Durability of Carbon Fiber Splay Anchors in Bond Critical, Externally Bonded CFRP under Hygrothermal Conditioning

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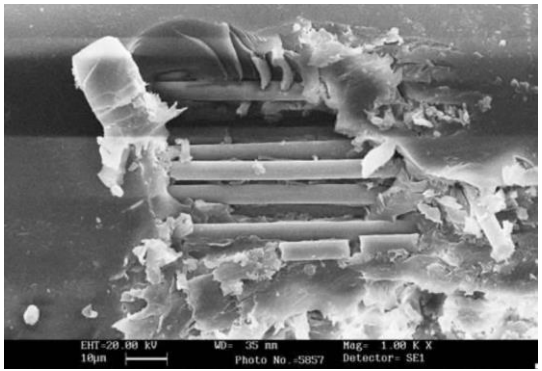
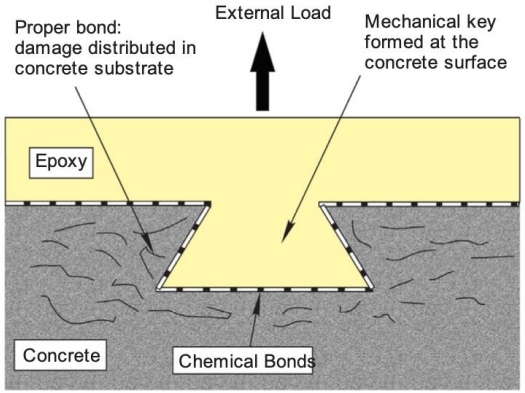
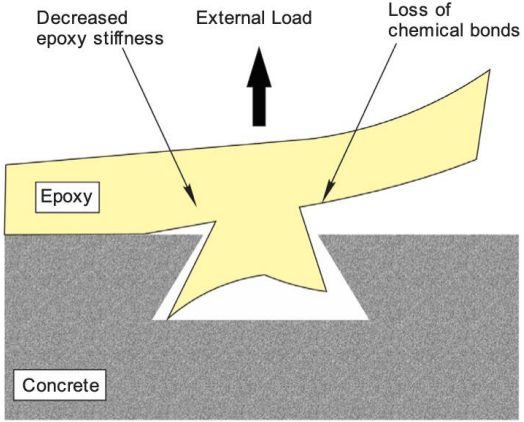
Environmental Exposure

- Moisture in particular is detrimental to properties of epoxy constituent in composites
- Switch from cohesive failure to adhesive failure
- Decrease in interlaminar shear strength

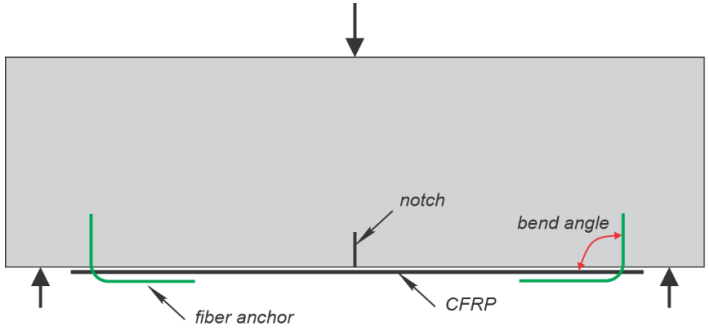


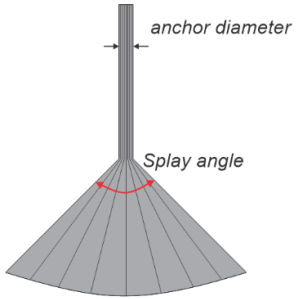


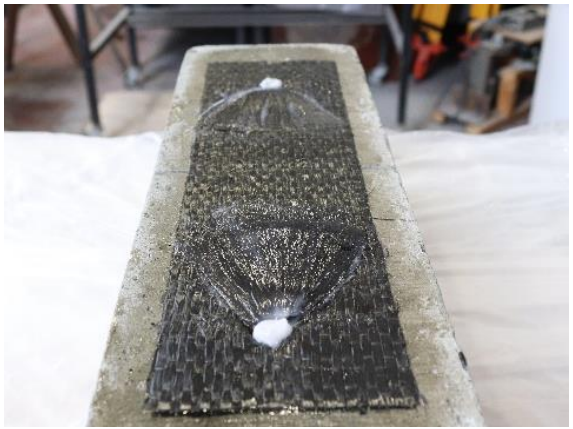


Carbon Fiber Splay Anchors

- Prevent detachment of FRP from concrete substrate following debonding
- Increase strain utilization of CFRP
- Improve pseudoductility of strengthened specimen

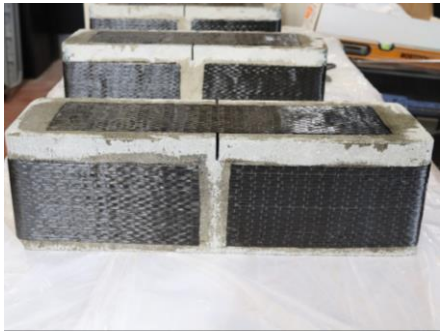






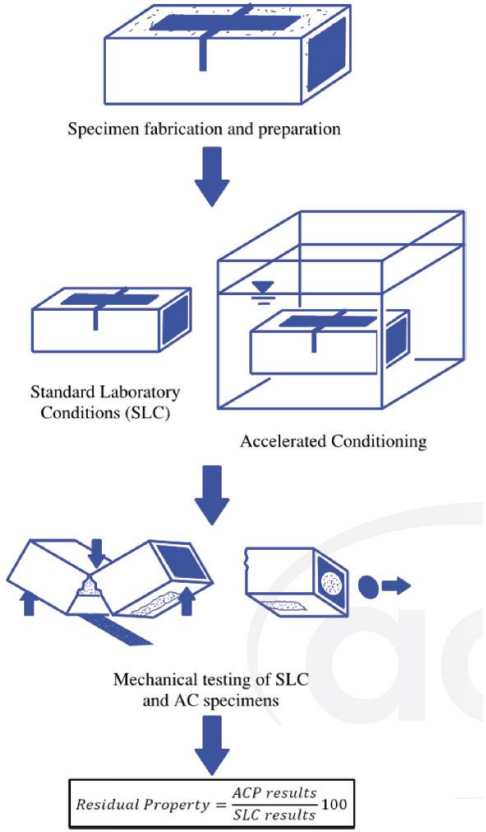
Research Objectives

- Quantify hygrothermal (moisture & heat) conditioning on externally bonded (EB) anchored CFRP system durability
- Evaluate the effects of the selected accelerated conditioning protocol on epoxy and CFRP composite



Conditioning Protocol

- Accelerated conditioning protocol (ACP)—3000-hr. water immersion at 50 ℃ per ACI 440.9R
- Unconditioned control group kept in standard laboratory conditions (SLC)



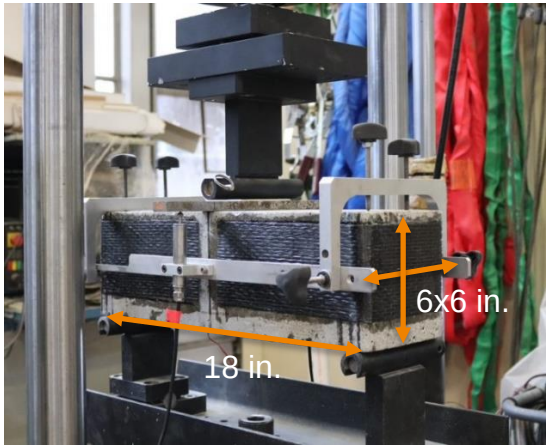
Materials

- 7,200 (SLC) and 9,000 (ACP) psi concrete
- 40% cement, 60% slag replacement to minimize substrate degradation
- 5.5% air-entrainment for better adhesive-concrete mechanical interlocking

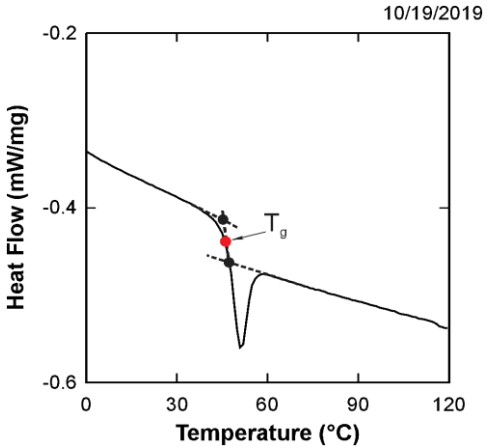
- 11.6 $\frac{oz}{yd^2}$ (393 $\frac{g}{m^2}$) unidirectional carbon fiber
- Low viscosity epoxy used as substrate primer and fiber saturant
- Putty – epoxy mixed with 5.4 wt% of silica fume

Methodology

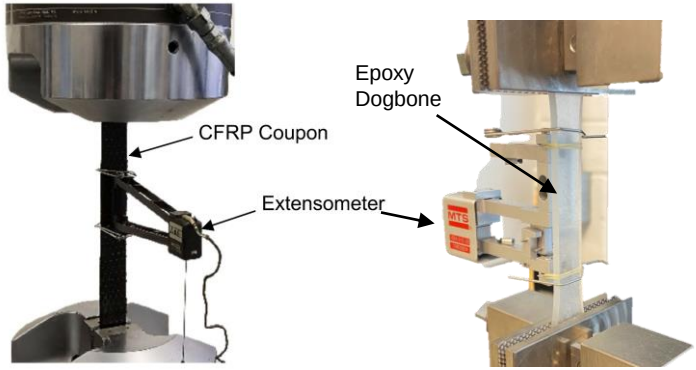
Three-point bending test



Differential Scanning Calorimetry (DSC)



Tensile Tests



Test Variables

Conditioning Protocol

Standard Laboratory Conditions (SLC)

Accelerated Conditioning Protocol (ACP)
Immersion in 50℃ potable water for 3000 hours

Bonded vs. Unbonded CFRP

Bonded - B

Unbonded - UB

Anchor Diameter - AMR

1/4 in. – 0.625

3/8 in. - 1.375

1/2 in. – 2.50

Fabrication of Small-Scale Beams

Drilling and chamfering anchor holes

Rounding corners to ½ in. radius

Introduce Notch

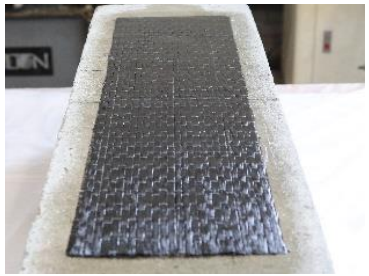
Sandblasting

Fabrication of Small-Scale Beams

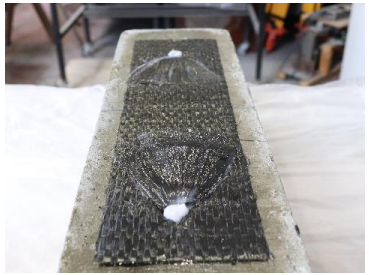
Epoxy primer coat

Putty layer

CFRP application

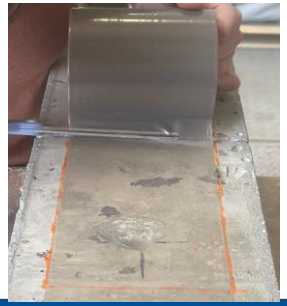


Anchor installation



Strengthened beam

OR **Teflon tape**



Results – Constituent Tests

CFRP Coupons

Property	SLC	ACP	% Change
Tensile Modulus (Gpa)	97.6 ± 9.4	89.1 ± 4.3	-8.8
Tensile Strength (Mpa)	1484 ± 97	1252 ± 67	-16
Elongation (%)	1.53 ± 0.2	1.41 ± 0.1	-7.8

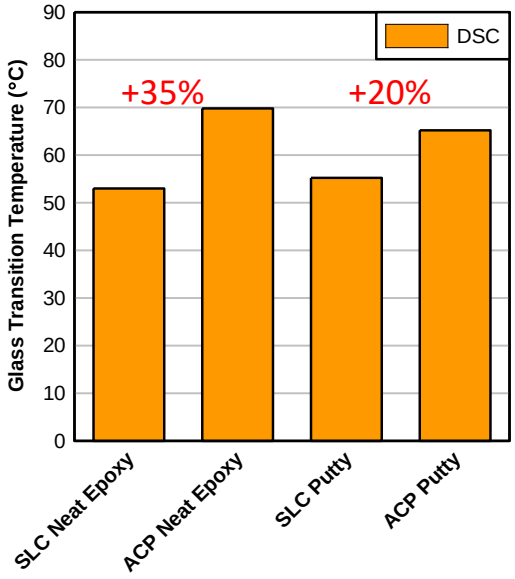
Results – Constituent Tests

Epoxy Dogbones

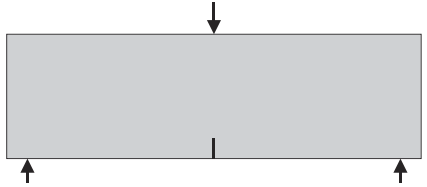
Property	SLC	ACP	% Change
Tensile Modulus (Mpa)	2,928 ± 11.8	2,316 ± 45.4	-21
Tensile Strength (Mpa)	46.7 ± 3.72	60.0 ± 2.38	+28.5
Elongation (%)	1.71 ± 0.167	1.94 ± 0.118 [1]	+13.5

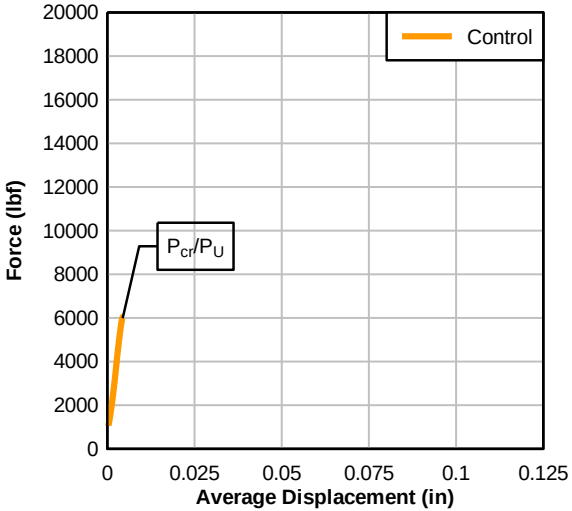
[1] Elongation at yield

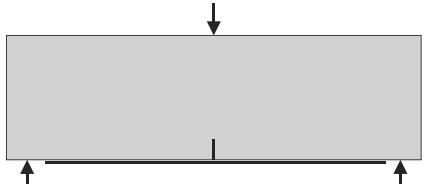
Epoxy & Putty DSC

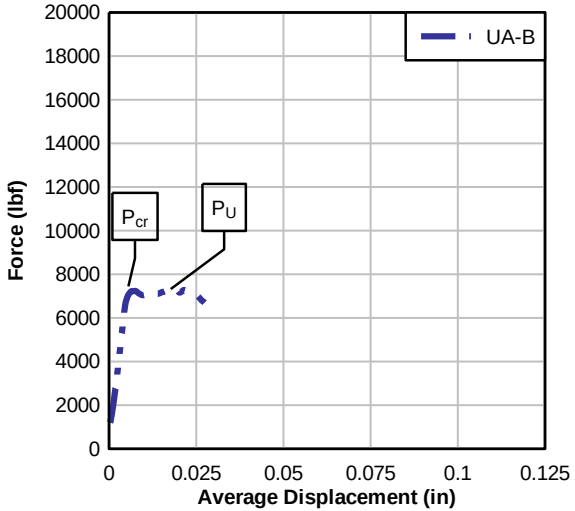


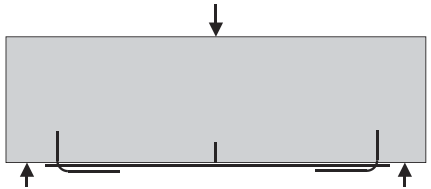
Results - Beam Behavior

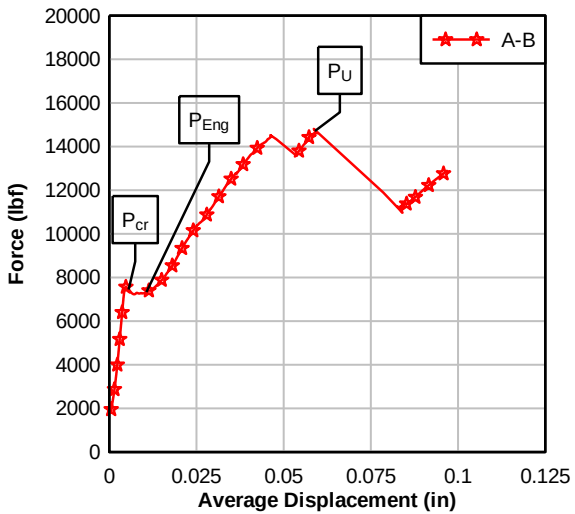












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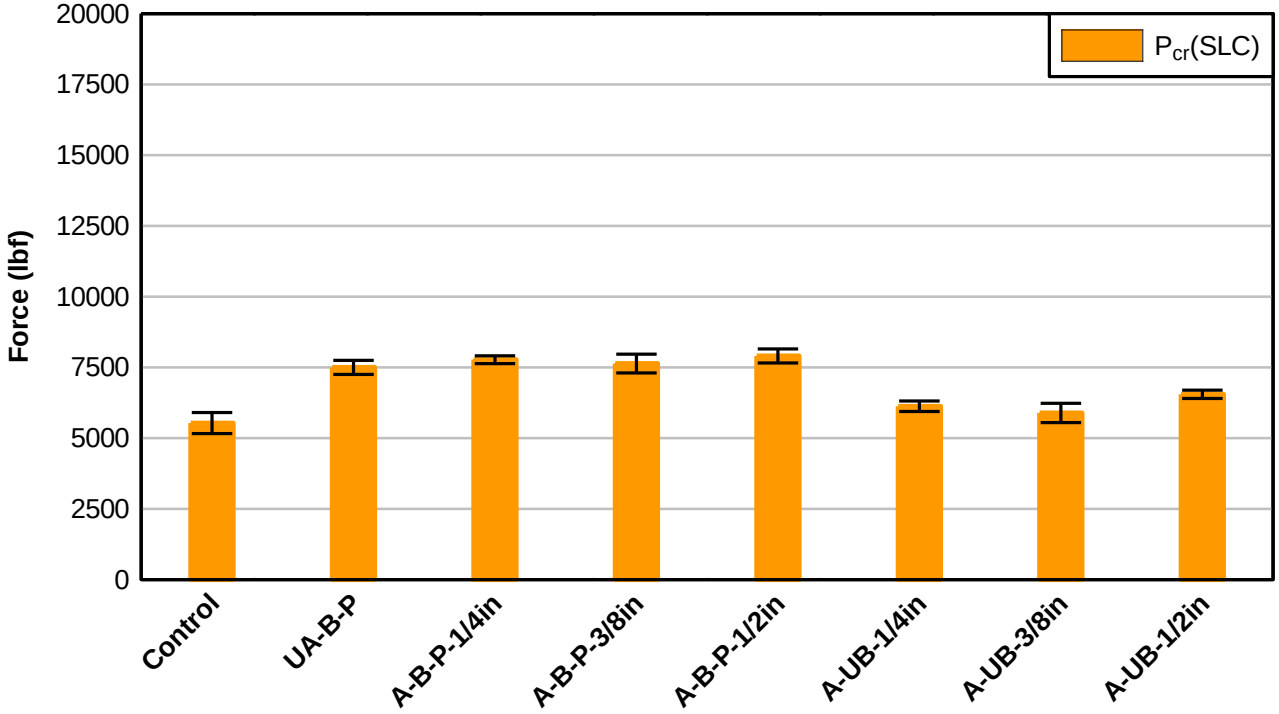

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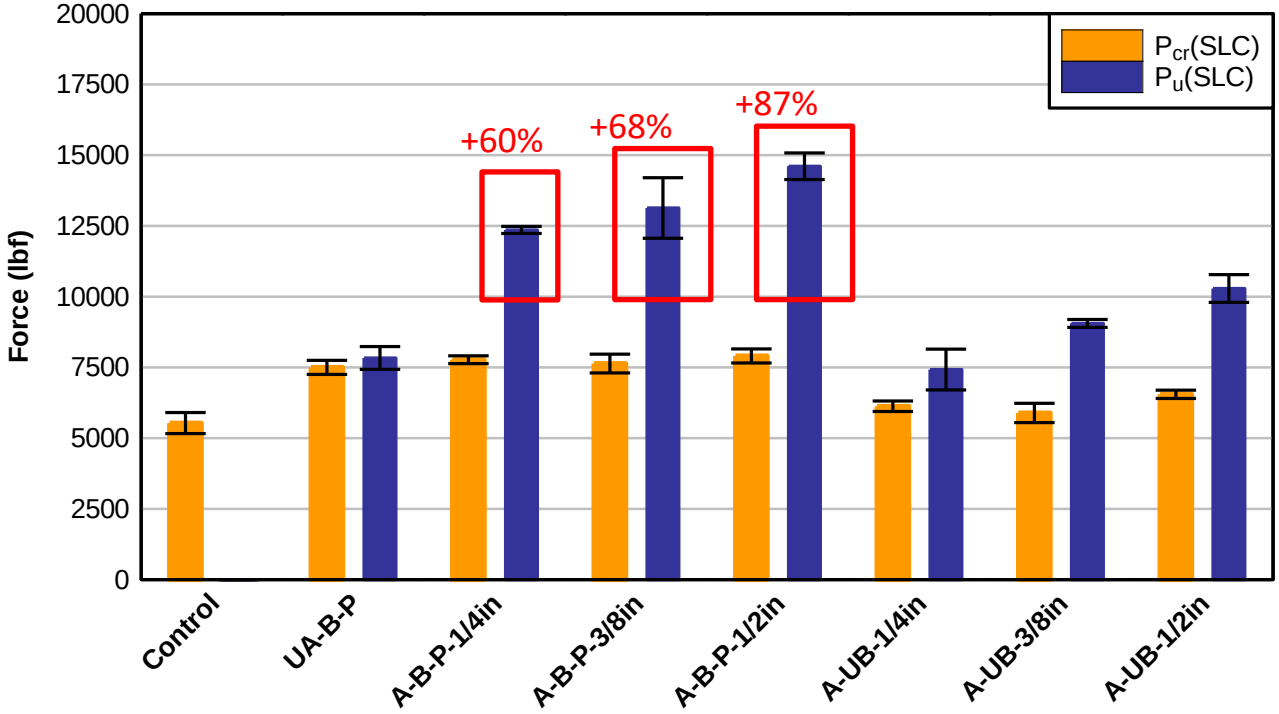

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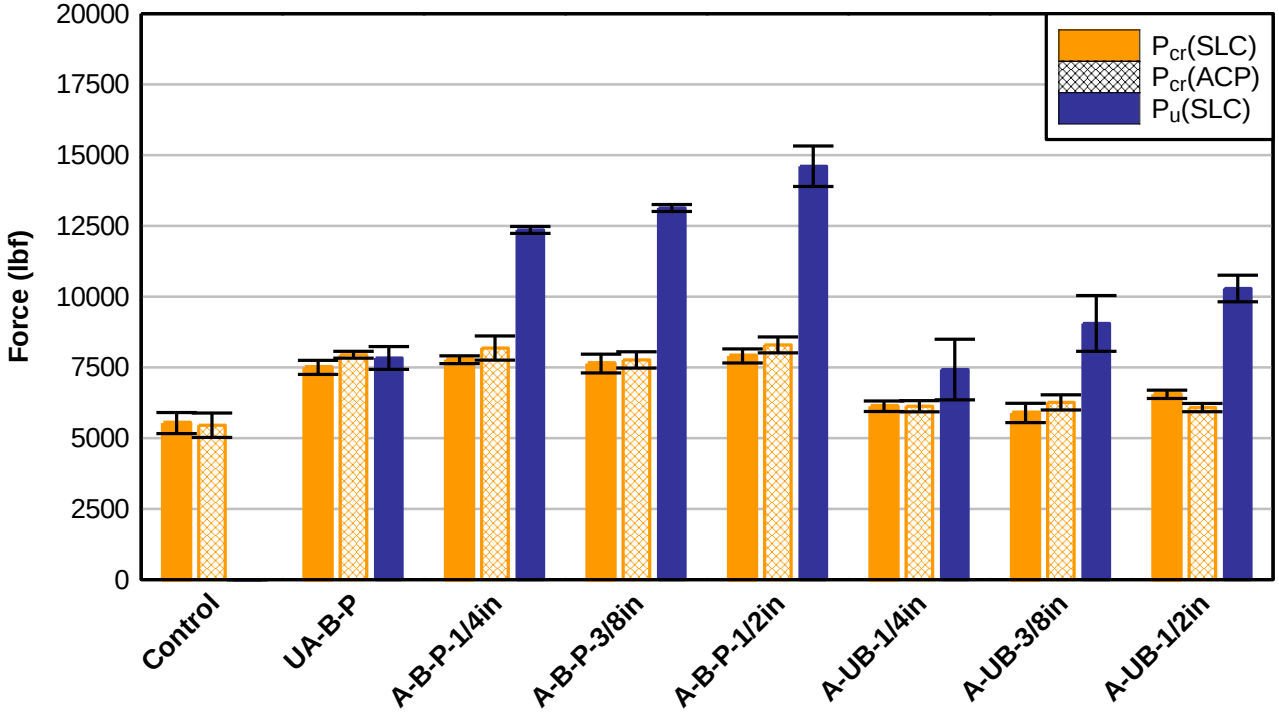
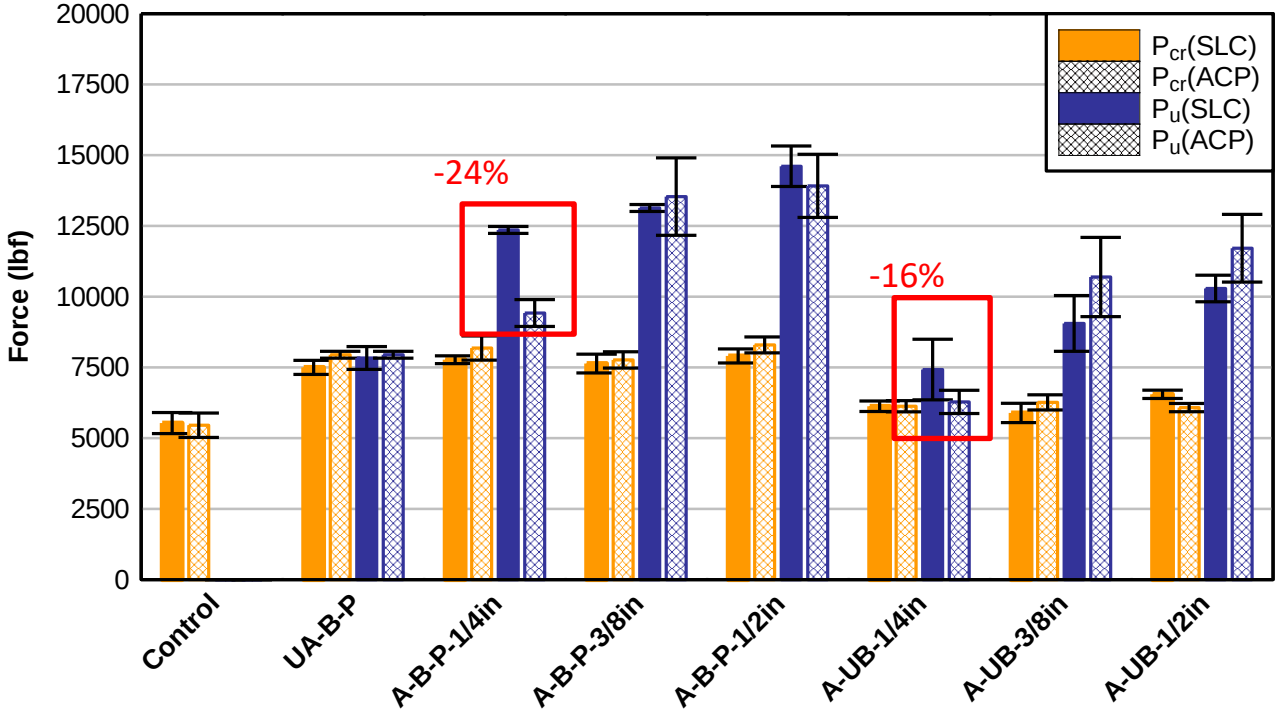
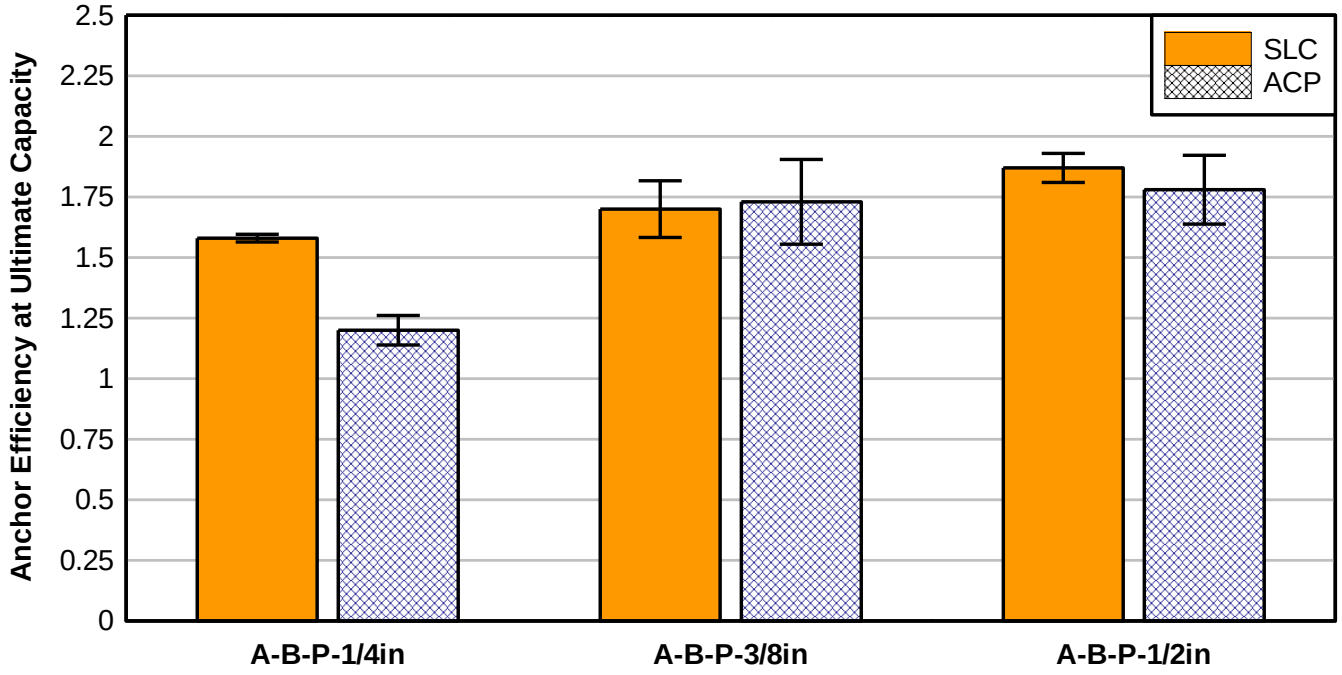


Results – Beam Tests



Results – Beam Tests

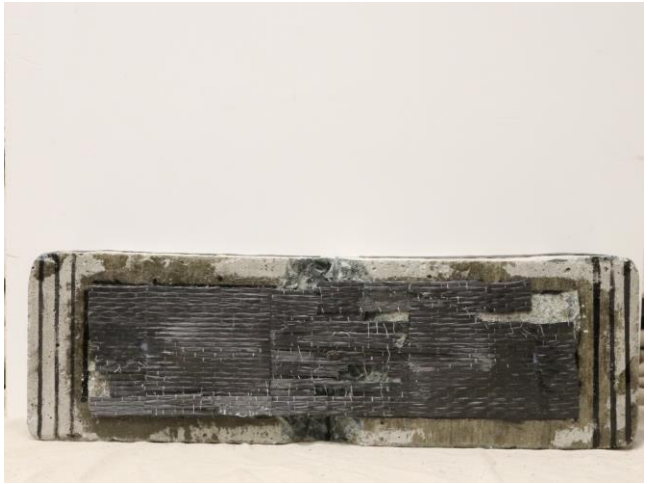


$* \; Anchor\ Efficiency = \frac{SLC\ or\ ACP\ Anchored\ P_U}{SLC\ Unanchored\ P_U}$

Results – Failure Modes

1/4 in. – 0.625 AMR

3/8 in. and 1/2 in. –
1.375 and 2.50 AMR



Conclusions

- Anchored SLC-UB beams demonstrated 30-40% lower capacity compared to corresponding anchored SLC-B beams
- 1/4 in. anchor groups demonstrated greatest susceptibility to conditioning:
  - 24% decrease in P_{Ult} in ACP bonded group
  - 16% decrease in P_{Ult} in ACP unbonded group
  - Anchor efficiency is limited in 1/4 in. anchor group following ACP
- 3/8 in. and 1/2 in. anchor groups attained strip fracture with no capacity loss while 1/4 in. anchors failed primarily by anchor rupture

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