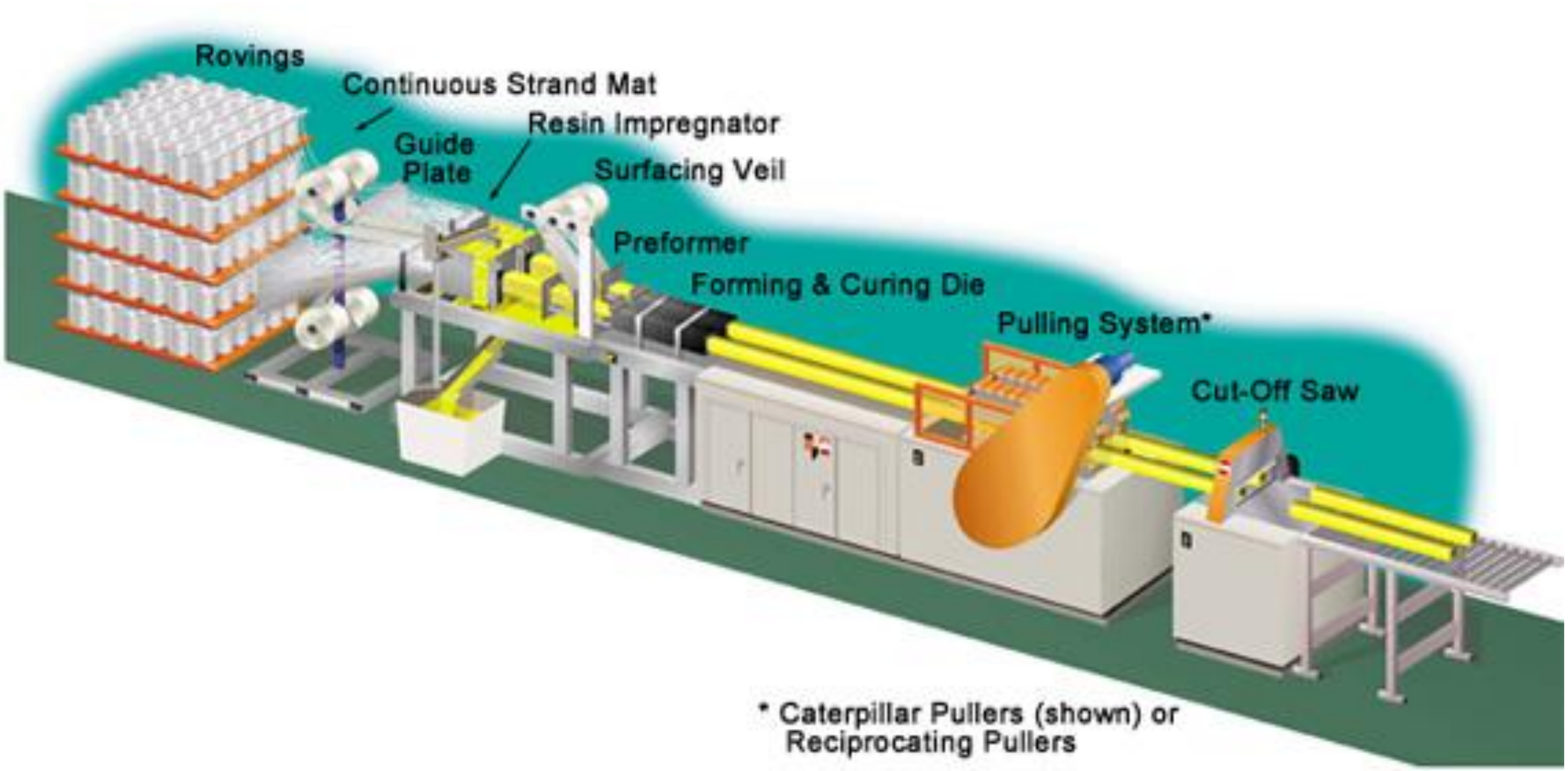
Introduction

- Typical FRP Bar
  - **Fibers:** Glass, Carbon, etc.
  - **Polymer matrix:** Epoxy, Vinyl Ester, etc.
  - **Interface:** Fiber-Matrix bonding; Fibers must be “sized”



Introduction

- Fabrication of FRP bars
  - Pultrusion, or variations thereof



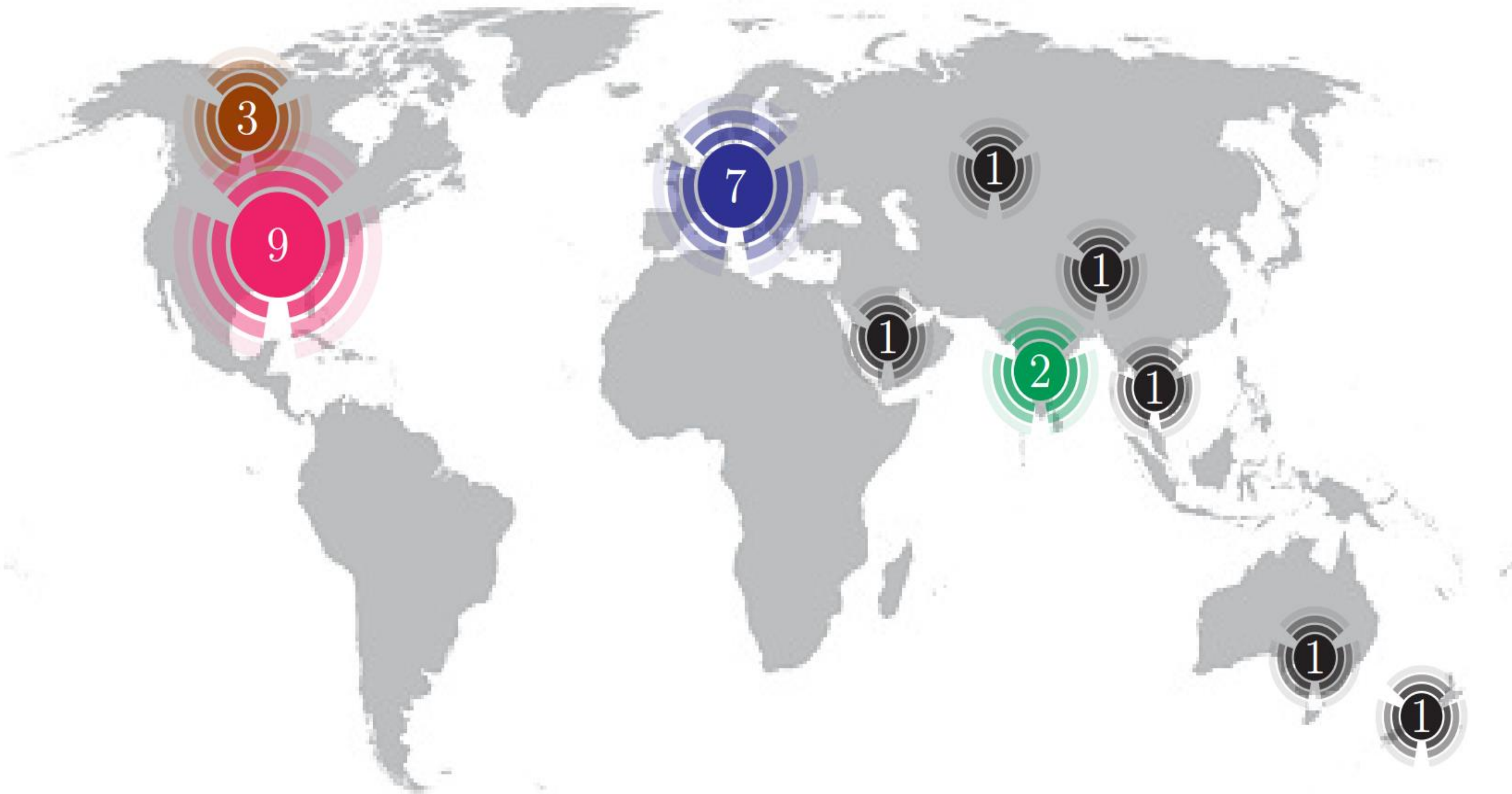
GFRP Rebar

- Diverse FRP rebar market
- Low level of product standardization
  - Diverse offering of products
  - Variations in product properties

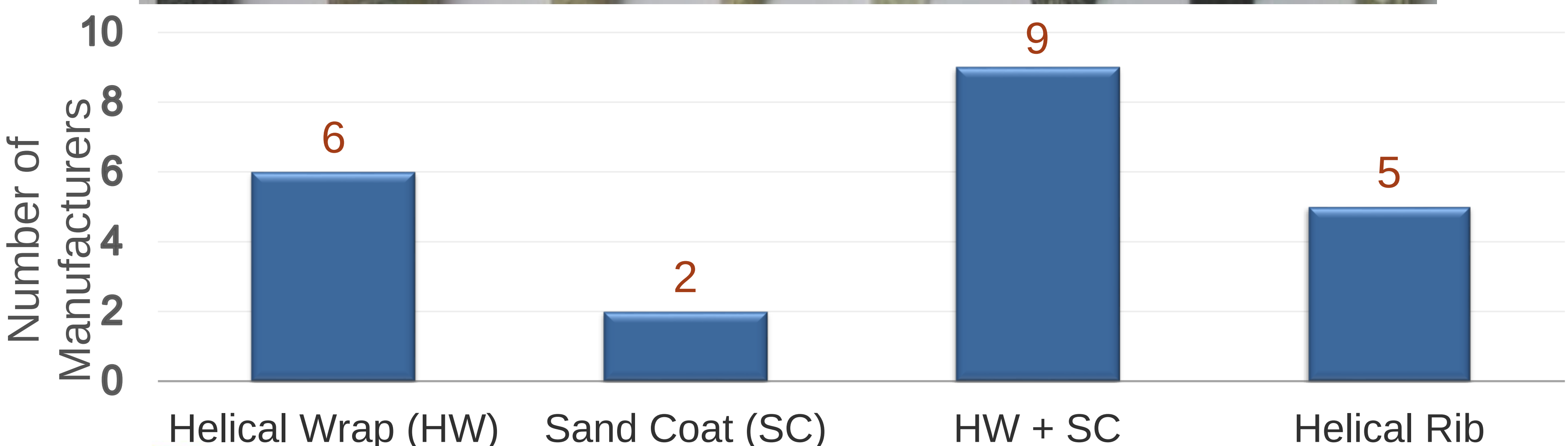
GFRP Rebar – Research Focus

- Survey manufacturers
  - Types, sizes, surface features and properties of bars produced
- Select representative types of bars based on type of surface features
- Evaluate performance and durability of bond to concrete

GFRP Rebar – Locations of Producers



GFRP Rebar – Surfaces Produced



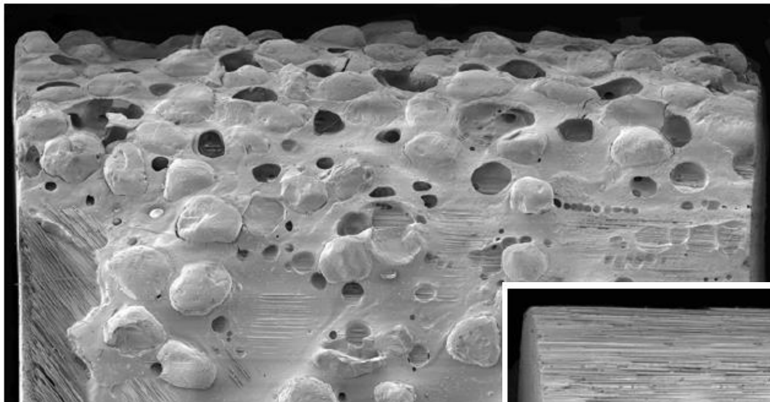
GFRP Rebar – Surface Types

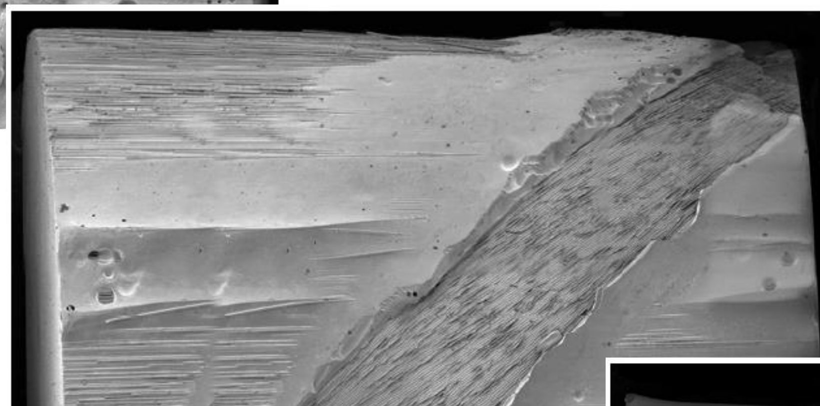
- Three representative surface types

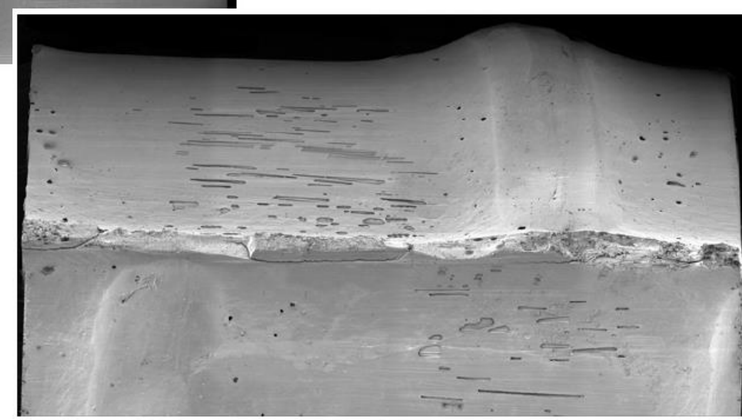
Figure 1: Rebar type A, B, and C (from left to right)

GFRP Rebar – Surface Types

- Three representative surface types







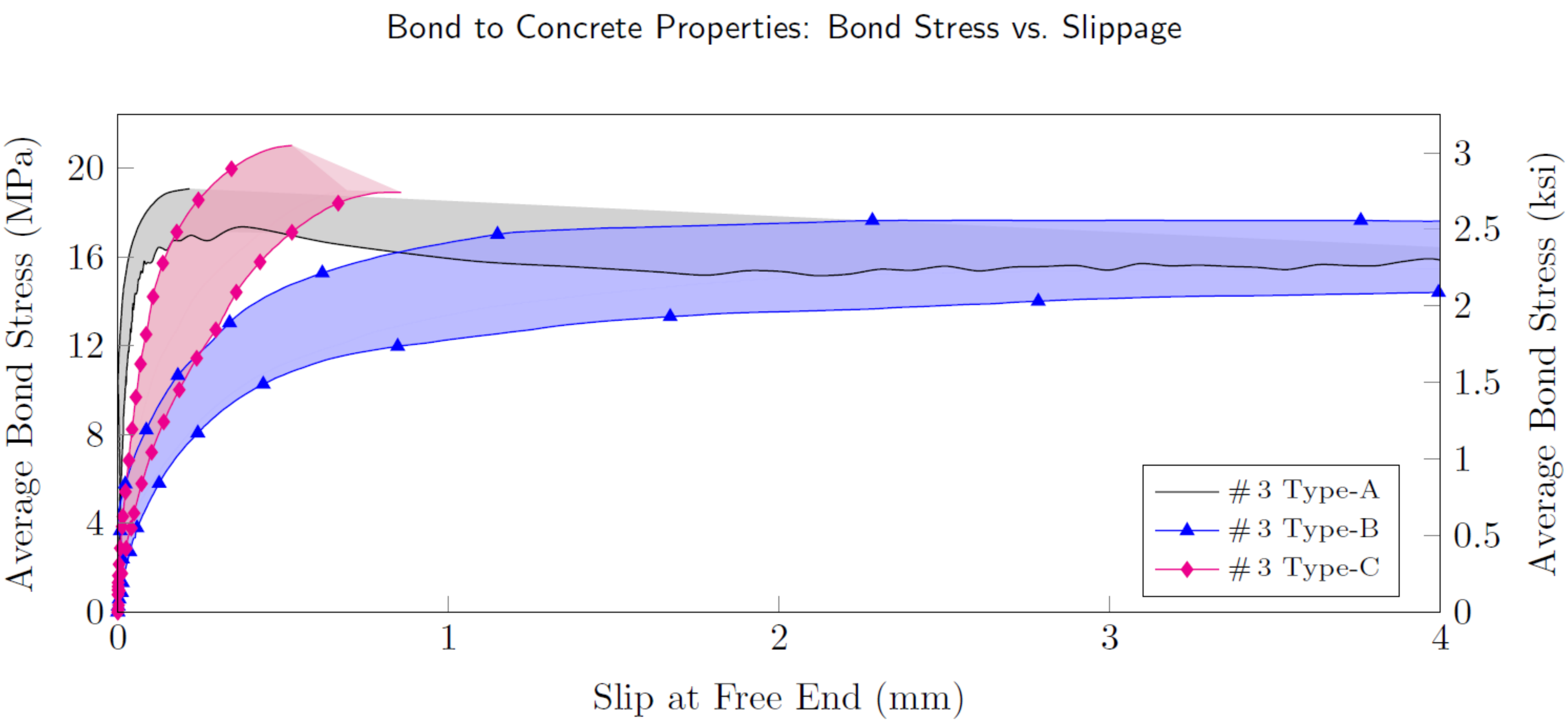
GFRP Rebar – Bond to Concrete

- Specimen preparation (ASTM D7913)

Figure 2: Concrete casting (left) and grip installation (right)

GFRP Rebar – Bond to Concrete

- Virgin properties



GFRP Rebar – Durability of Bond

- Exposure and testing
  - Circulating seawater (from Biscayne Bay) at controlled temperatures

Figure 3: Exposure process of bond samples

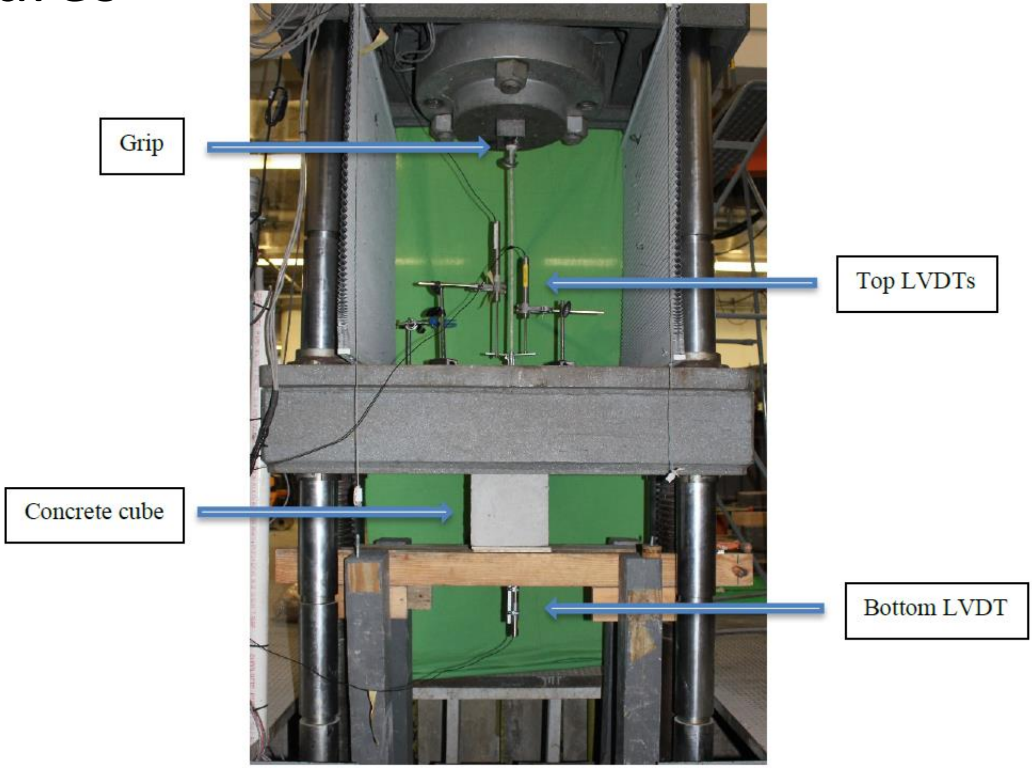
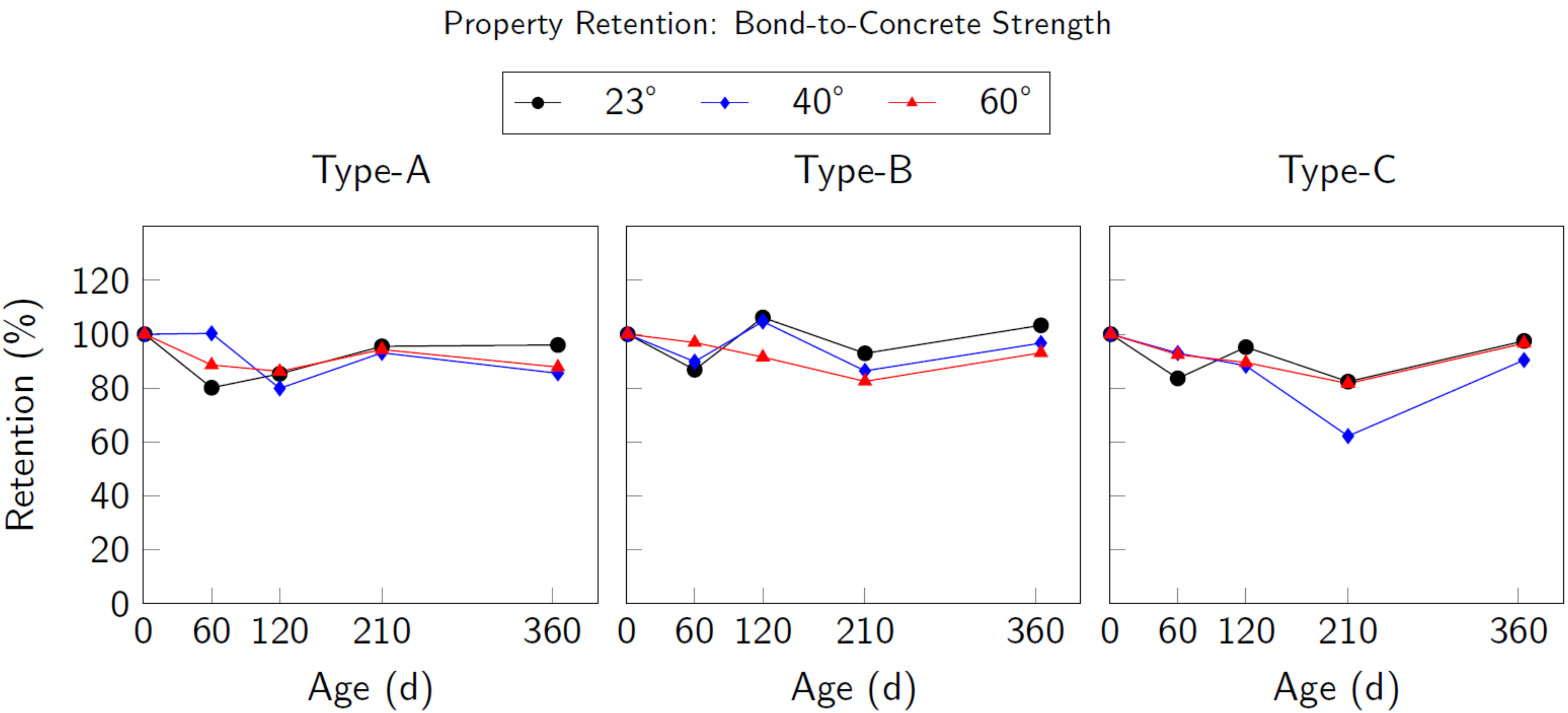


Figure 4: 'Pull-out test' configuration per ASTM D793

Ruiz, De Caso, Kampmann, Nanni; CICE 2018

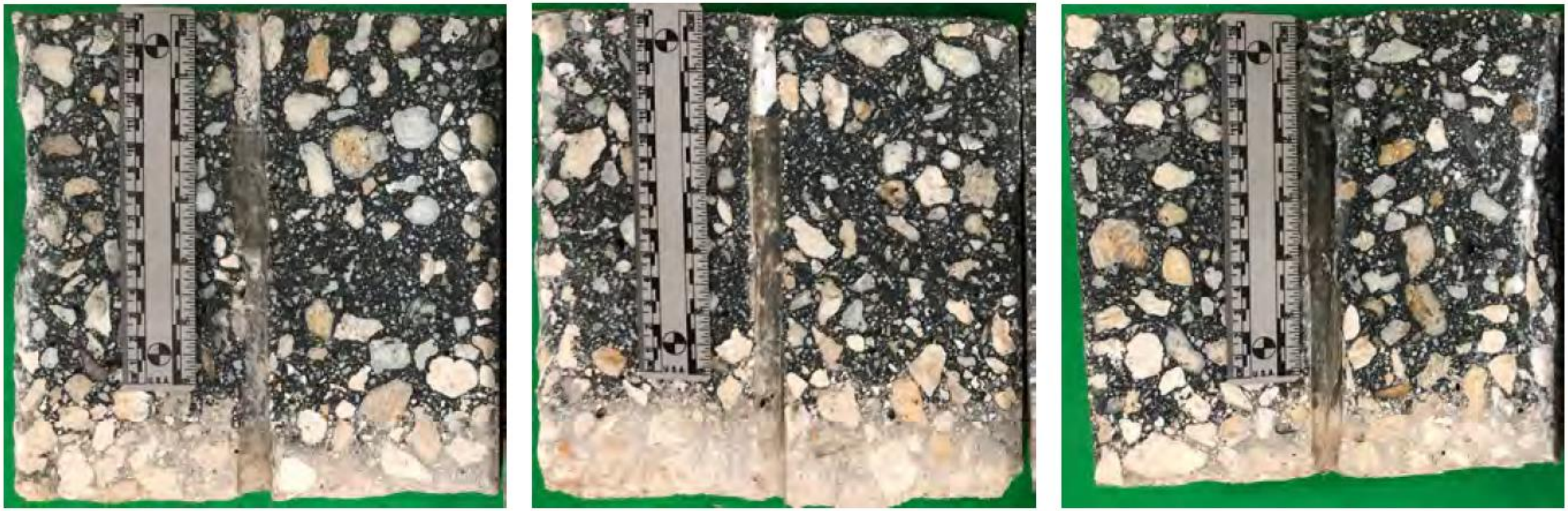
GFRP Rebar – Durability of Bond

- Bond strength retention



GFRP Rebar – Durability of Bond

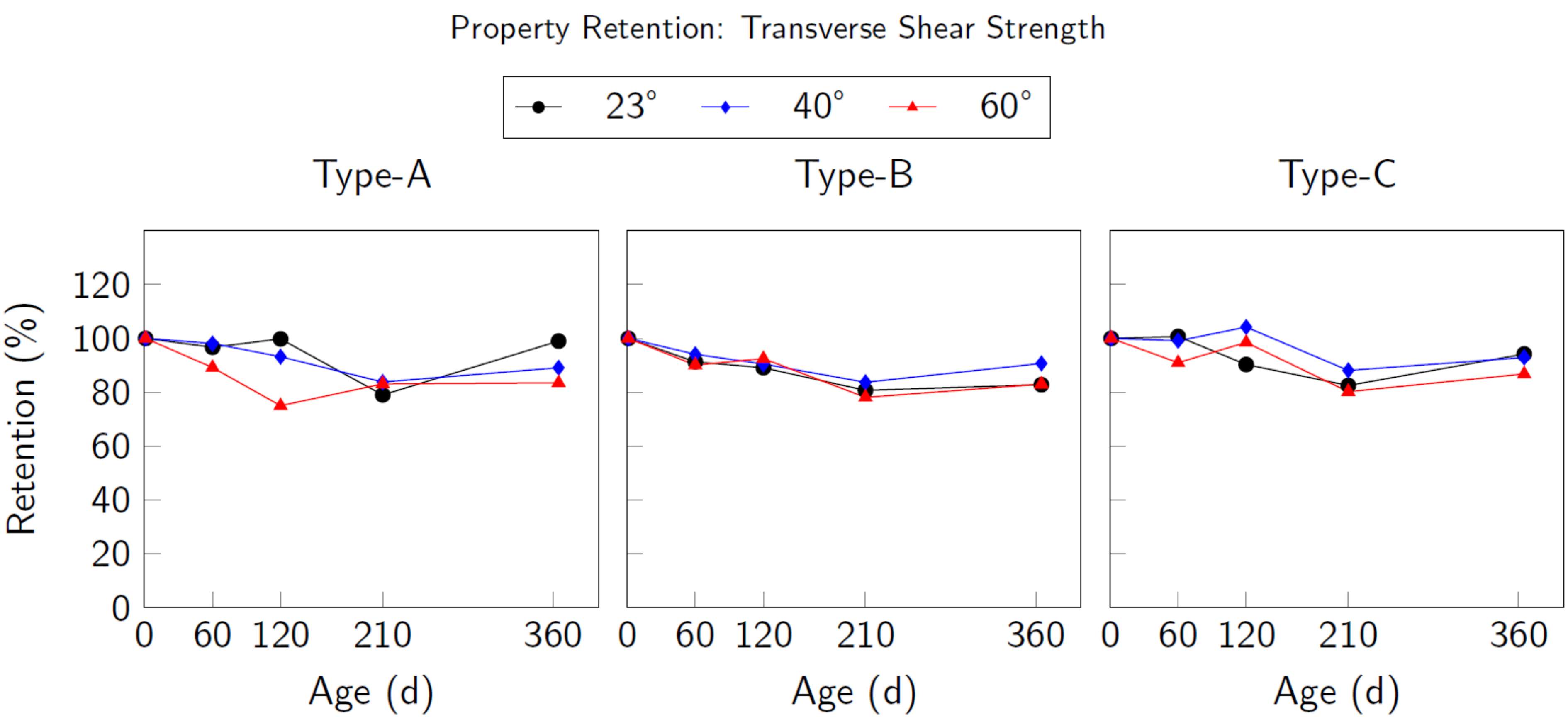
- Bond failure at concrete surface (365 days)



(a) Type-A (b) Type-B (c) Type-C

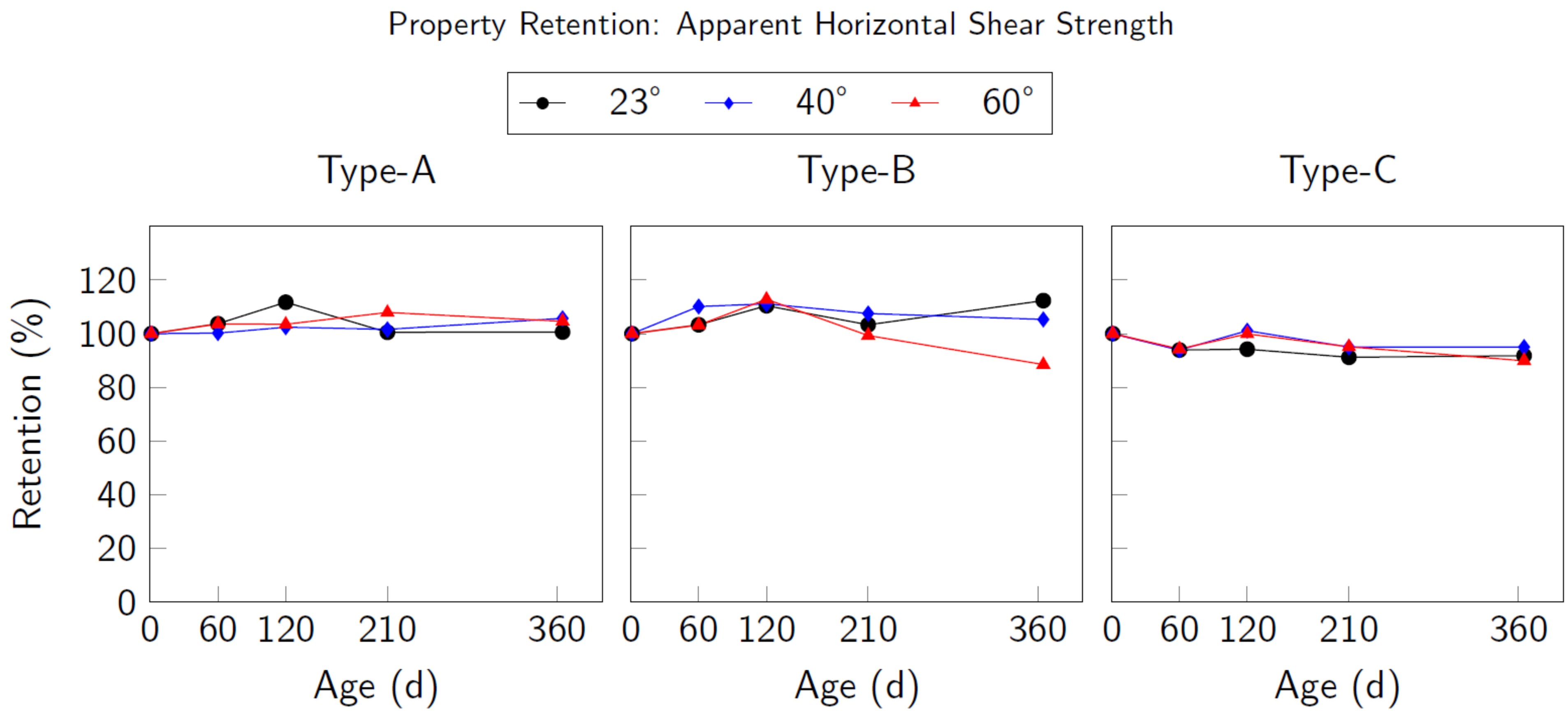
GFRP Rebar – Durability

- Transverse shear strength retention



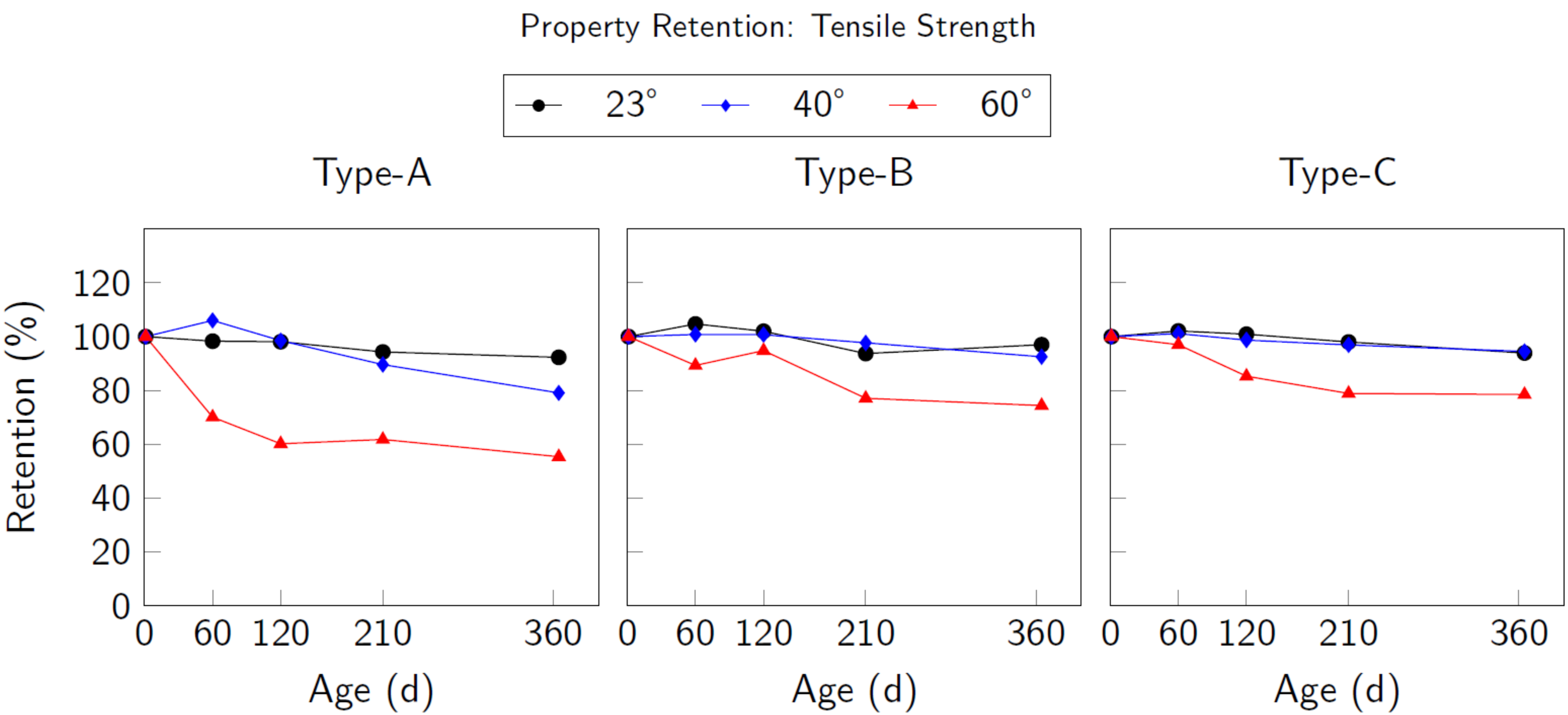
GFRP Rebar – Durability

- Apparent horizontal shear strength retention



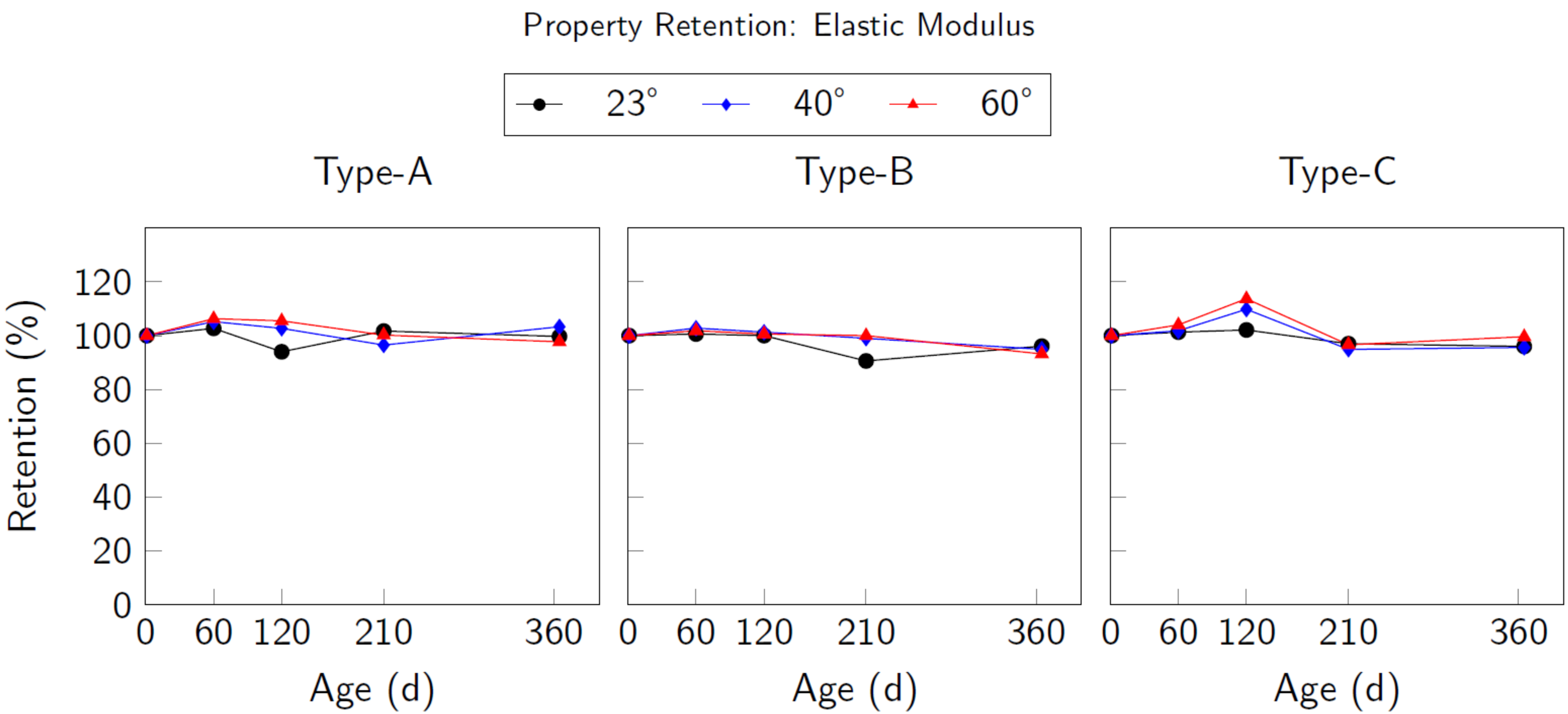
GFRP Rebar – Durability

- Tensile strength retention



GFRP Rebar – Durability

- Elastic modulus retention

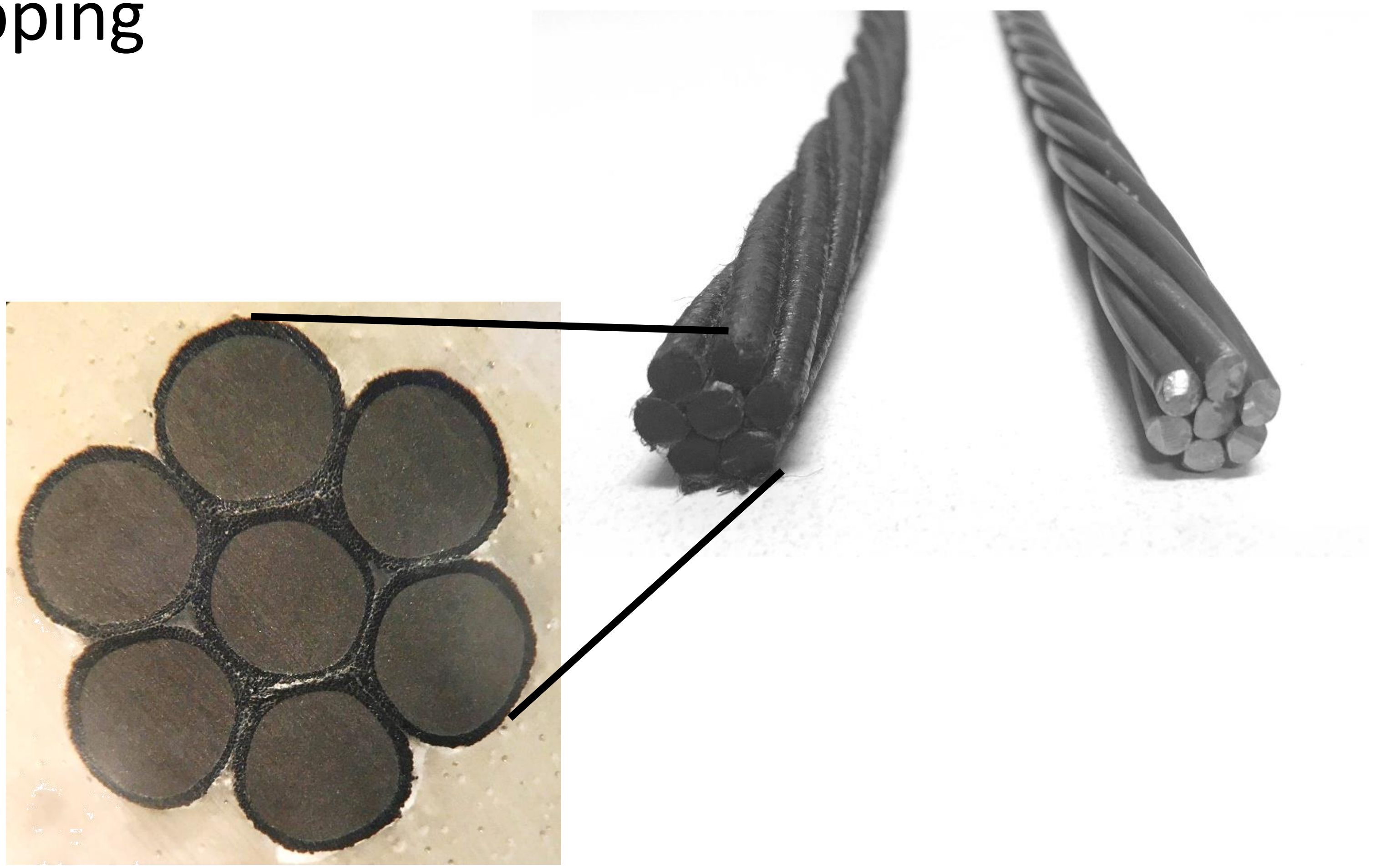


GFRP Rebar – Conclusions

- In general, minimal deviation of properties from original values
  - Tensile strength under 60°C the exception
- No linear trends observed versus temperature
  - Arrhenius modelling not valid
- While a definitive model was not feasible, results indicate relatively high retention of GFRP rebar properties in submerged concrete.

CFRP Strand

- Each wire = carbon fibers + epoxy + polyester wrapping

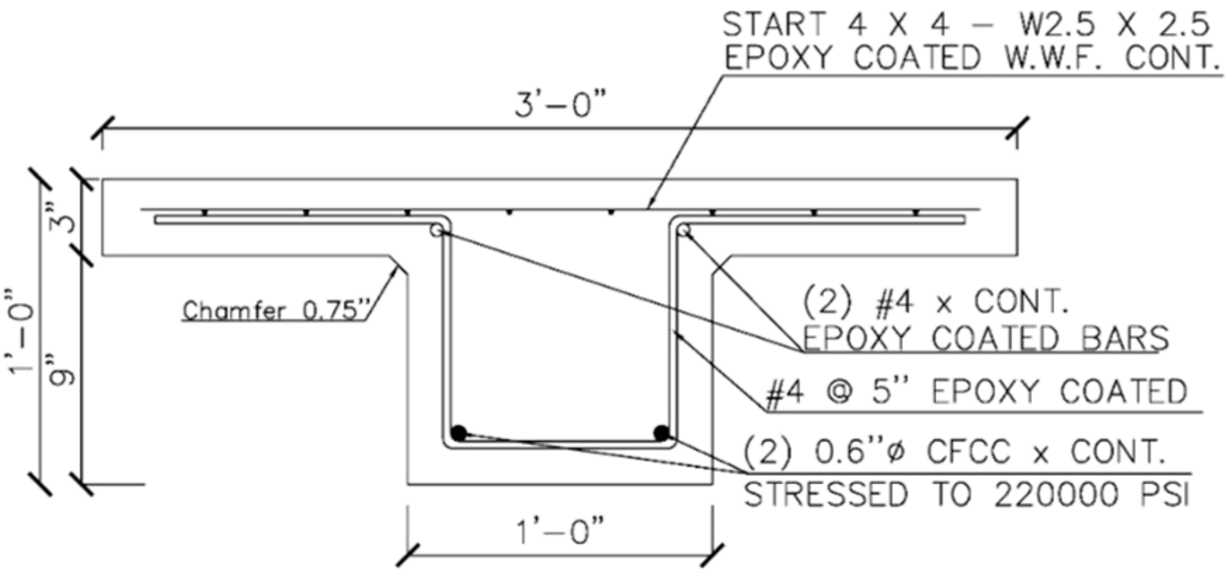


CFRP Strand – Research Focus

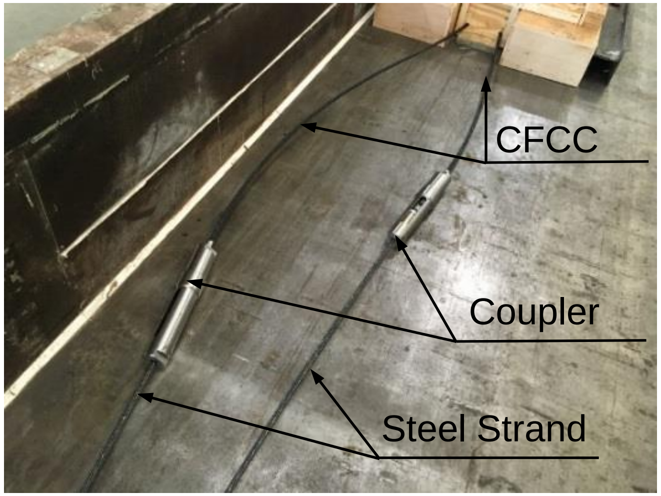
- Accelerated aging of CFRP prestressed concrete elements
- Durability of constituent materials
- Alkali resistance of strands under load
- Service life model based on degradation

CFRP Strand – Aging in Concrete

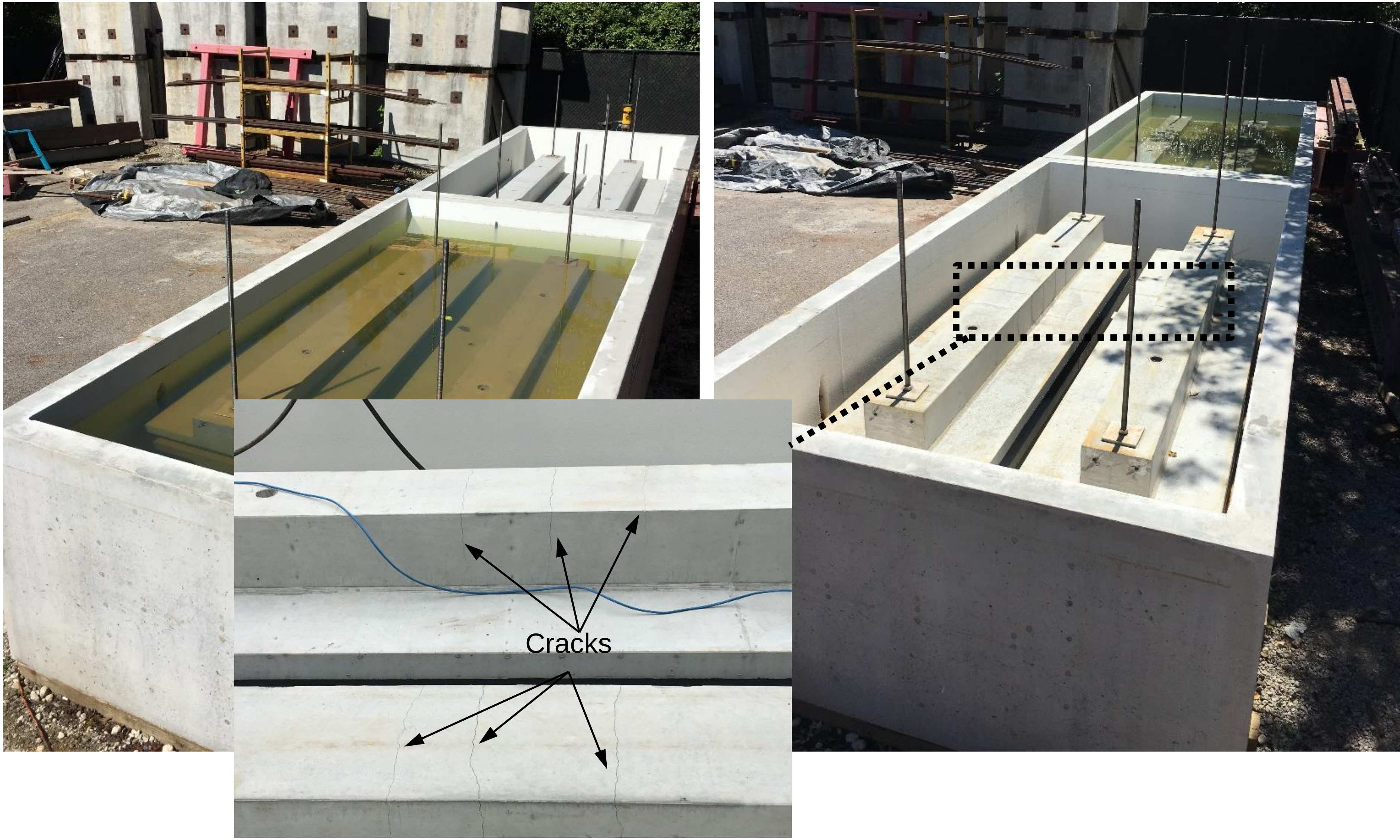
Construction of 12 Concrete Beams Gate Precast Company, Jacksonville, Florida.



Design Criteria: Rupture of strands



CFRP Strand – Aging in Concrete



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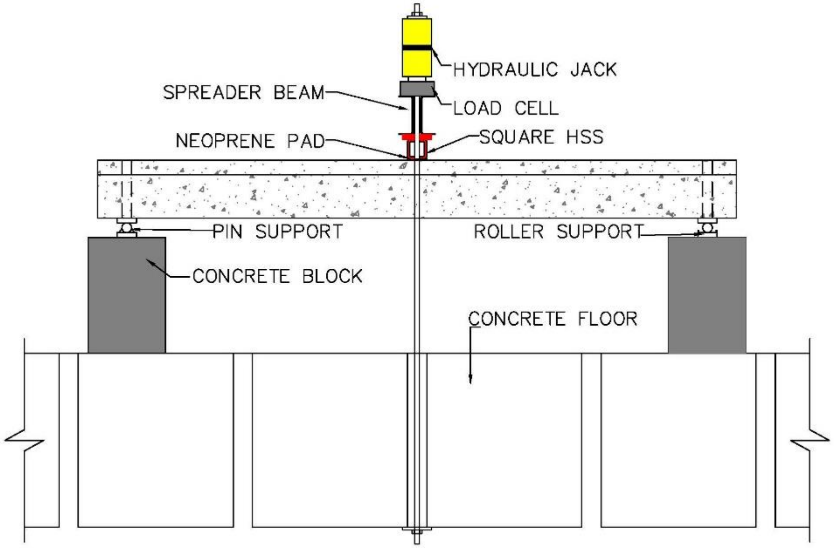
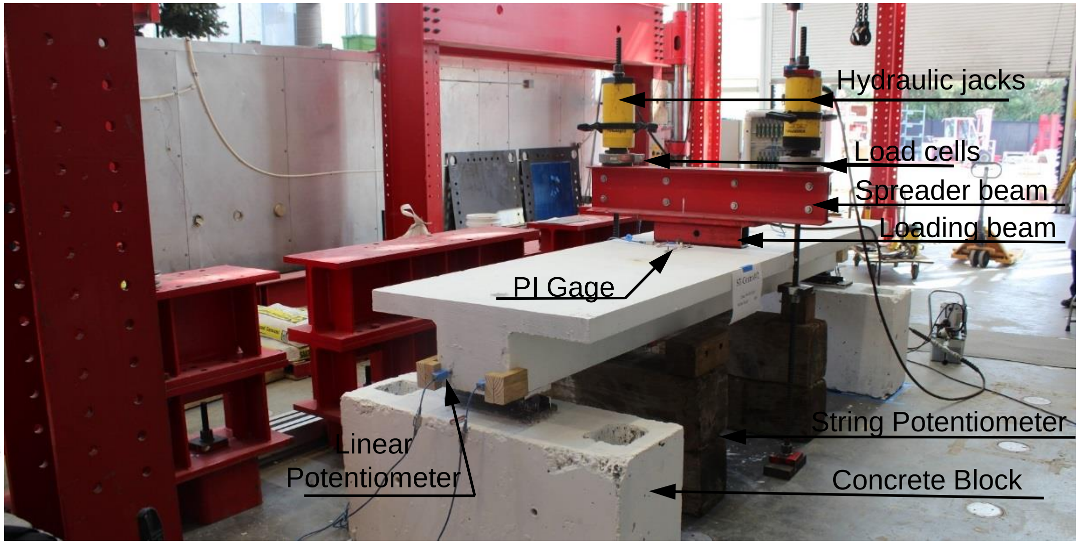
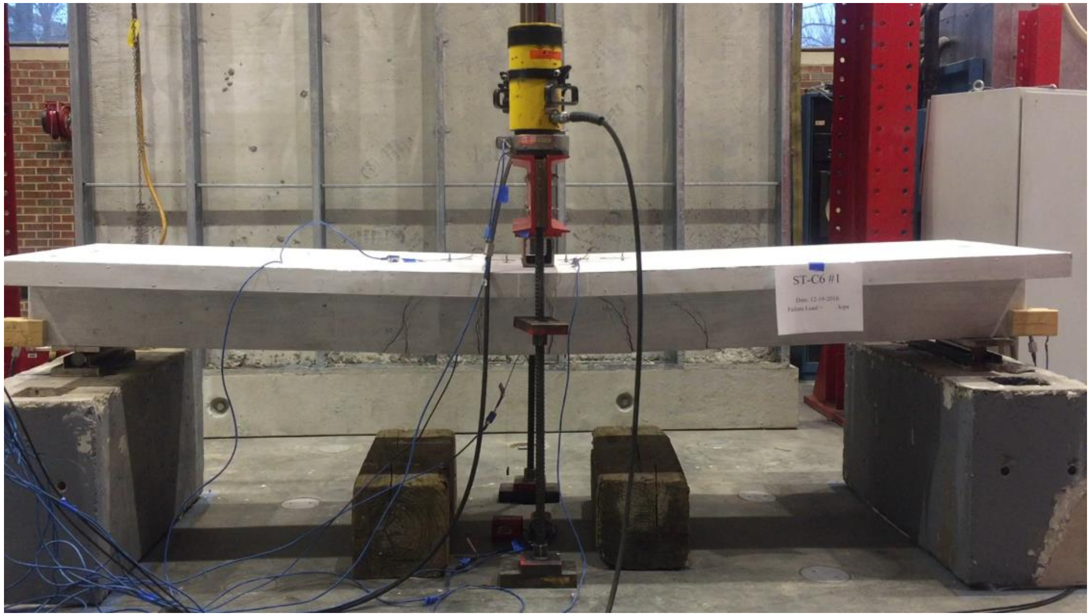
CFRP Strand – Aging in Concrete

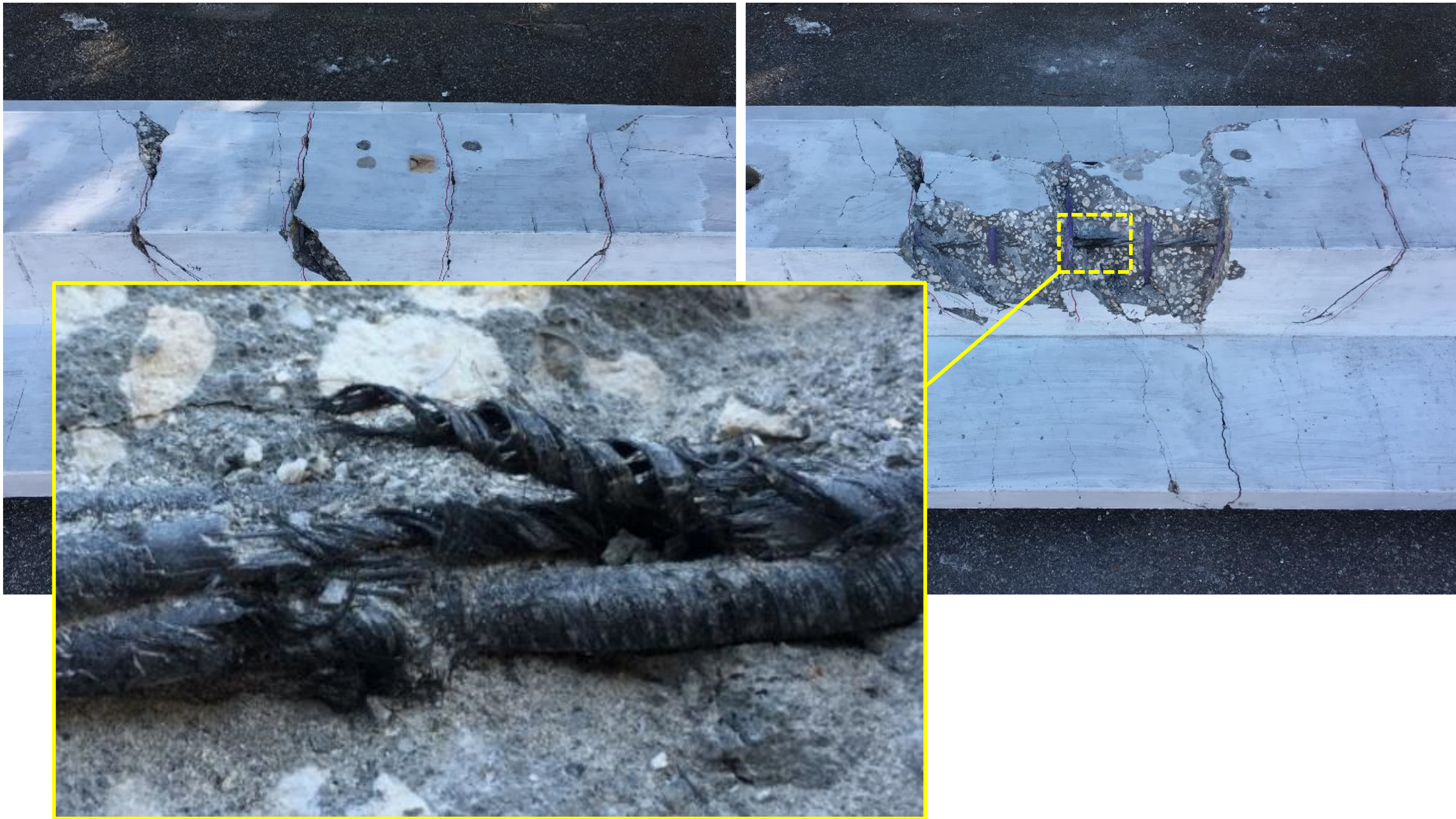




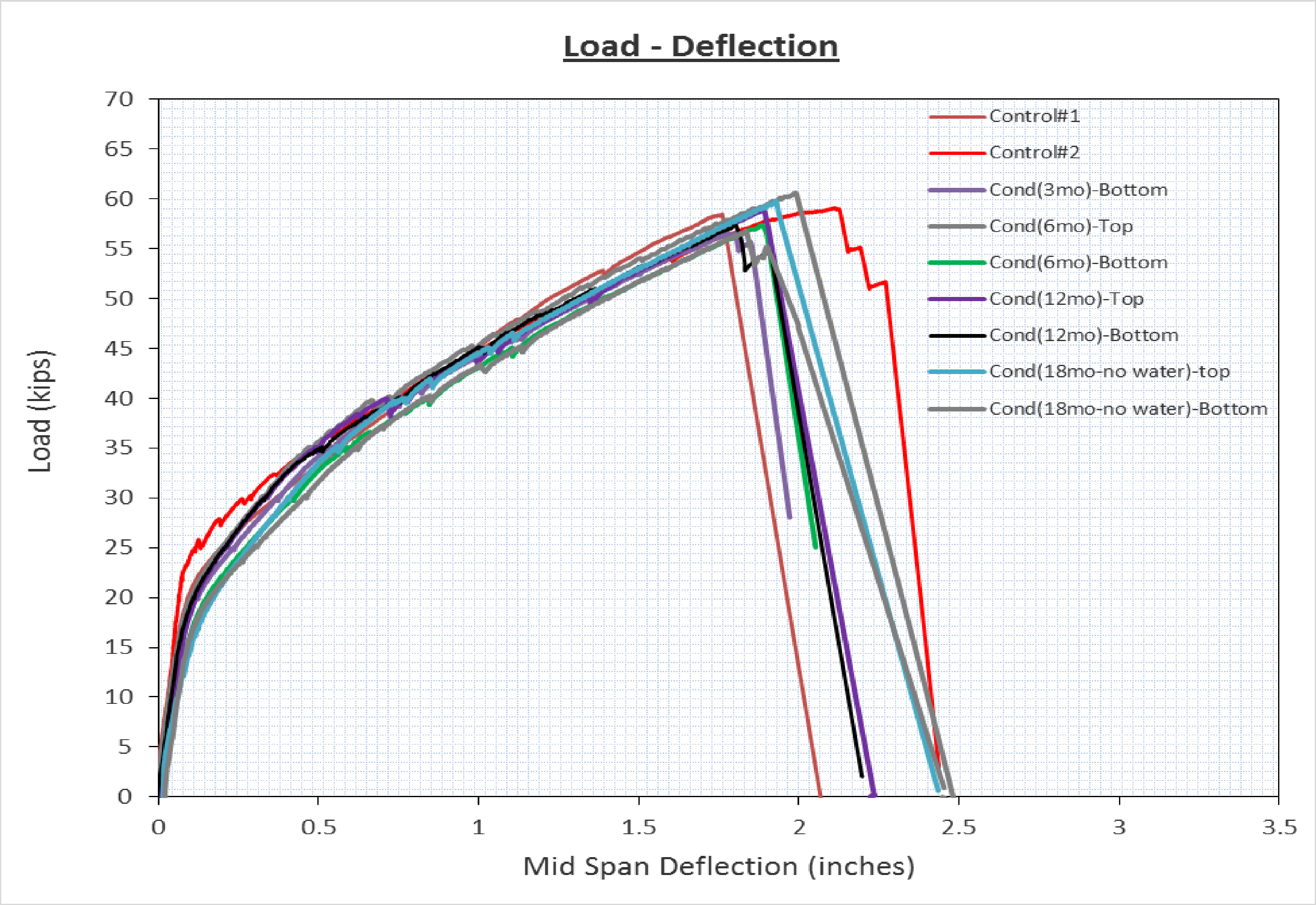


CFRP Strand – Aging in Concrete

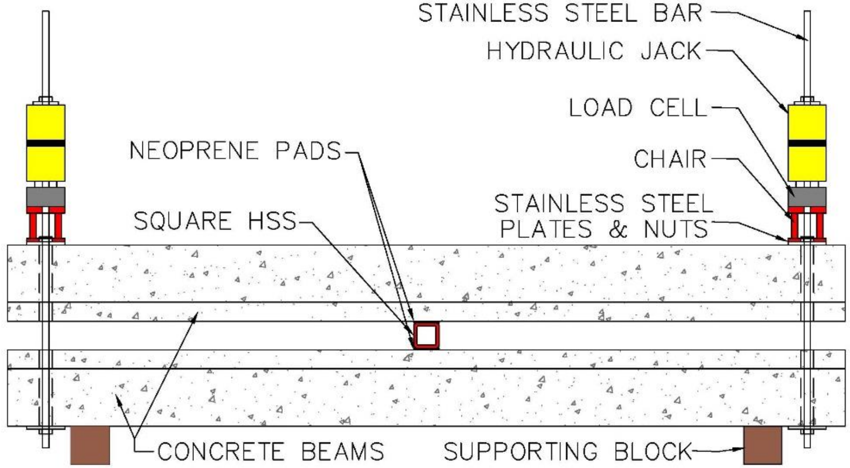
Strand Failure

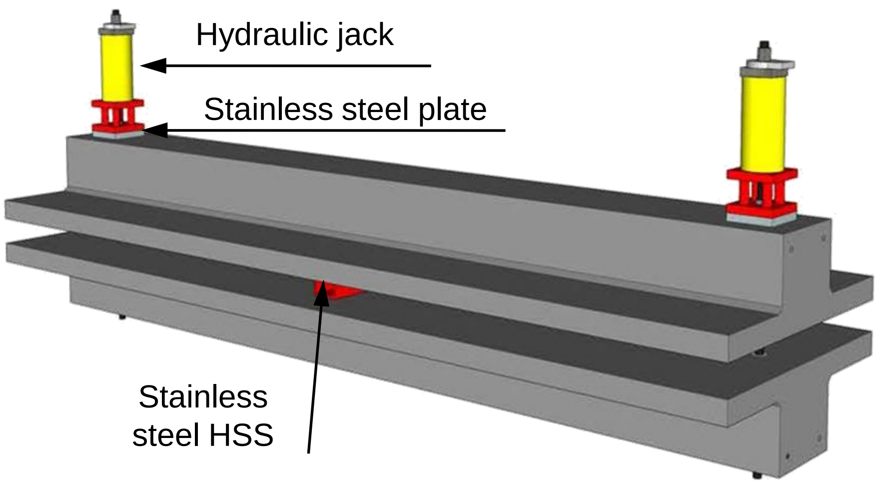


CFRP Strand – Aging in Concrete

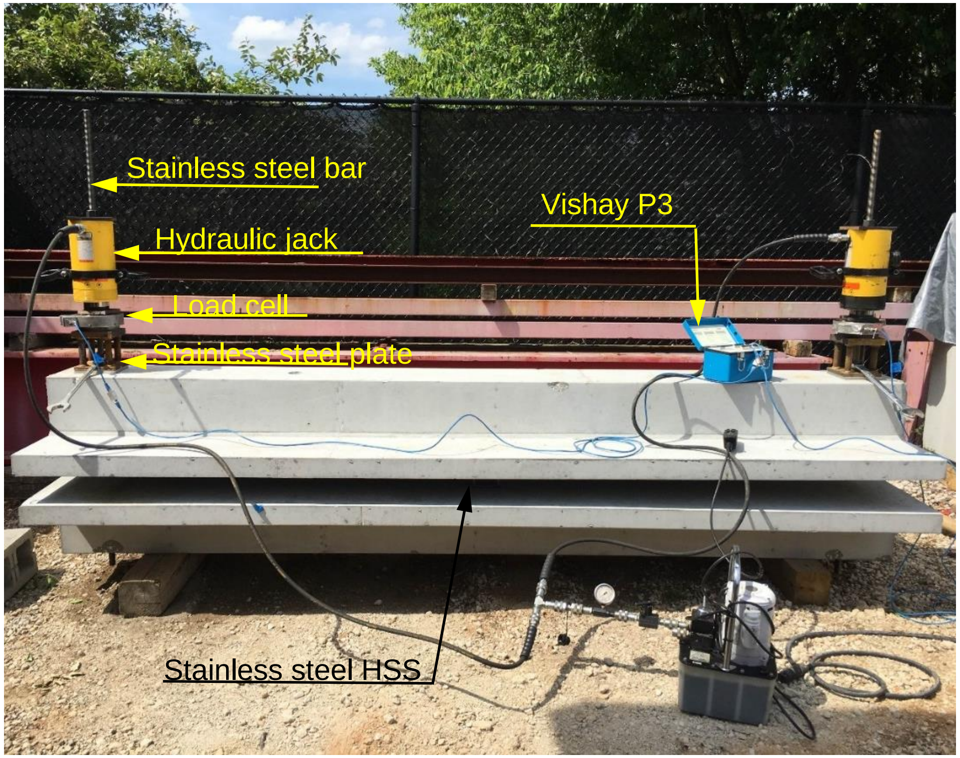


CFRP Strand – Aging in Concrete





- Beams subjected to sustained load equivalent to 50 percent of their ultimate flexural capacity



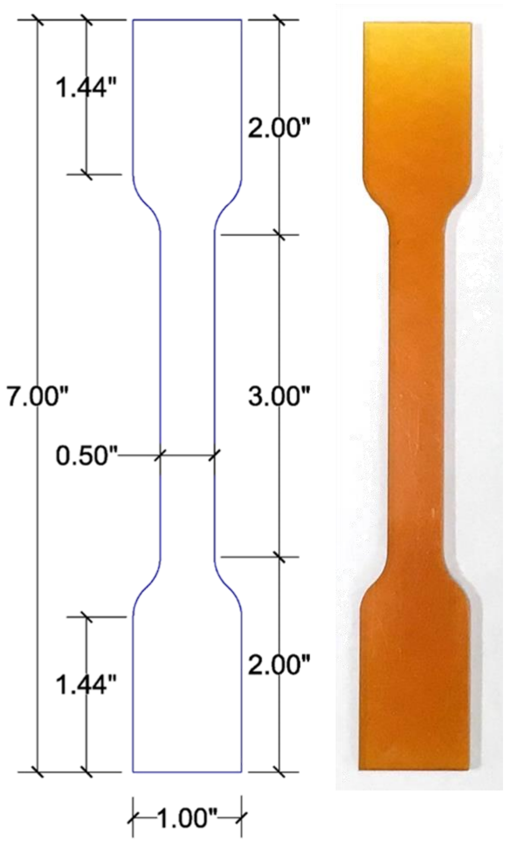
CFRP Strand – Constituent Durability

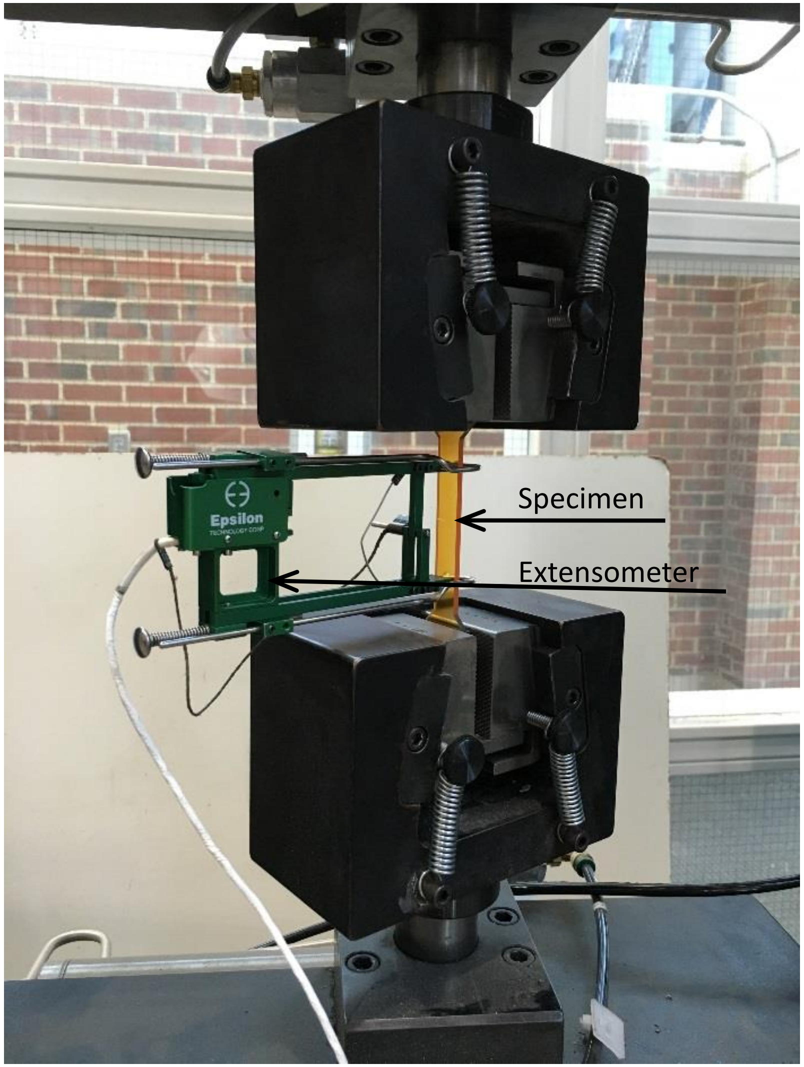
Epoxy (Cured)

Carbon Fibers

CFRP Strand – Durability of Epoxy

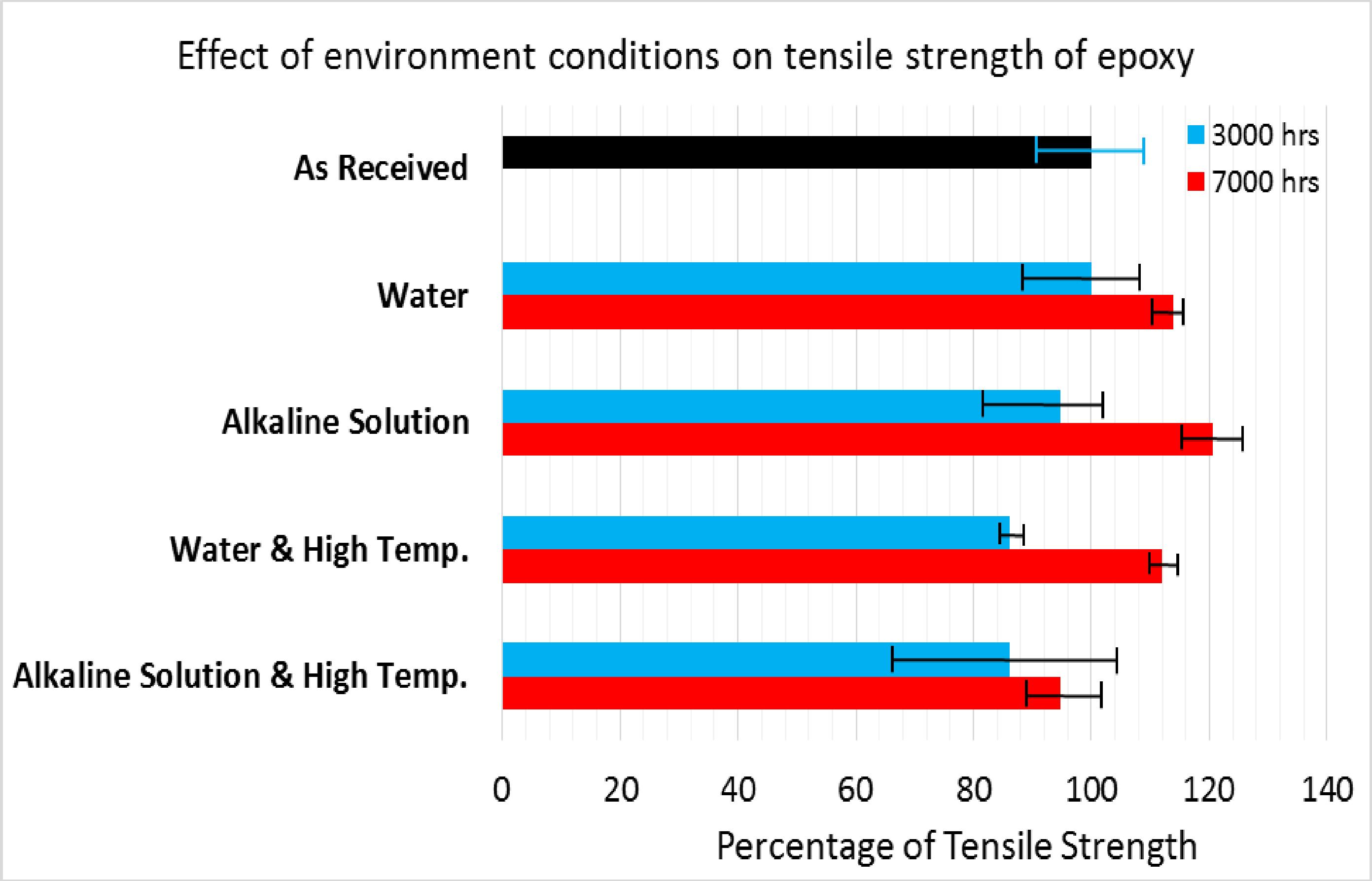
- Tensile testing of epoxy coupons



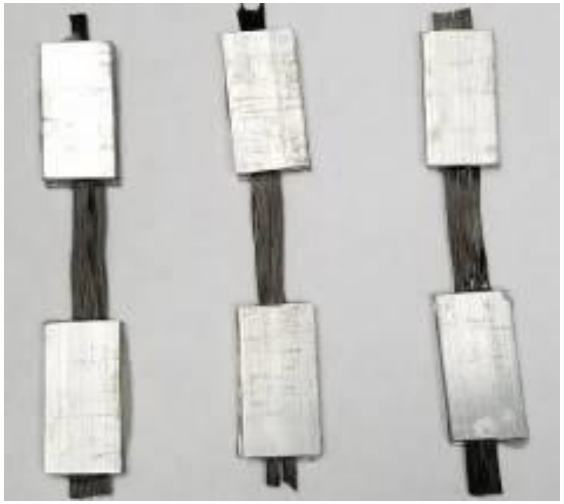


CFRP Strand – Durability of Epoxy

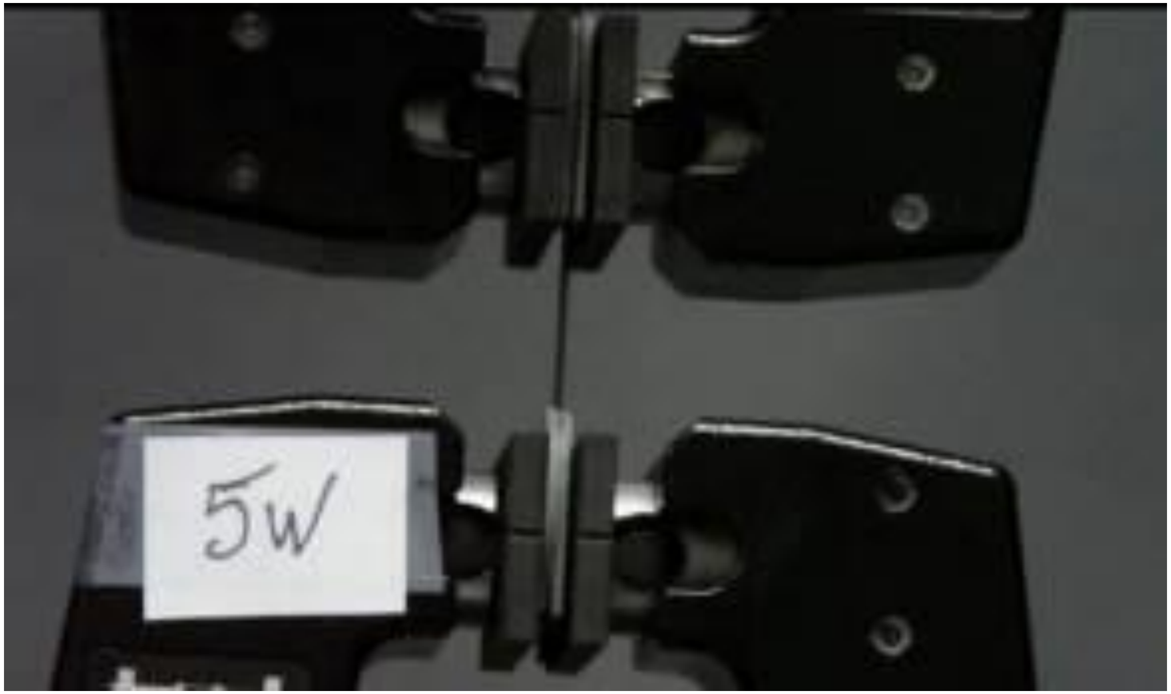
- Durability of epoxy



CFRP Strand – Durability of Fibers

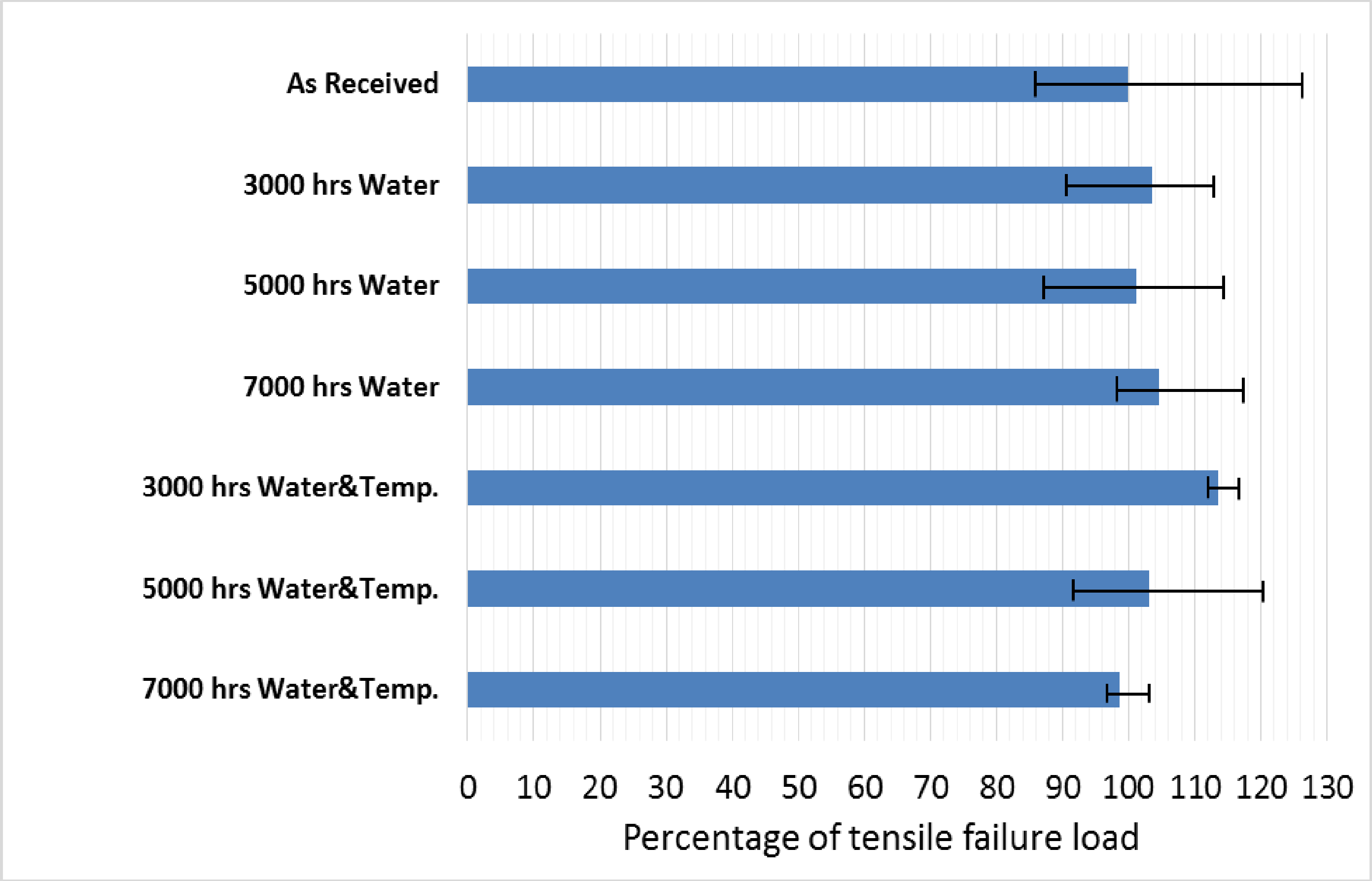


- Tensile testing of carbon fibers



CFRP Strand – Durability of Fibers

- Durability of carbon fibers



CFRP Strand – Alkali Resistance

- Test Matrix (ASTM D7705)

<table>
<tr><th>Load</th><th>Alkali Solution</th><th>Duration of exposure (hr)</th><th colspan="2">Temp. (°F)</th><th>No. of specimens</th></tr>
<tr><td rowspan="7">0%</td><td>No</td><td>As received</td><td colspan="2">77</td><td>5</td></tr>
<tr><td>No</td><td>3000</td><td colspan="2">130</td><td>5</td></tr>
<tr><td>No</td><td>5000</td><td colspan="2">130</td><td>5</td></tr>
<tr><td>No</td><td>7000</td><td colspan="2">130</td><td>5</td></tr>
<tr><td>Yes</td><td>3000</td><td>77</td><td>130</td><td>10</td></tr>
<tr><td>Yes</td><td>5000</td><td>77</td><td>130</td><td>10</td></tr>
<tr><td>Yes</td><td>7000</td><td>77</td><td>130</td><td>10</td></tr>
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<tr><td>No</td><td>5000</td><td>77</td><td>130</td><td>10</td></tr>
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<tr><td>Yes</td><td>7000</td><td>77</td><td>130</td><td>10</td></tr>
<tr><td>Total</td><td colspan="4"></td><td>110</td></tr>
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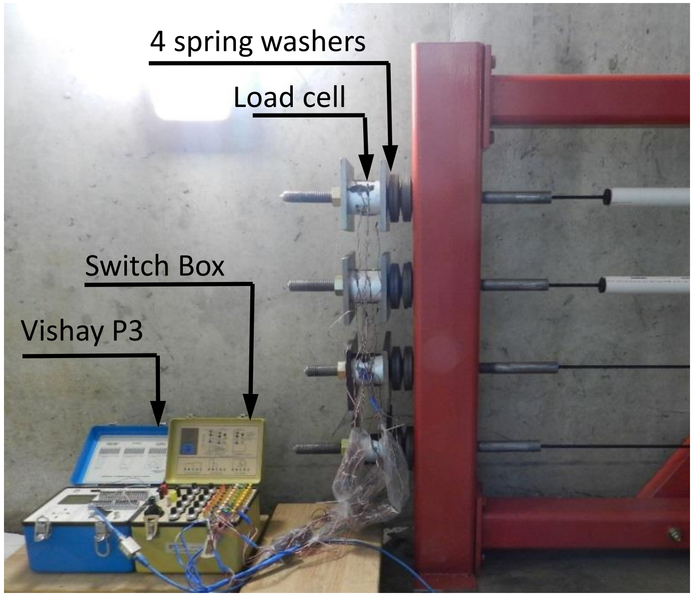
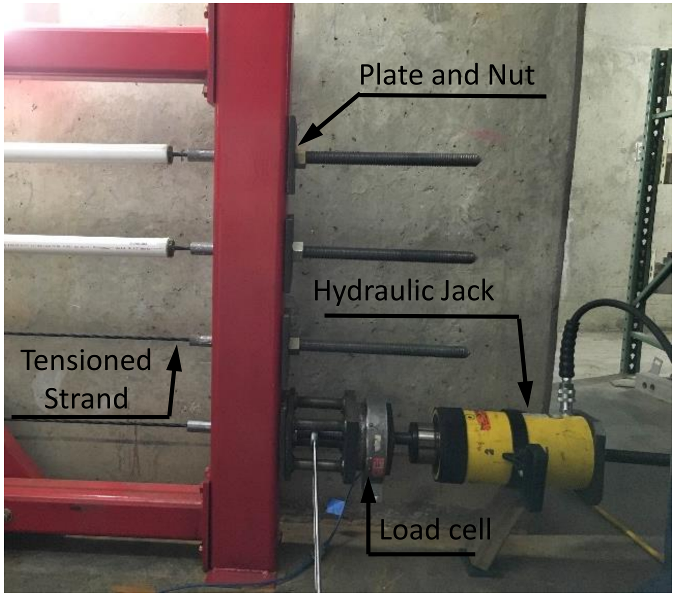
CFRP Strand – Alkali Resistance

Accelerated Aging Apparatus

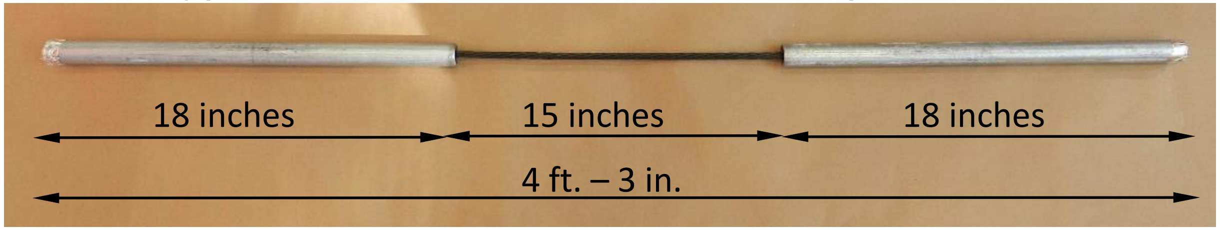




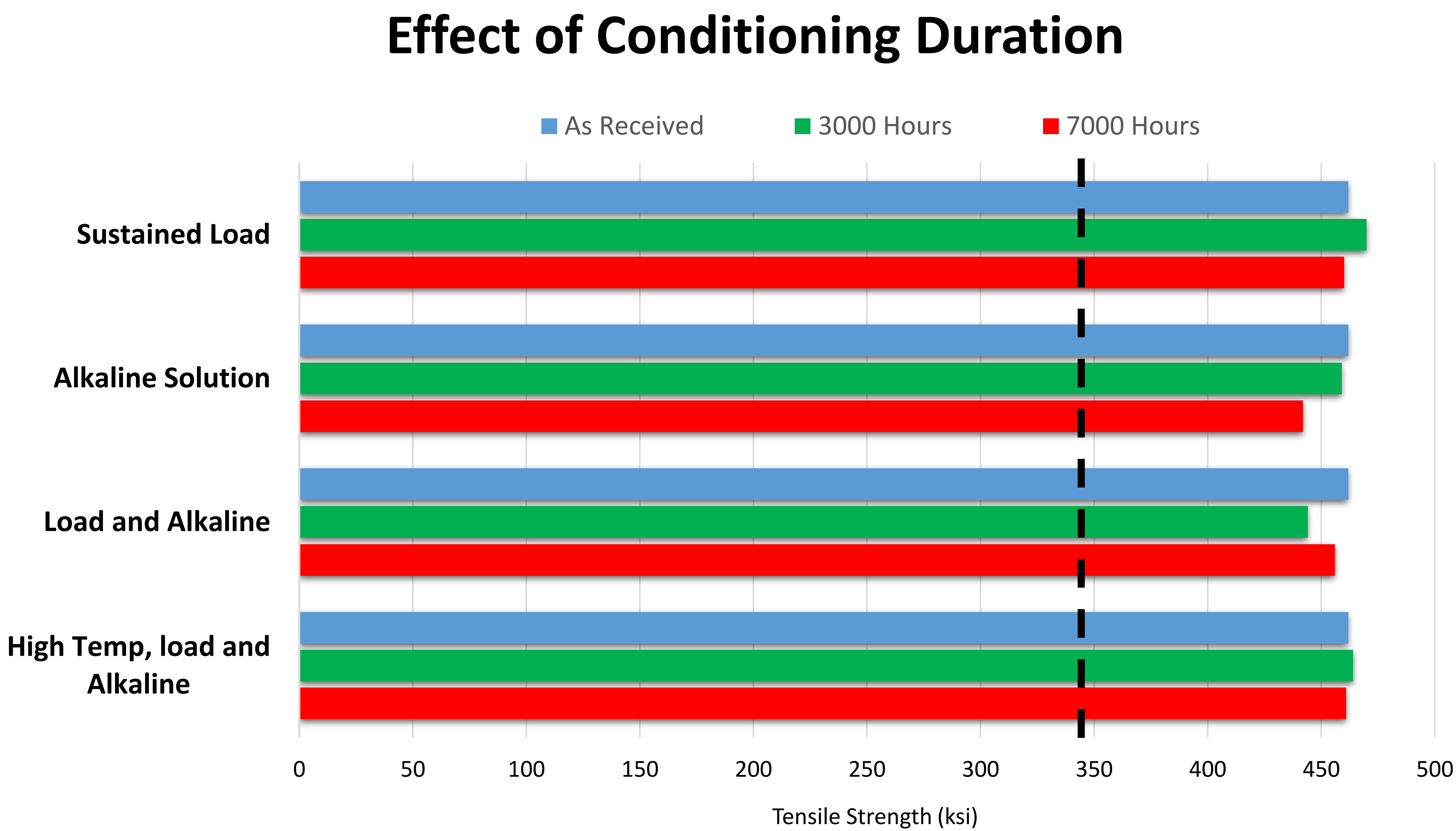
CFRP Strand – Alkali Resistance

Accelerated Aging Apparatus

Typical Dimensions of Tensile Test Specimens



CFRP Strand – Alkali Resistance



CFRP Strand – Conclusions

- Proposed prediction model for 100-yr service life taking temperature and humidity into account:

CFRP Strand – Conclusions

T ºC	Tensile Retention Factor (RF)							
	100% RH	90% RH	80% RH	70% RH	60% RH	50% RH	40% RH	Less than 30 % RH
0	0.90	0.932	0.953	0.968	0.979	0.985	0.992	1
5	0.89	0.926	0.950	0.965	0.977	0.983	0.992	1
10	0.88	0.921	0.944	0.962	0.975	0.982	0.991	1
15	0.86	0.916	0.940	0.960	0.973	0.981	0.991	1
20	0.85	0.911	0.937	0.957	0.971	0.980	0.990	1
25	0.84	0.906	0.933	0.955	0.970	0.979	0.989	1
30	0.83	0.901	0.930	0.953	0.968	0.978	0.989	1
35	0.82	0.896	0.927	0.950	0.967	0.976	0.988	1
40	0.81	0.891	0.923	0.948	0.965	0.975	0.988	1
45	0.81	0.887	0.920	0.946	0.964	0.974	0.987	1
50	0.80	0.883	0.917	0.944	0.963	0.973	0.987	1
55	0.80	0.879	0.914	0.942	0.961	0.972	0.986	1
60	0.80	0.875	0.911	0.940	0.960	0.972	0.985	1

Acknowledgements

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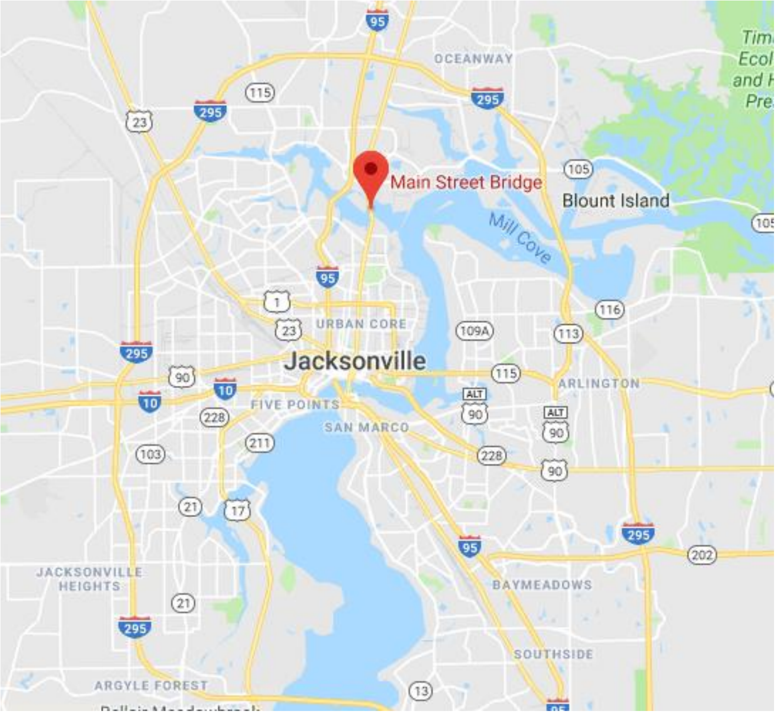
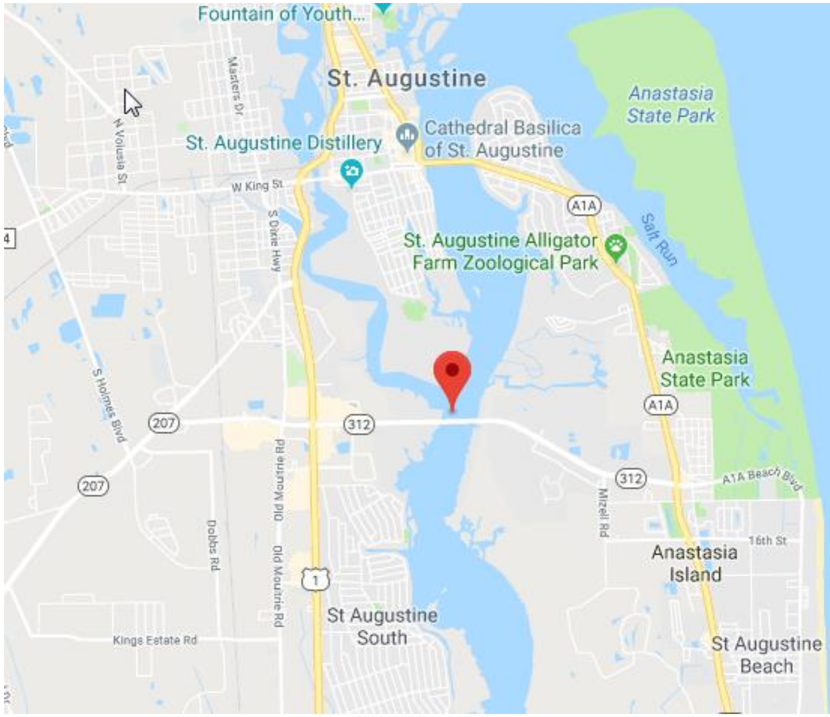
Dr. Mohammad Pour-Ghaz

Pilot Project Examples



US 17 Over Trout River. Bridge No. 720011



SR 312 Over Matanzas River. Bridge No. 780089

FRP Structures Research & Construction

Project Scope

US 17/Trout River: Concrete deterioration in the substructure and foundation. Work activities included –

- removal of existing Pile Jackets;
- installation of new Pile Jackets and Pier Footing Jackets with Impressed Current Cathodic Protection (ICCP). *GFRP dowels and reinforcement were used in select locations*.

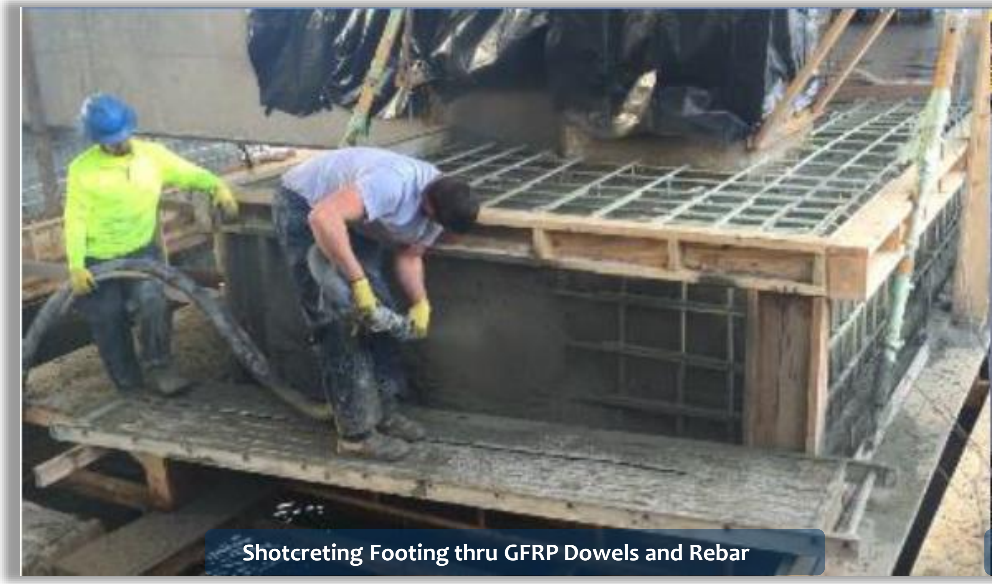
Project Scope

SR 312/Matanzas River: Concrete deterioration in the substructure and Foundation. Work activities included:

- removal of existing multi-column pier jackets;
- installation of new jackets on the multi-column pier - New jackets were installed at the specific multi-column piers.
- Pier Footing Jackets with Impressed Current Cathodic Protection (ICCP) were installed - Ribbon anodes were installed in between the piles on the pier footing. *GFRP dowels and basalt reinforcement were used in select locations.*

US17 Trout River (GFRP-RC *Tech#1*)

Utilization of GFRP bars in conjunction with Shotcrete; traditional cast-in-place; and removal of concrete from GFRP bars in the splash zone



Shotcreting Footing thru GFRP Dowels and Rebar

GFRP Rebar Cage

SR 312 Over Matanzas River (BFRP-RC *Tech#7*)

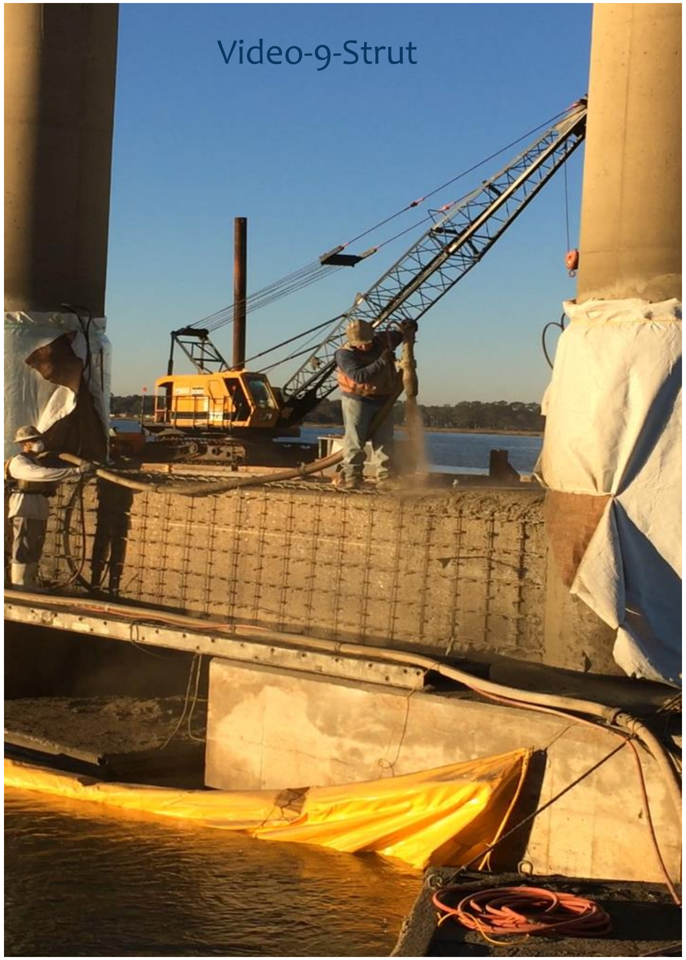
Use of GFRP dowel bars in conjunction with BFRP mesh in the marine environment

Shotcreting Pier Columns thru BFRP mesh

Pier Strut and Columns rehabilitation due to corrosion

Construction – Shotcreting Trial Panels *(30 sec. video)*

Construction -
Shotcreting Pier Strut
(30 sec. video)



Lessons Learned – SR 312

Lessons Learned – GFRP & BFRP

- **Material Availability**
- **Accuracy of rebar sheet**
  - **Modifications in the Field**
  - **Lead time to get additional material during construction**
- **Splicing**
- **Material Storage**

End

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