Session 4: Ongoing Research and New Applications

(10:20 - 12:00pm)

Presentations (20 mins)

4.1 Bond of FRP bars embedded in UHPC with an emphasis on design aspects *(Yail Jimmy Kim)*

4.2 Correlation between Moisture Absorption and Mechanical Strength Properties of Glass Fiber Reinforced Polymer Rebars Other *(Raphael Kampmann)*

Discussion 4.3 (30 mins)

Application of GFRP Bars to Ultra-High Performance Concrete

Yail Jimmy Kim, Ph.D., P.Eng. F.ACI

Professor, Department of Civil Engineering

University of Colorado Denver

*President, **Bridge Engineering Institute***

An International Technical Society

Jun Wang

University of Colorado
Denver | Anschutz Medical Campus

BEI
An International Technical Society

Contents

Introduction

I II III IV V

Introduction

Background

- A recent survey reports that corrosion costs more than 2.7% of the nation’s gross domestic product

- The use of fiber-reinforced polymer (FRP) composites in bridge construction is proven technology to accomplish sustainable built-environments

- Ultra-high performance concrete (UHPC) is a state-of-the-art construction material

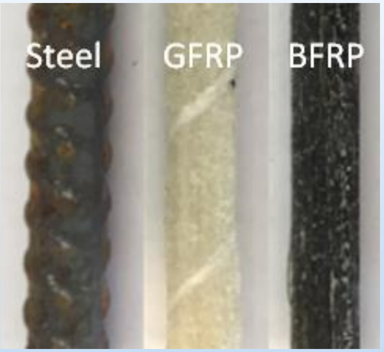
- A combination of these two non-conventional materials (FRP and UHPC) can create synergies in the performance and durability of concrete structures (little is known about bond)

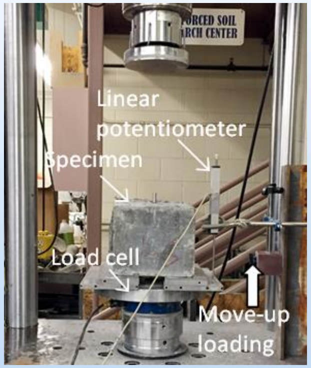
Experimental Program

Experimental Program

UHPC

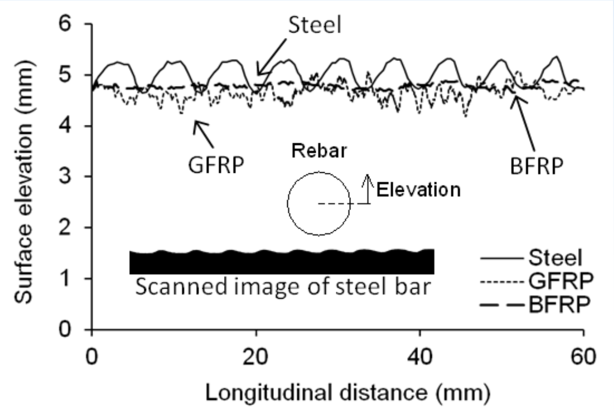
S/C (%)		w/c	Water (kg/m^3)	Cement (kg/m^3)	Silica fume (kg/m^3)	Silica sand (kg/m^3)	Finer silica sand (kg/m^3)	HRWR (kg/m^3)	Steel fiber (kg/m^3)
Without steel fiber	20	0.22	198	900	166	939	304	21	0
	30	0.22	198	900	269	939	304	21	0
	40	0.22	198	900	359	939	304	21	0
With steel fiber	20	0.22	198	900	166	939	304	40	180
	30	0.22	198	900	269	939	304	40	180
	40	0.22	198	900	359	939	304	40	180

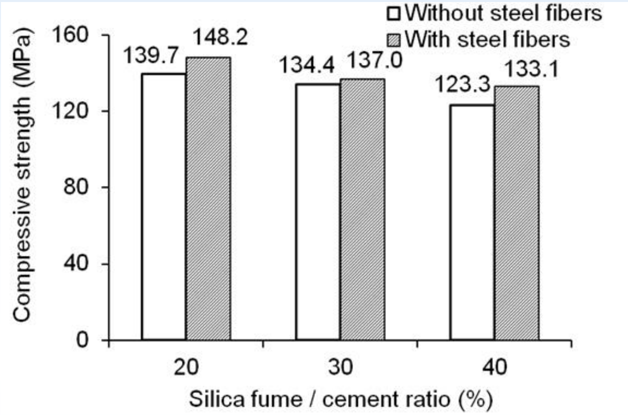


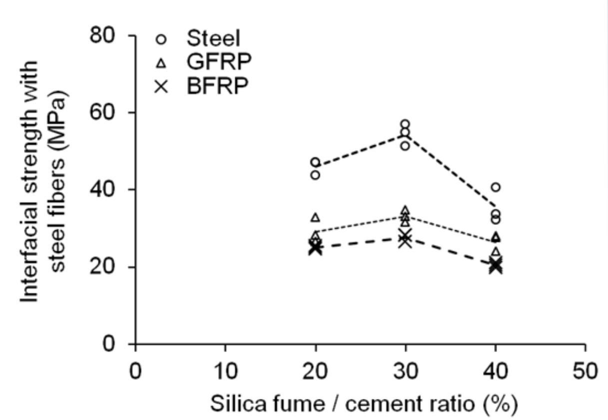


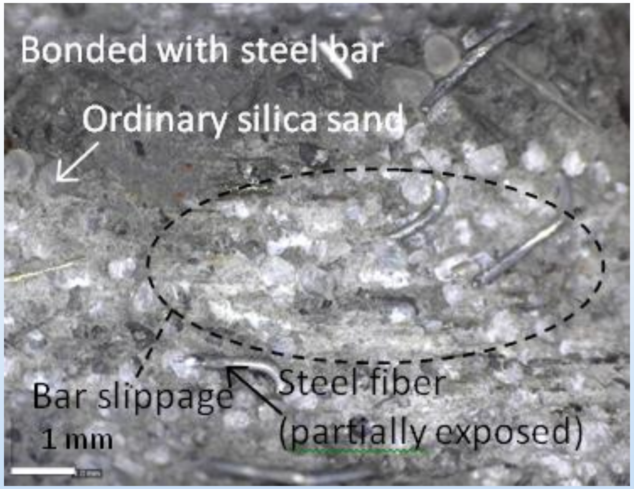
Experimental Program

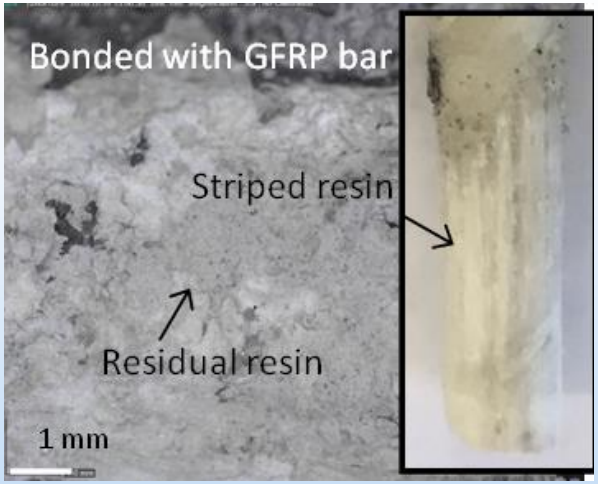
Results

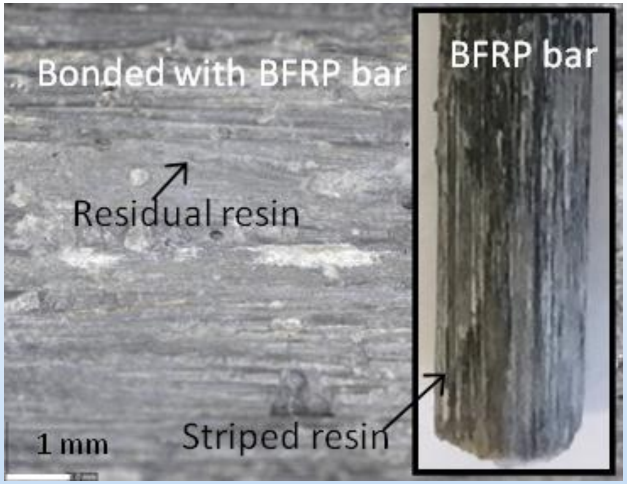










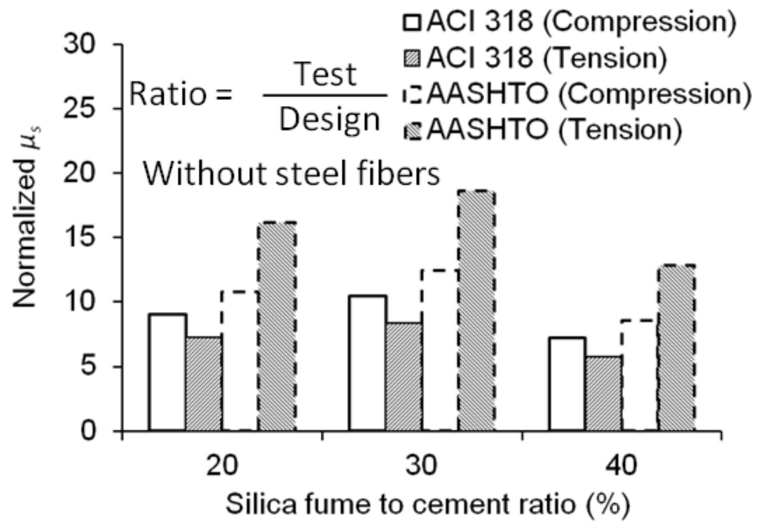


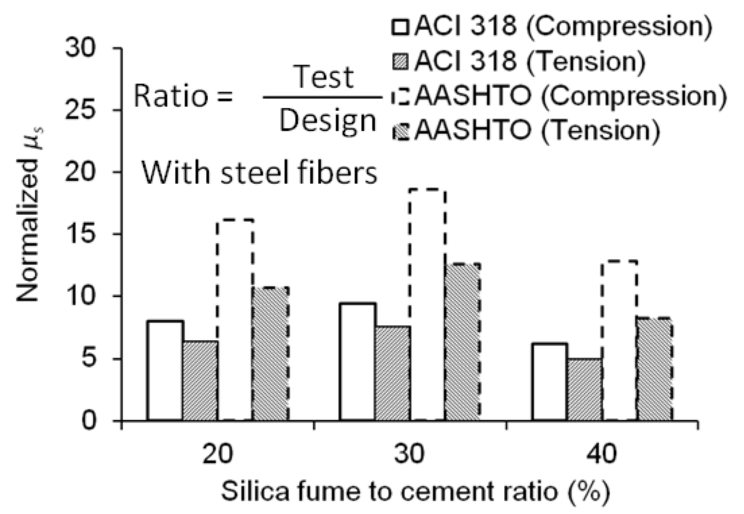
Design Perspectives

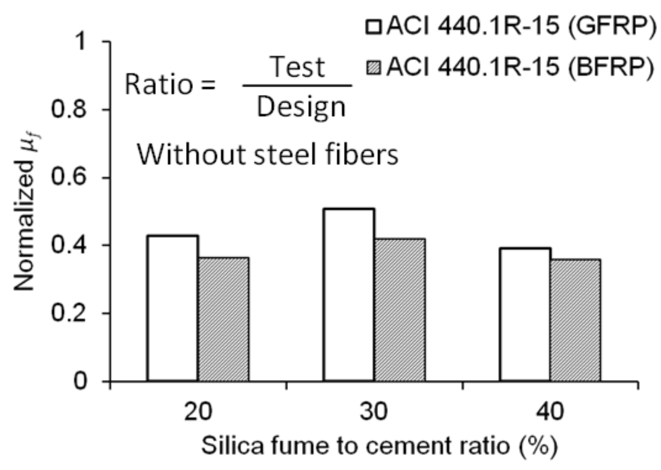
I II III IV V

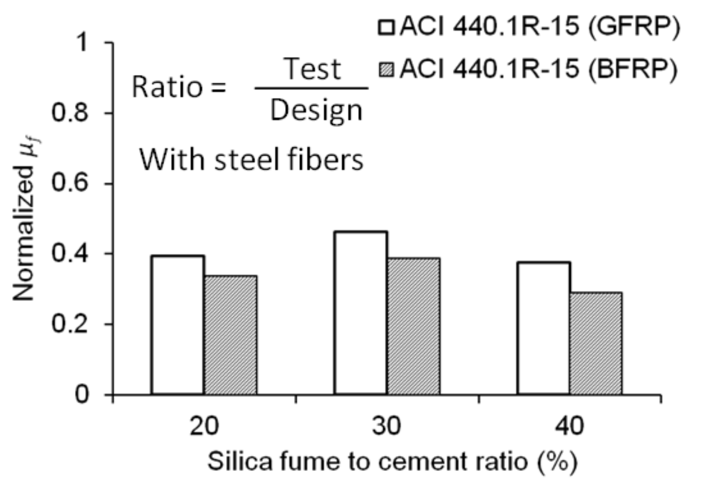
Design Perspectives

Assessment of Existing Expressions









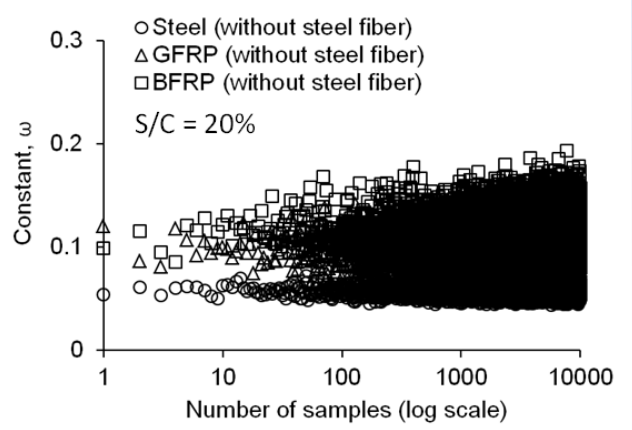
Design Perspectives

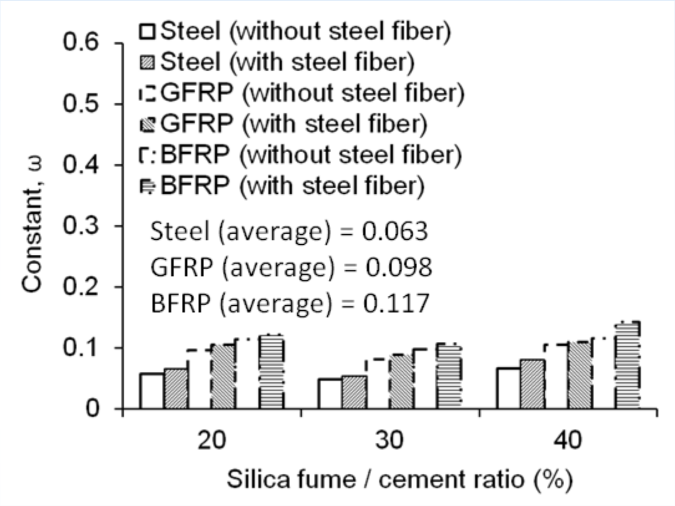
Proposed expression

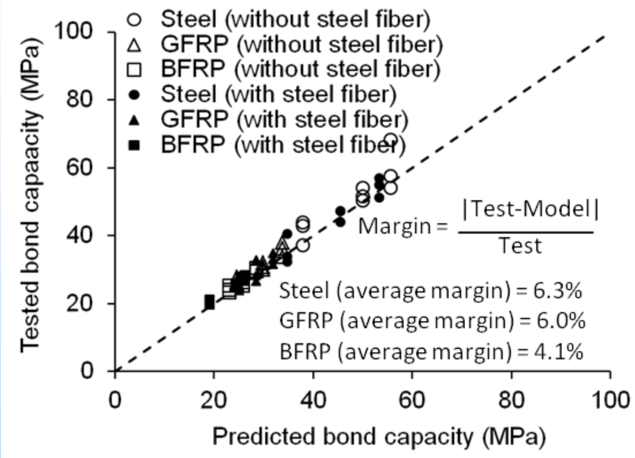
$$l_d = \varpi \frac{f_y}{\sqrt{f_c'}} d_b$$

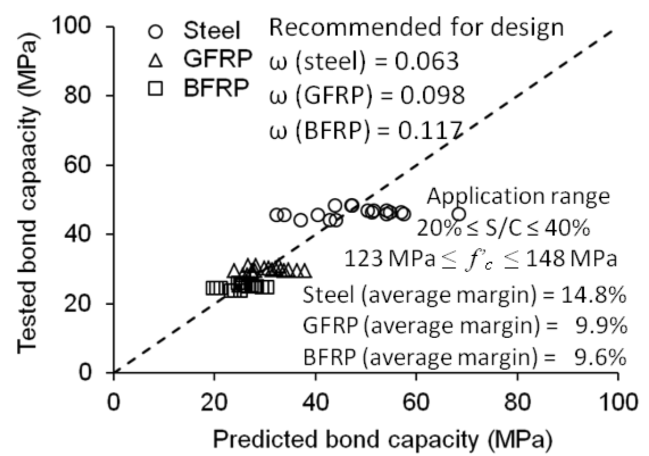
$$\varpi_s = \frac{A_s\sqrt{f_c'}}{\pi\mu_s d_b^2} \qquad \varpi_f = \frac{A_f\sqrt{f_c'}}{\pi\mu_f d_b^2}$$

$$\varpi = a(S/C)^2 + b(S/C) + c$$









Summary

Summary

- The compressive strength of UHPC increased when mixed with the steel fibers that restrained the onset of local cracks. As the amount of silica fume rose, the strength decreased owing to the weakening of the cement-aggregate interface.

- Due to the reliance on the prescribed requirements and empirical constants, the ACI 318 and AASHTO expressions underestimated the bond strength, while the ACI 440.1R-15 equation overestimated.

- The proposed bond equation showed an improvement and covered a strength range of UHPC from 123 MPa (18 ksi) to 148 MPa (21 ksi)

Acknowledgments

I II III IV V

- Thank-you to:

- Colorado Department of Transportation
- Co-Chairs (Dr. Nanni, Dr. Benmokrane, and Mr. Nolan)
- Owens Corning (GFRP) and Neuvokas Corporation (BFRP)

Bridge Engineering Institute Conference 2019
(BEI-2019)
July 22 to 25, 2019
Honolulu, Hawaii, USA
www.beibridge.org

Session 4: Ongoing Research and New Applications

(10:20 - 12:00pm)

Presentations (20 mins)

- **4.1 Bond of FRP bars embedded in UHPC with an emphasis on design aspects** *(Yail Jimmy Kim)*
- **4.2 Correlation between Moisture Absorption and Mechanical Strength Properties of Glass Fiber Reinforced Polymer Rebars Other** *(Raphael Kampmann)*
  - *Discussion 4.3 (30 mins)*

2nd International Workshop on GFRP Bars for Concrete Structures

FAMU-FSU Engineering

MIAMI

The Correlation Between Moisture Absorption and Tensile Strength Retention of Glass Fiber Reinforced Polymer Rebars

Alvaro Ruiz Emparanza, Srichand Telikapalli, Jan Suhrheinrich,
Raphael Kampmann, and Francisco De Caso

Introduction

GFRP as Internal Reinforcement for Concrete

- GFRP rebars are desirable for concrete in aggressive environments
- Rebar properties and rebar quality varies (between different products)
- GFRP rebar durability/performance dependent on production quality

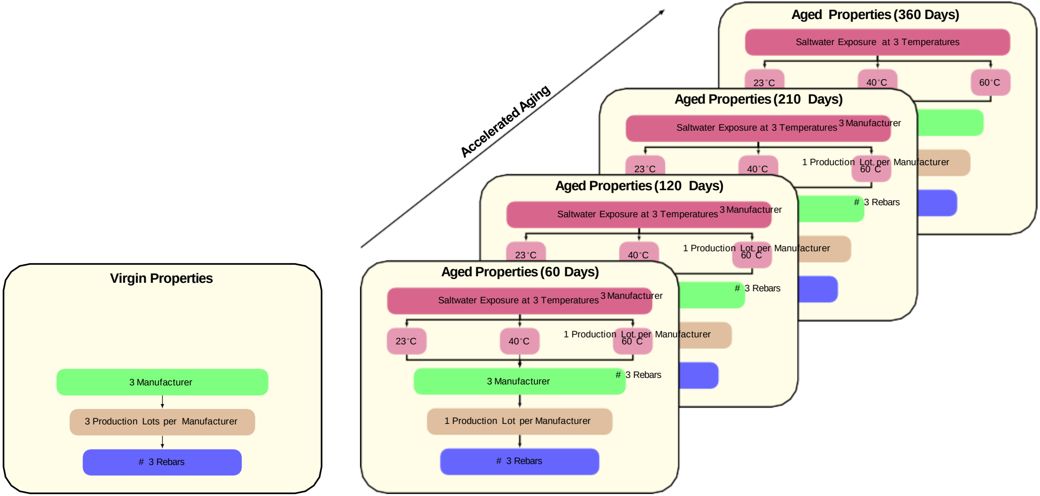
Introduction

Objectives

- Test various GFRP rebars for durability in aggressive environment
- Evaluate strength retention
- Compare strength retention to microstructure (SEM) and moisture absorption

Methodology

Experimental Program



Accelerated Aging

Aged Properties (360 Days)

Saltwater Exposure at 3 Temperatures

23 °C 40 °C 60 °C

Aged Properties (210 Days)

Saltwater Exposure at 3 Temperatures

23 °C 40 °C 60 °C

3 Manufacturer

1 Production Lot per Manufacturer

3 Rebars

Aged Properties (120 Days)

Saltwater Exposure at 3 Temperatures

23 °C 40 °C 60 °C

3 Manufacturer

1 Production Lot per Manufacturer

3 Rebars

Aged Properties (60 Days)

Saltwater Exposure at 3 Temperatures

23 °C 40 °C 60 °C

3 Manufacturer

1 Production Lot per Manufacturer

3 Rebars

Virgin Properties

3 Manufacturer

3 Production Lots per Manufacturer

3 Rebars

Experimental Program

Experimental Concept

Rebar		Exposure	ACP*		Material Property	Test Method	Specimen per Test
Type	Size		Temp °C	Days			
A, B, C	# 3	Saline Solution	23, 40, 60	60,120,210,365	Moisture Absorption	ASTM D 792	9†
					Cross Sectional Area	ASTM D 570	9†
					Tensile Strength	ASTM D 7205	3
					Microstructure Observation	SEM**	1

† Test was only performed for the virgin material.

* Accelerated Conditioning Protocols

** Scanning Electron Microscope

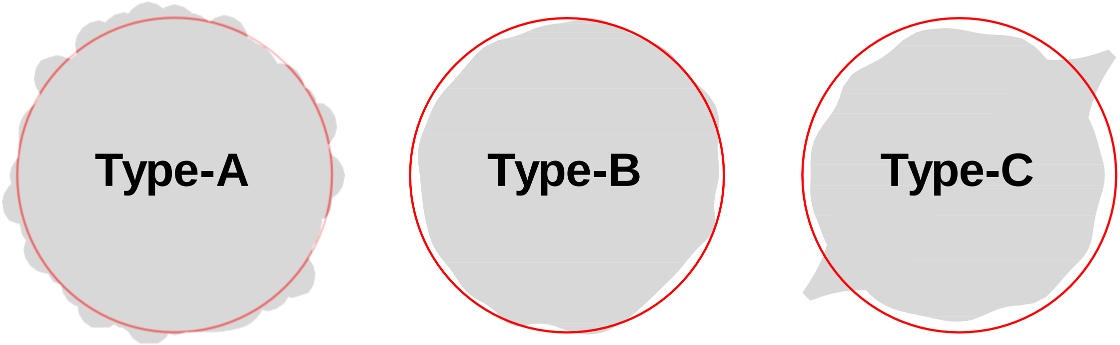
Experimental Program

GFRP Rebar Materials — Physical Features

ID	Cross Section	Surface Enhancement	Material	
			Resin	Glas
Type-A	Round and Solid	Helical Wraps + Sand	Vinyl-Ester	E-CR Glass
Type-B	Round and Solid	Helical Wraps	Vinyl-Ester	E-CR Glass
Type-C	Oval and Solid	Rips	Vinyl-Ester	E Glass

Experimental Program

GFRP Rebar Materials — Physical Features



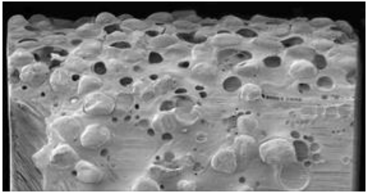
Experimental Program

GFRP Rebar Materials — Physical Features

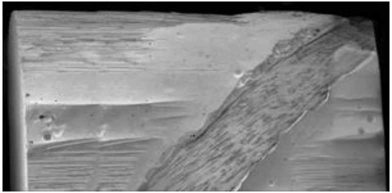
(a) Type-A **(b)** Type-B **(c)** Type-C

Experimental Program

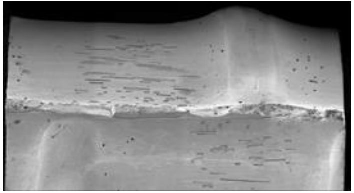
GFRP Rebar Materials — Surface Enhancement Under SEM



(a) Type-A



(b) Type-B



(c) Type-C

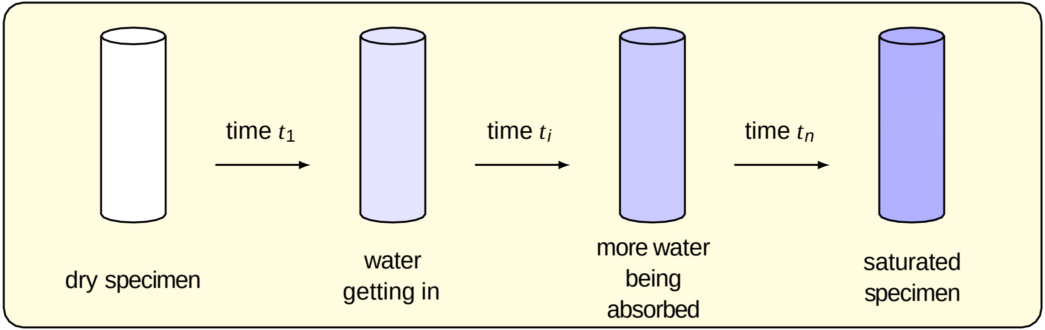
Experimental Program

GFRP Rebar Materials — Manufacturer Reported Properties

Size	ID	Unit Weight		Load Capacity		Max. Stress		Elastic Modulus		Ultimate Strain
		$\frac{kg}{m}$	$\frac{lbs.}{ft}$	kN	kip	MPa	ksi	GPa	10^6 psi	%
# 3	Type-A	0.174	0.117	58.7	13.20	827.4	120.0	46.0	6.70	1.79
	Type-B	0.190	0.128	58.9	13.24	830.0	120.4	40.0	5.83	1.50
	Type-C	0.148	0.100	59.6	13.40	840.0	121.0	42.0	6.00	2.00

Experimental Program

Moisture Absorption Test



dry specimen

time t_1

water getting in

time t_i

more water being absorbed

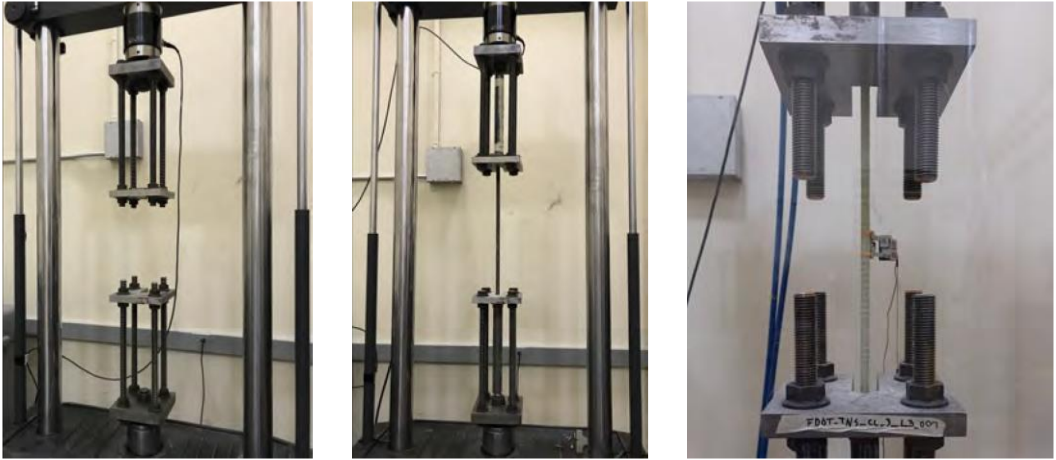
time t_n

saturated specimen

$$\frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} \tag{1}$$

Experimental Program

Tensile Test Setup



Experimental Program

Accelerated Aging

Results and Discussion

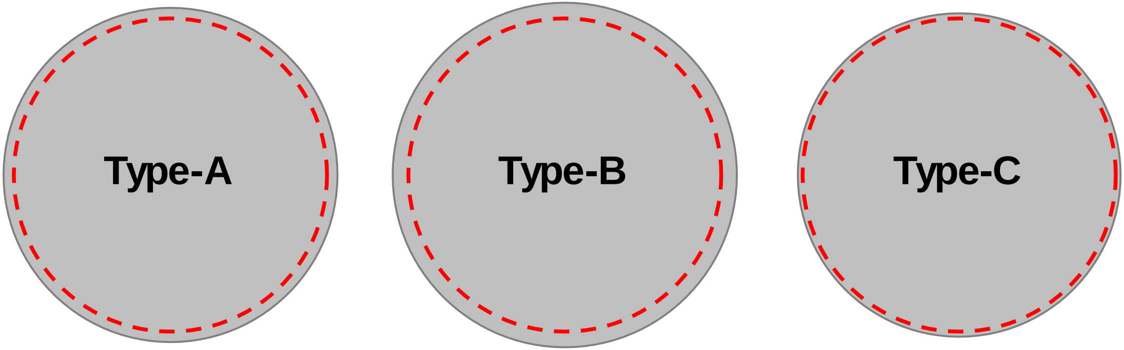
Results and Discussion

Average Measured Cross-Sectional Properties

Rebar Type		Specific Gravity ϕ/ϕ_w	Density ϕ	Area		Diameter	
			kg/m^3	mm^2	in.^{2}	mm	in.
# 3	Type-A	2.05	2047	81.0	0.126	10.2	0.402
	Type-B	1.85	1845	86.1	0.133	10.5	0.413
	Type-C	2.01	2008	80.0	0.124	9.8	0.386

Results and Discussion

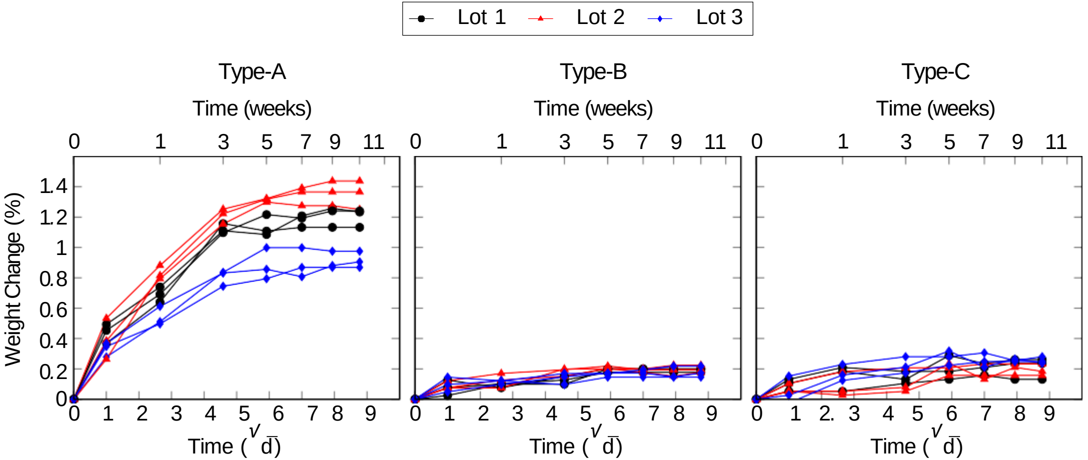
Cross-Sectional Area



$1.14 A_{nom}$ $1.21 A_{nom}$ $1.12 A_{nom}$

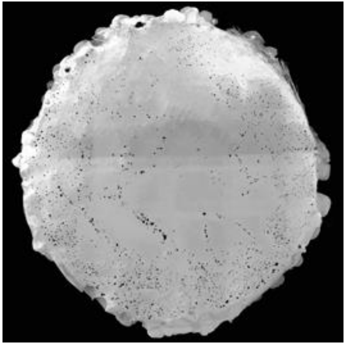
Results and Discussion

Moisture Absorption

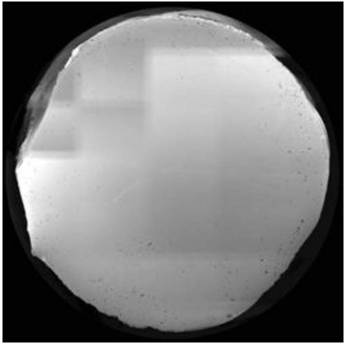


Results and Discussion

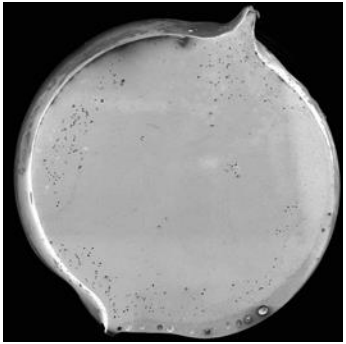
SEM Images of Virgin Rebars



(a) Type-A in virgin state



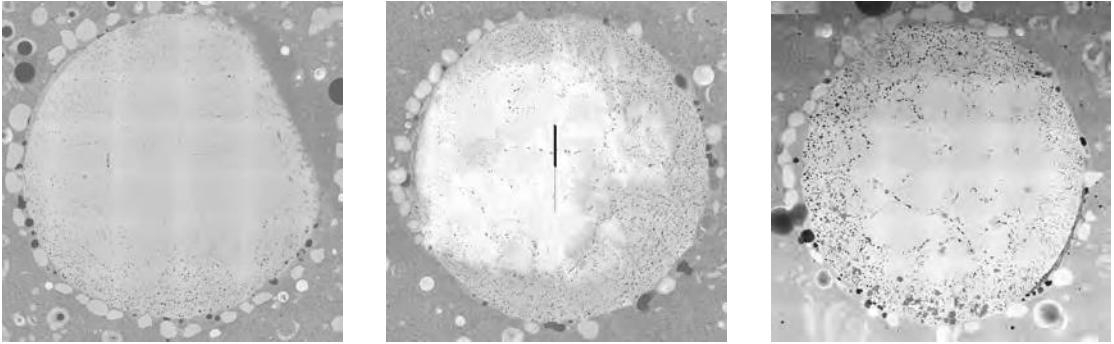
(b) Type-B in virgin state



(c) Type-C in virgin state

Results and Discussion

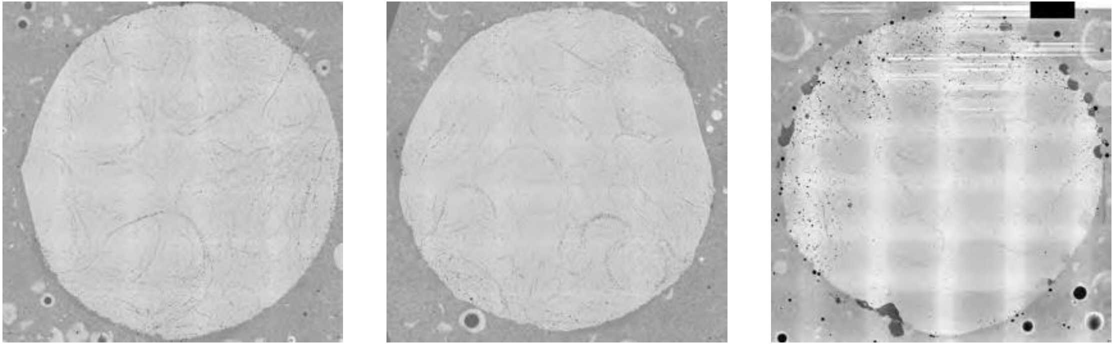
SEM Images of Type-A Rebar after 365 Days Saltwater Exposure



(a) Type-A at 23 °C (73 °F) **(b)** Type-A at 40 °C (104 °F) **(c)** Type-A at 60 °C (140 °F)

Results and Discussion

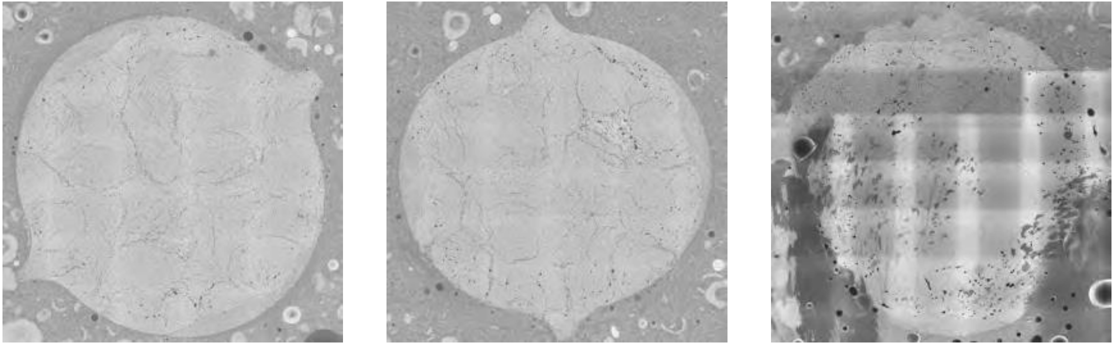
SEM Images of Type-B Rebar after 365 Days Saltwater Exposure



(a) Type-B at 23 °C (73 °F) **(b)** Type-B at 40 °C (104 °F) **(c)** Type-B at 60 °C (140 °F)

Results and Discussion

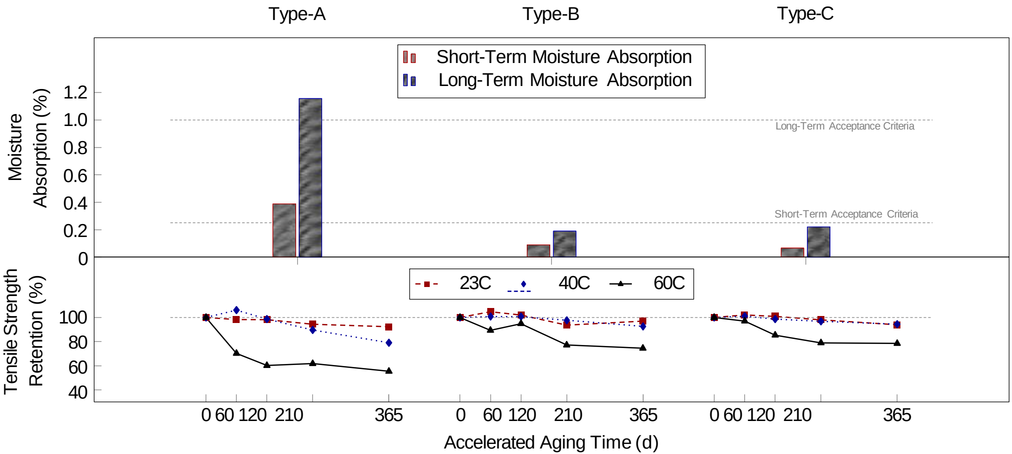
SEM Images of Type-C Rebar after 365 Days Saltwater Exposure



(a) Type-C at 23 °C (73 °F) **(b)** Type-C at 40 °C (104°F) **(c)** Type-C at 60 °C (140°F)

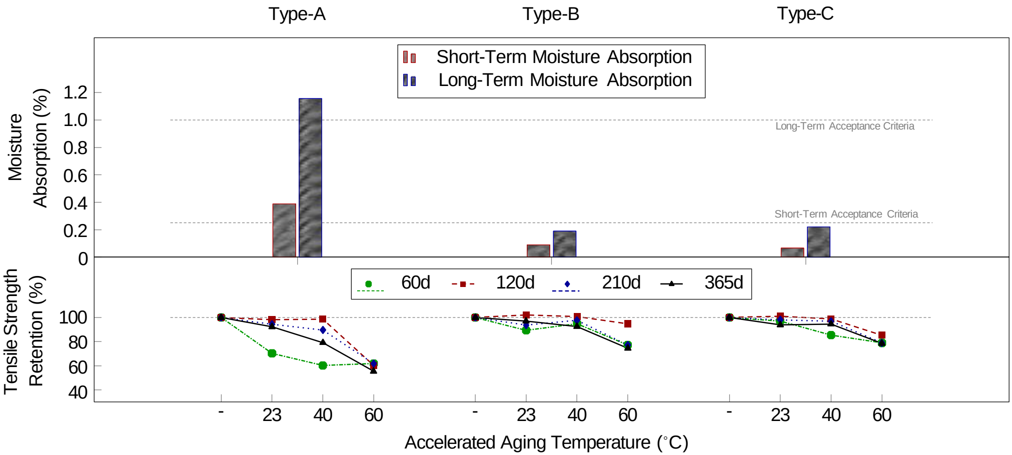
Results and Discussion

Moisture Absorption vs. Tensile Strength Retention



Results and Discussion

Moisture Absorption vs. Tensile Strength Retention



Conclusions

Conclusions

Summary

- Type-A rebars measured highest moisture absorption
    - Above short- and long-term limitation criteria
- SEM reveled porosity of microstructure ⇒ Most concerning for Type-A rebars
- Microstructure damages were more significant at higher exposure temperatures
- Highest moisture absorption lead to lowest tensile strength retention

Conclusions

- Different surface enhancements lead to different surface porosity
    - Affects moisture absorption
- A porous microstructures leads to higher moisture absorption
- Microstructure (porosity) indicative of rebar vulnerability
- Correlation between moisture absorption and long-term rebar performance
- Elevated temperature intensifies GFRP rebar degradation
    - 23 °C to 40 °C (73 °F to 104 °F) vs. 40 °C to 60 °C (104 °F to 140 °F)

Closing Remarks

Questions ?

Raphael Kampmann
kampmann@eng.famu.fsu.edu