American Concrete Institute

Investigation of Mechanical Splices for Titanium Alloy Bars

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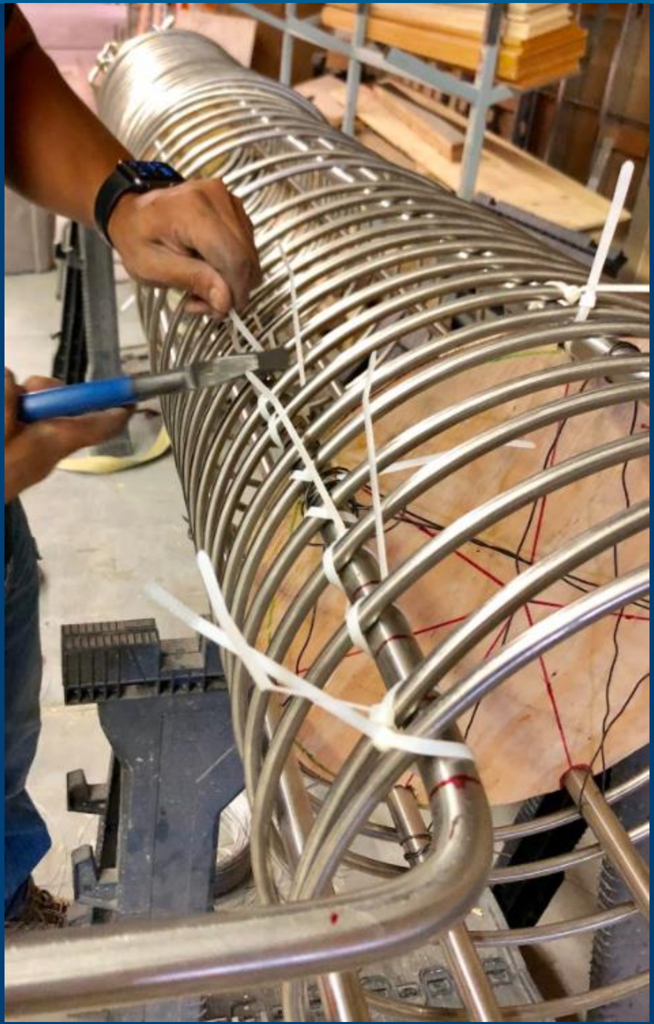
Outline

- Objectives
- Literature
- Experimental Program

  Tension Test
- Discussion
- Conclusions



Objectives

- Review literature on Titanium Alloy Bars (TiABs) in civil engineering industry
  - Research
  - Current use
- Experimental test (i.e., tension test) to identify appropriate mechanical coupler to splice TiABs
- Provide recommendations regarding the use of TiABs

Literature

- New Advanced Materials for Civil Engineering Industry

  Titanium Alloy

- Widely used Grade of Titanium: Grade 5 (Ti6Al4V)
- Advantages

  Great corrosion resistance

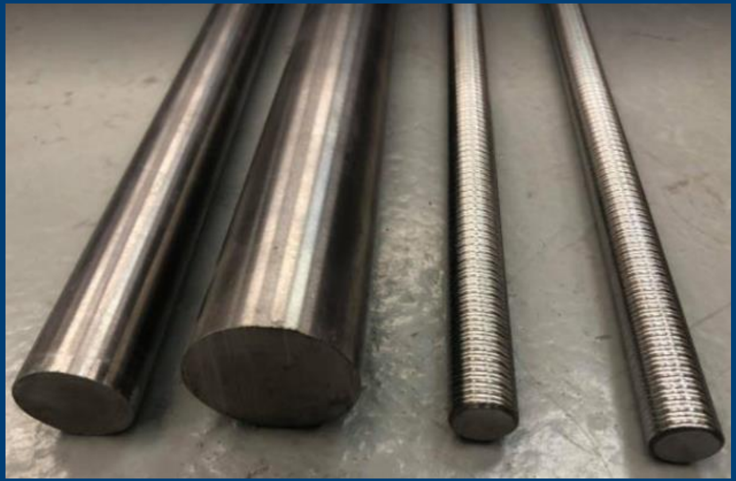
  High strength to weight ratio

  Flexibility

  Ductility

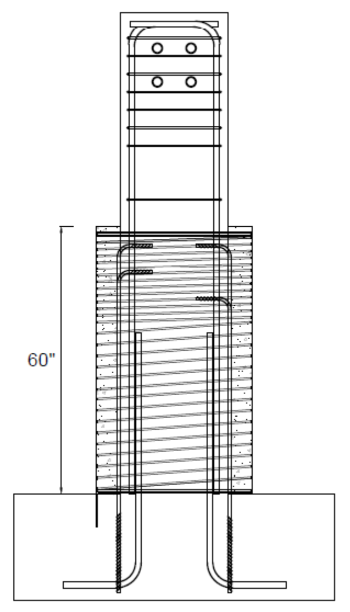
- Disadvantage

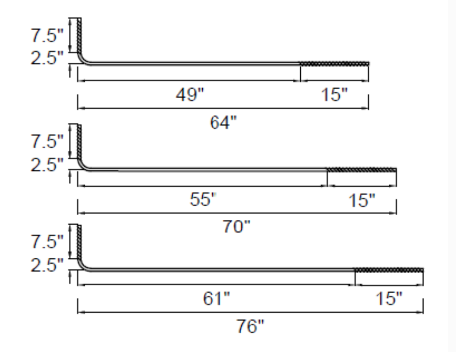
  Expensive material



Literature

- Oregon State University (Retrofitting) (Shrestha et. Al)





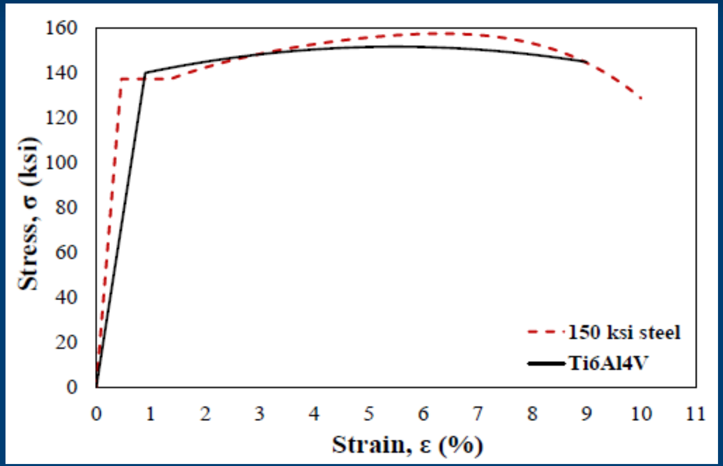
All bars 5/8" dia. - 7.5" threaded section along 90° hook with 5" bend diameter, 15" threaded section tail of bar

Full-scale column specimens:

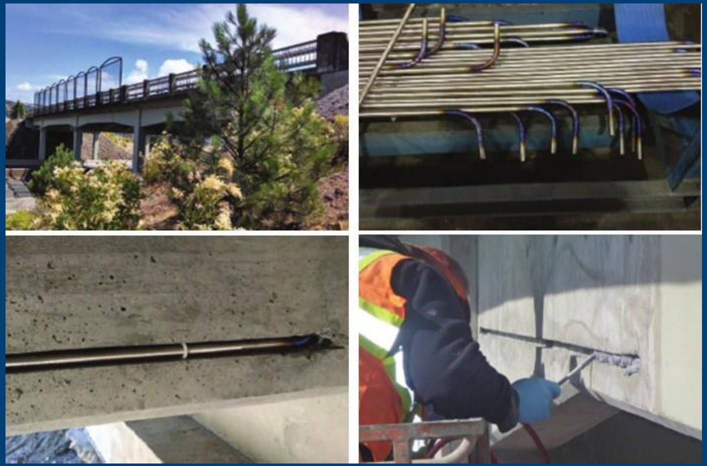
- 24 in. x 24 in. square columns
- 4-#10 Gr. 60 corner bars
- #3 Gr. 40 square ties @ 12 in.
- 36 in. lap-splice length
- f'_c = 3,300 psi

- Improved seismic performance with TiAB retrofit
- Titanium alloy bars (TiABs) provide:
  - High strength with well-defined material properties
  - Greatly improved ductility
  - Environmental durability (corrosion resistance)
  - Ease of fabrication and installation
- Conventional construction methods, economic retrofit solution

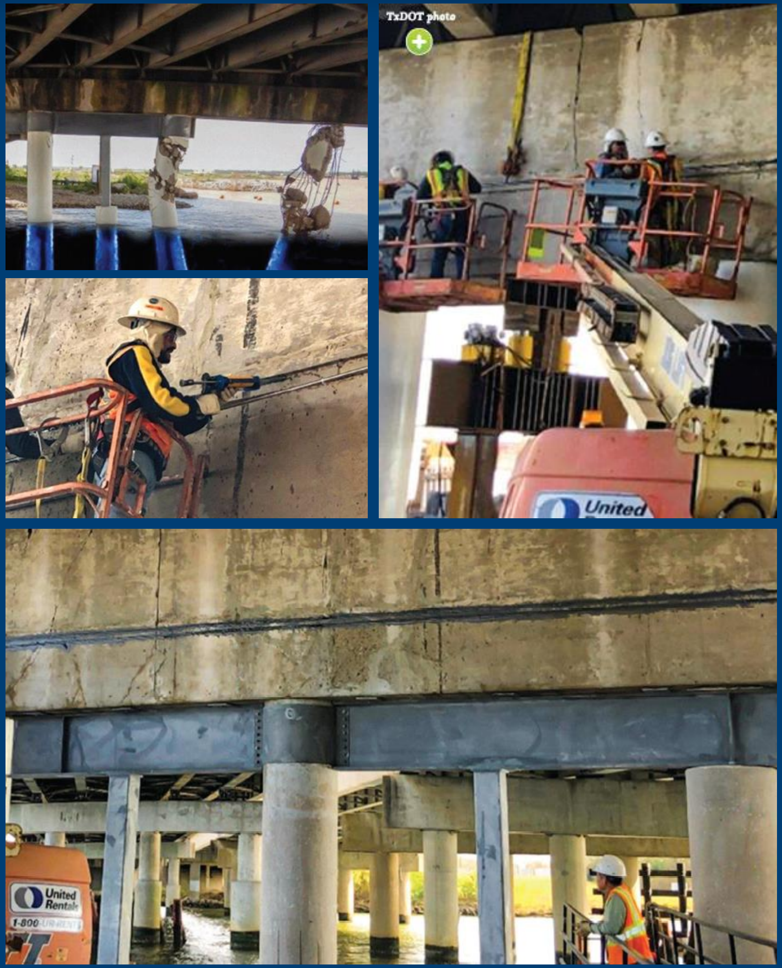
Literature



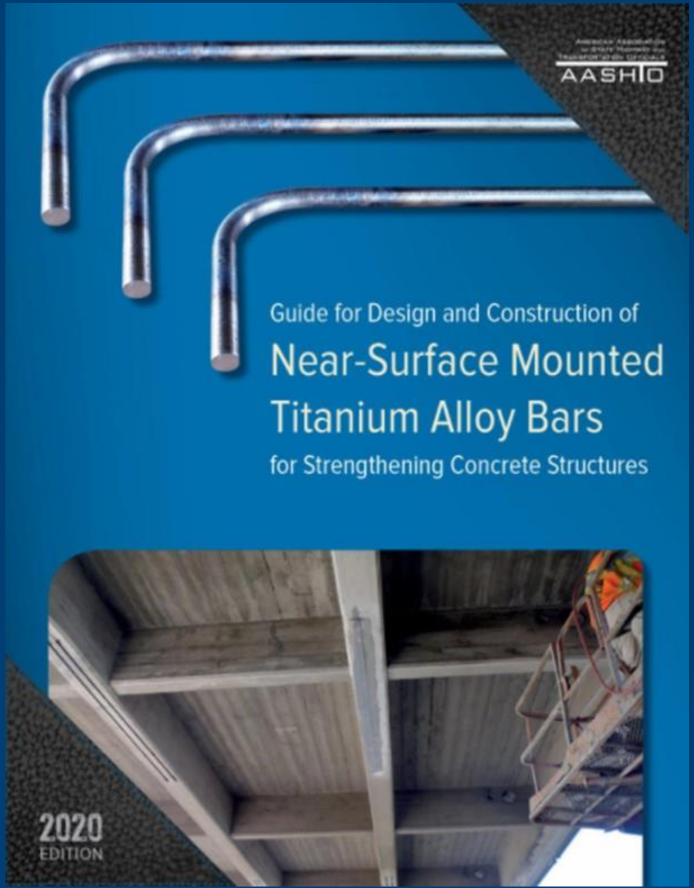
Stress-Strain Plot for Ti6Al4V and 150 ksi Steel Specimen



NSM TiABs Technology Used in Mosier Bridge by ODOT



NSM TiABs Technology Used in San Jacinto River Bridge by TxDOT



1st Edition, AASHTO Publication

Splicing of TiABs

- Coupler ‘A’
  - Uses shear screw to splice bar
  - Positive center
  - Twist-off-screw
- Coupler ‘B’
  - Cold swaged steel sleeves
  - Installed in-situ w/ overlapping bites
  - Gripped using portable presses






Splicing of TiABs

- Coupler ‘C’

  Cold swaged steel sleeves

  Thicker

  Designed for high-strength bars

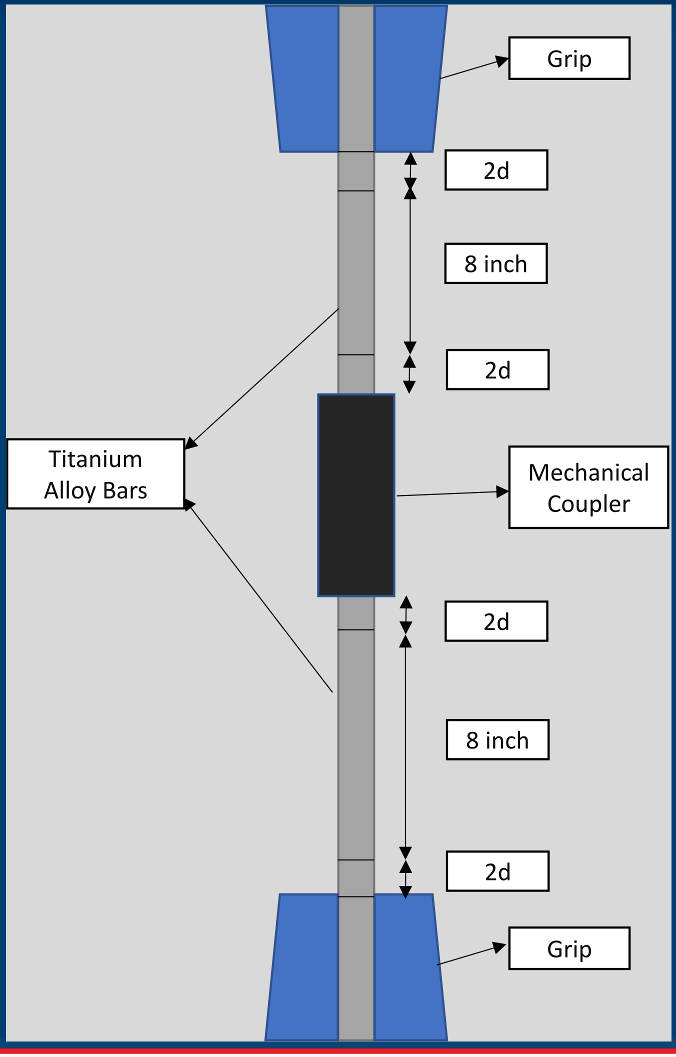
  Both male and female taper threaded coupler components maintain full cross-sectional area of the bar

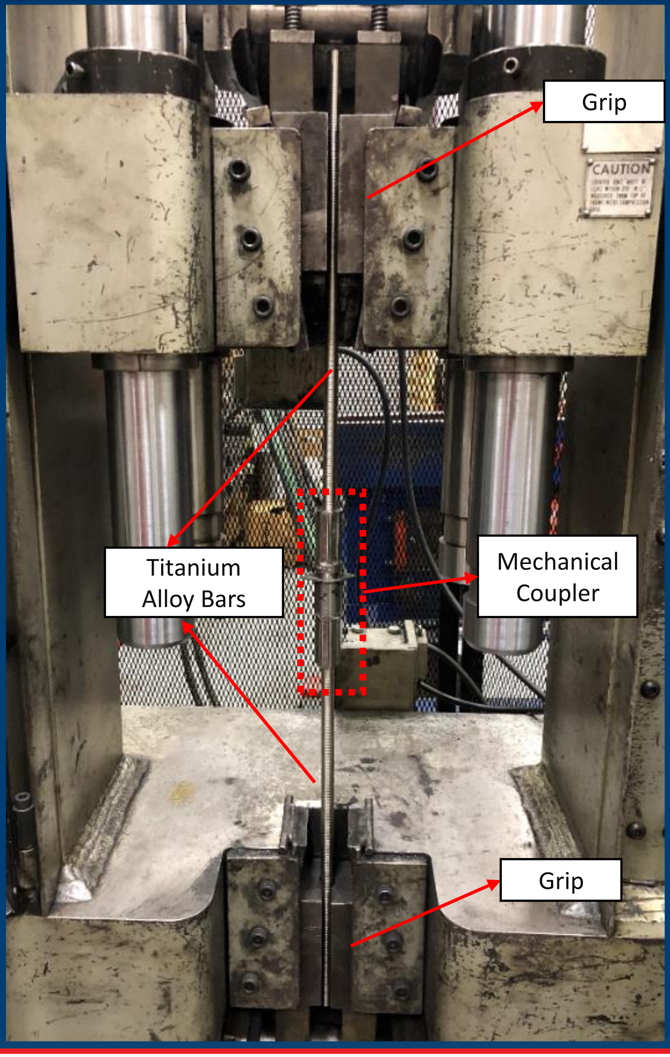



Splicing of TiABs

- ASTM A1034
- Tensile Test

ID	Description
$D_{Initial}$	Initial diameter of the titanium alloy bars
$L_{Initial}$	Total length of specimen after installation of the mechanical coupler
L_{Final}	Final length of each bar after fracture
D_{Final}	Diameter of bar at the point of fracture (3 measurements for precision)





Splicing of TiABs

- Tension Test Matrix for Couplers

Specimen ID	Diameter of TiABs	Product Code	Number of Tests	Description
A1	0.625 inch	05ZBA	1	Use Coupler 'A' for #5 pseudo-threaded bar
A2	0.750 inch	06ZBA	1	Use Coupler 'A' for #6 pseudo-threaded bar
A3	1.750 inch	14ZBA	1	Use Coupler 'A' for #14 smooth bar
B1	0.625 inch	05XL	1	Use Coupler 'B' for #5 pseudo-threaded bar
B2	0.750 inch	06XL	1	Use Coupler 'B' for #6 pseudo-threaded bar
C1, C2, C3	0.625 inch	XT05F and XT05M	3	Use Coupler 'C' on #5 bar
C4, C5, C6	0.750 inch	XT06F and XT06M	3	Use Coupler 'C' on #6 bar

Tension Test with Coupler 'A'

- #5 Bar, #6 Bar and #14 Bar
- % Change in Diameter

  A1: 0.46%

  A2: 1.6%

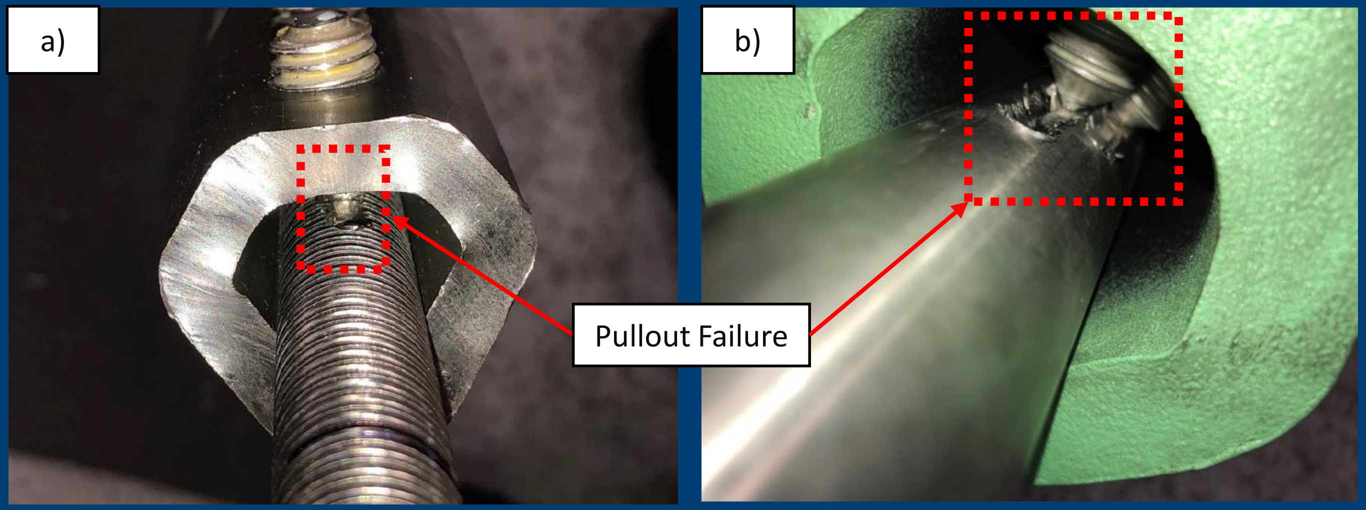
  A3: 0%
- % Change in Length

  A1: 1.0%

  A2: 2.2%

  A3: 1.0%

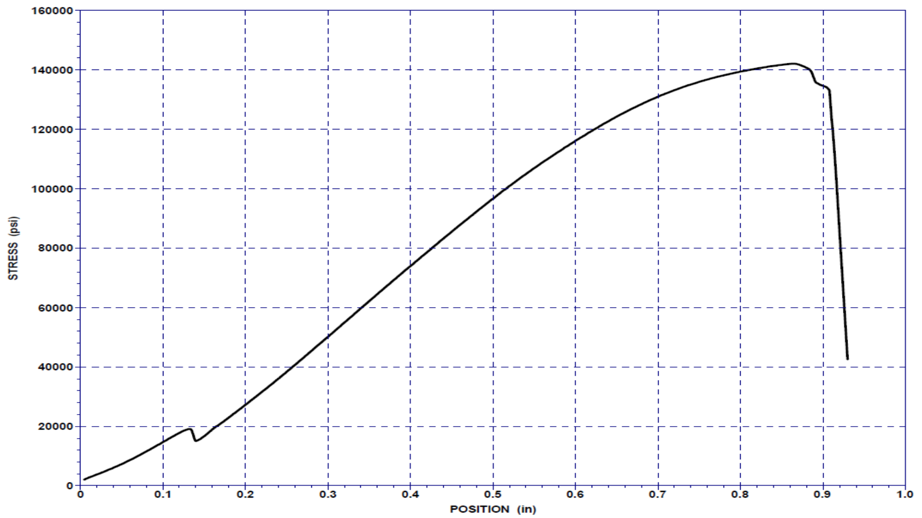
Specimen	Diameter of TiABs	Max Load (lb.)	Stress Value (psi)	Failure Mode
A1	0.625	44,040	142,065	Pullout
A2	0.750	58,020	131,864	Pullout
A3	1.500	160,485	90,823	Pullout



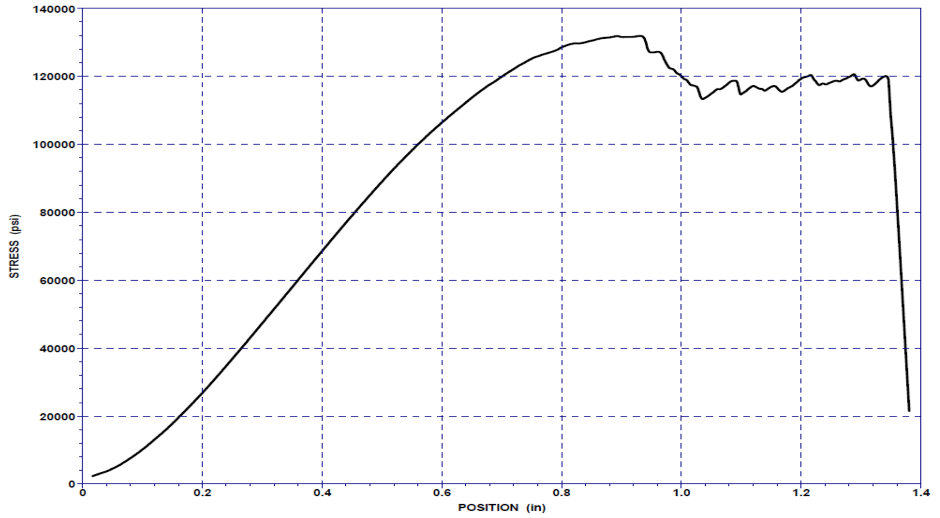
A1 Specimen

A3 Specimen

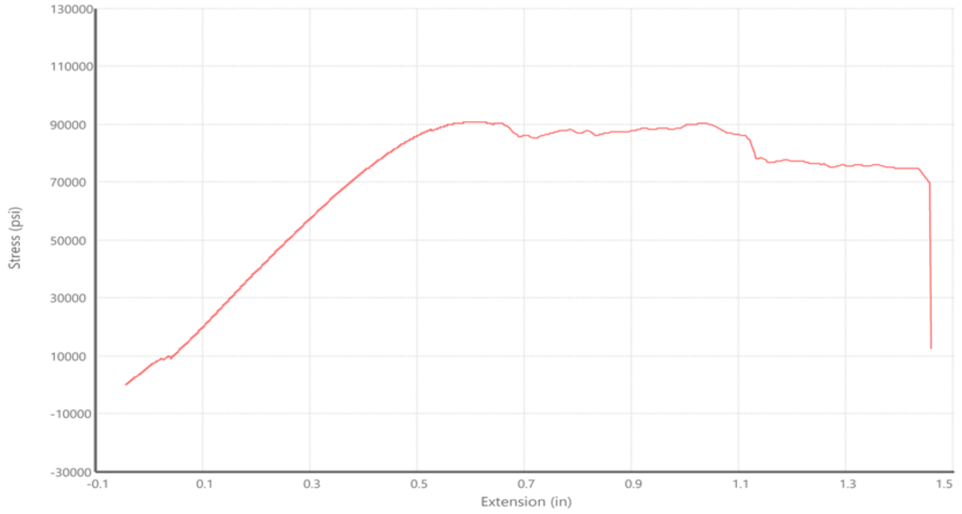
Tension Test with Coupler 'A'



A1 Specimen



A2 Specimen



A3 Specimen

Tension Test with Coupler 'B'

- #5 Bar, and #6 Bar
- % Change in Diameter

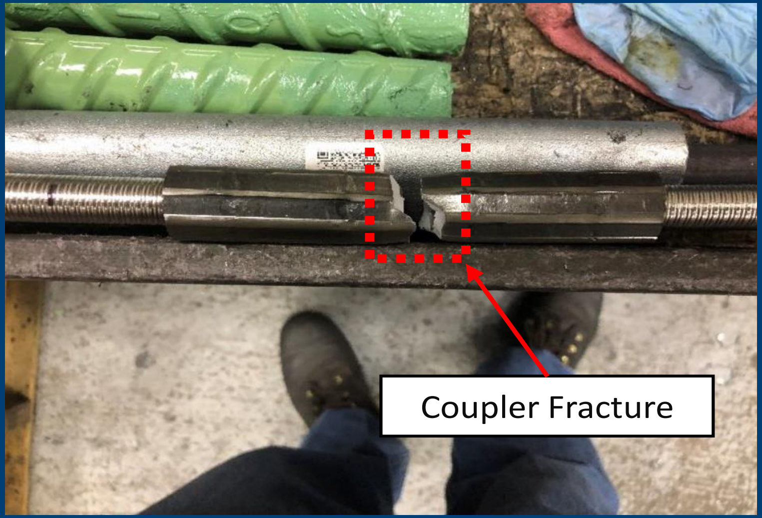
  B1: 0.2%

  B2: 0.4%
- % Change in Length

  B1: 0.2%

  B2: 2.2%

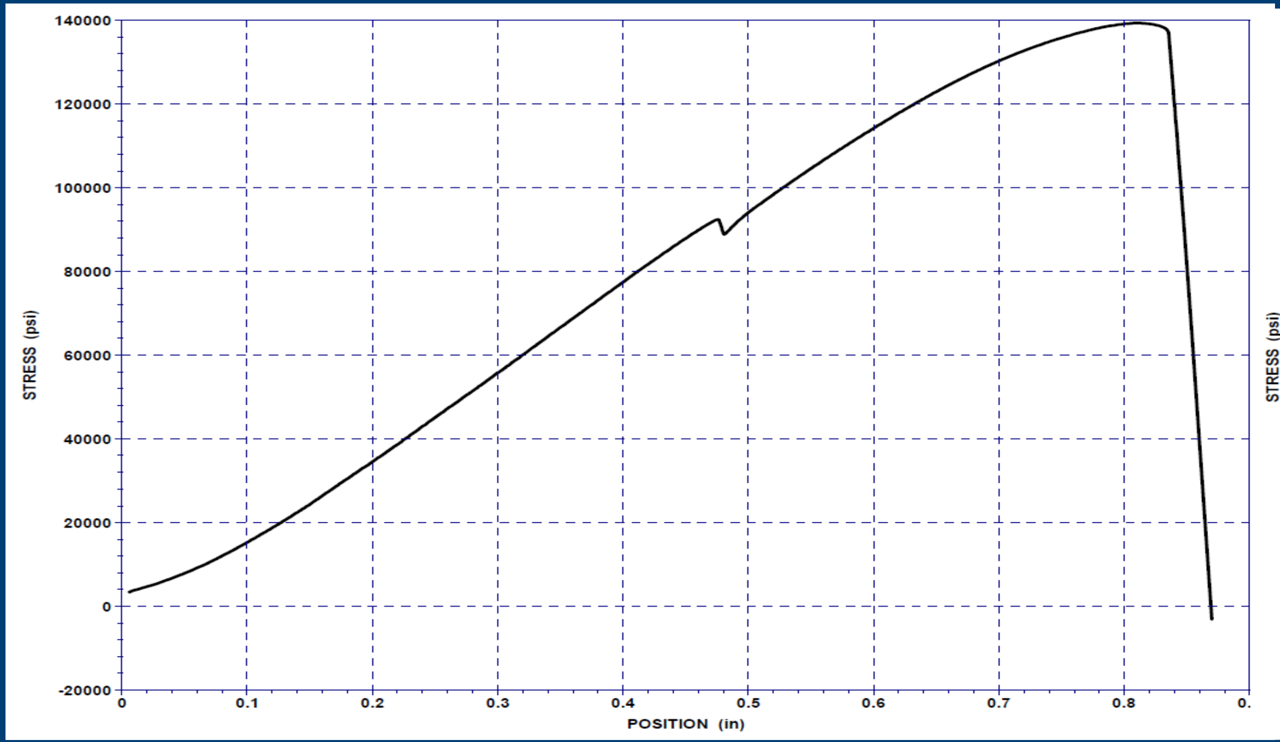
Specimen	Diameter of TiABs	Max Load (lb.)	Stress Value (psi)	Failure Mode
B1	0.625	43,190	139,323	Coupler Fracture
B2	0.750	63,860	145,136	Coupler Fracture



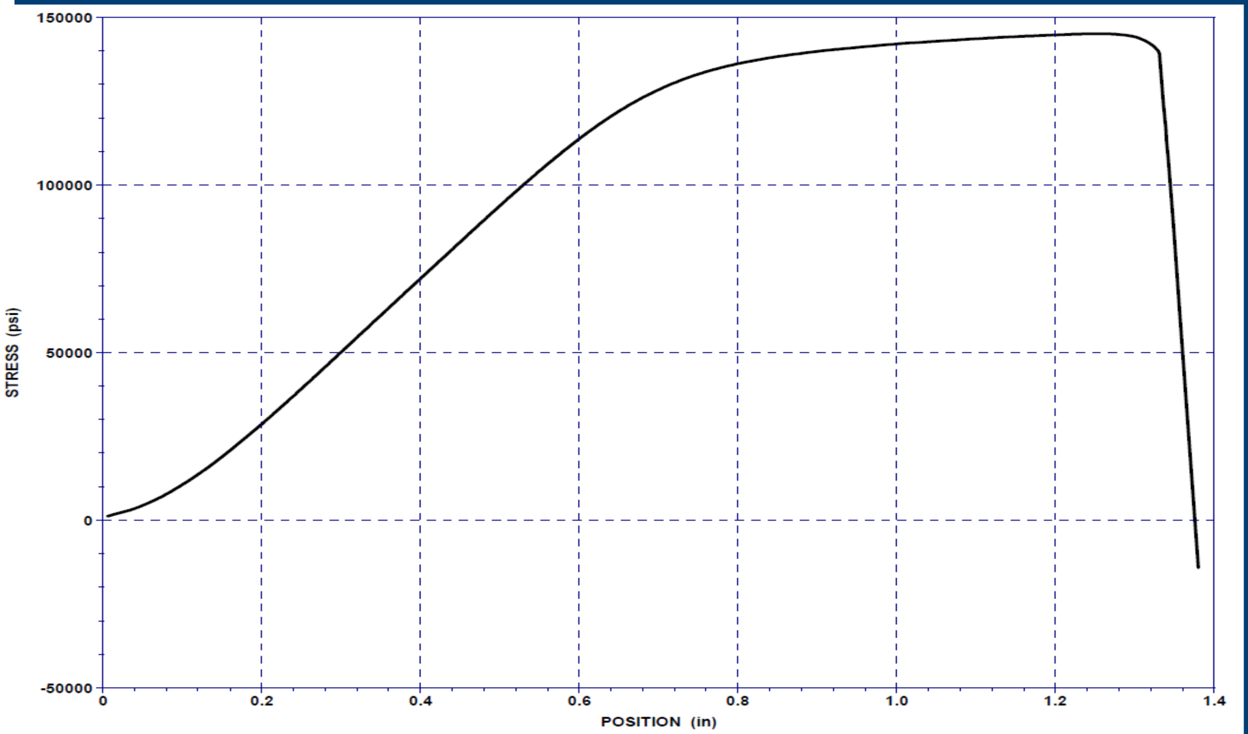
B1 Specimen

- Not able to withstand full tensile capacity of bar
- Successfully gripped the bar
- Failure in middle of bar

Tension Test with Coupler 'B'



B1 Specimen



B2 Specimen

Tension Test with Coupler 'C'

- #5 Bar, and #6 Bar
- % Change in Diameter

  C1 and C3: 8.3%

  C2: 1%

  C4, C5 and C6: 9%
- % Change in Length

  C1 and C3: 3%

  C2: 1.2%

  C4, C5 and C6: 3.1%

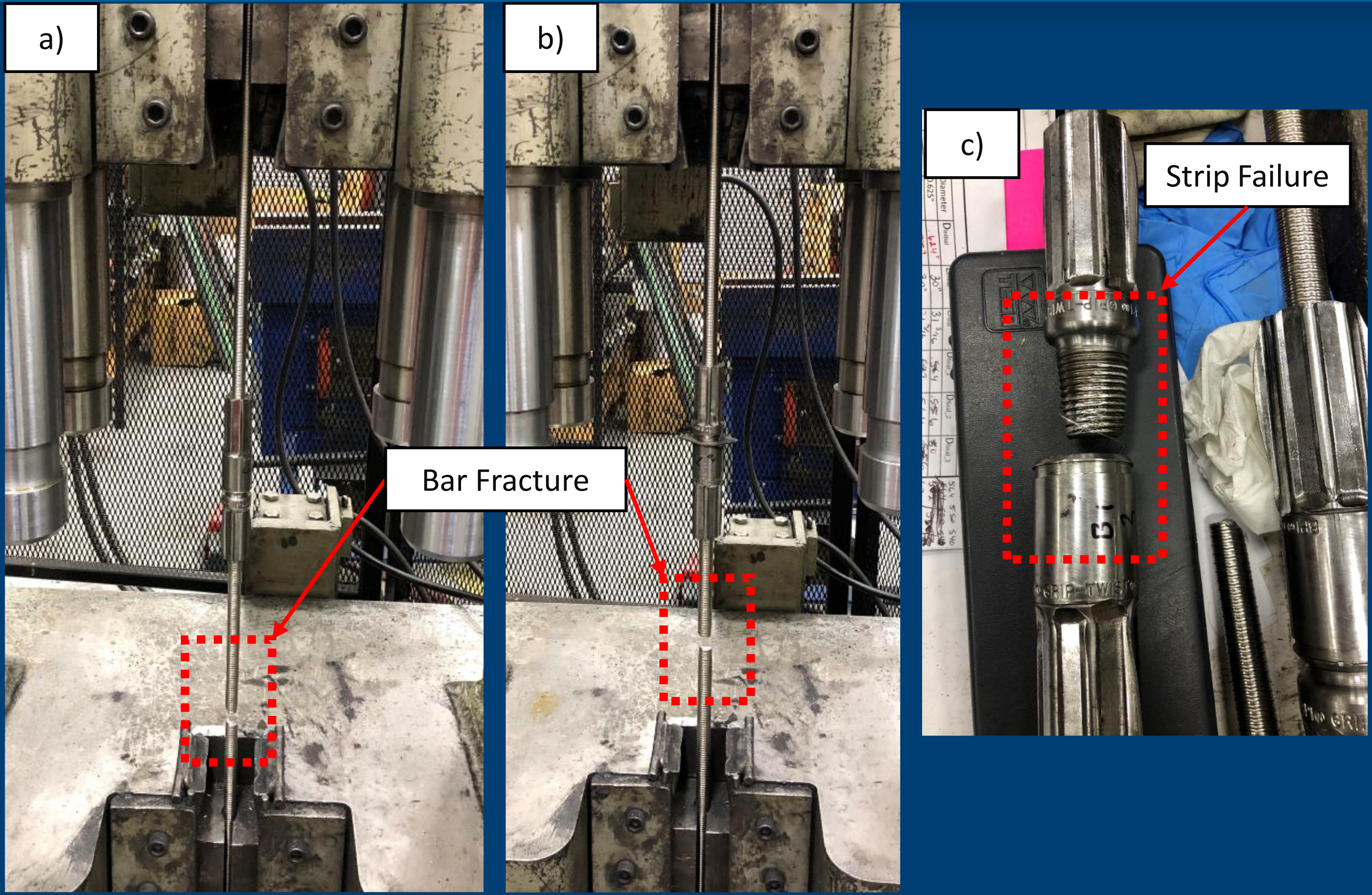
Specimen	Diameter of TiABs	Max Load (lb.)	Stress Value (psi)	Failure Mode
C1	0.625	48,680	157,035	Bar Break
C2	0.625	49,260	158,917	Thread Strip
C3	0.625	49,270	158,950	Bar Break
C4	0.750	67,840	154,187	Bar Break
C5	0.750	67,660	153,776	Bar Break
C6	0.750	67,490	153,393	Bar Break

- All specimen except C2 had bar fracture
- Failure away from splice area
- Thread strip failure indicates that test pushed coupler material near its limit
- All other tests bar break

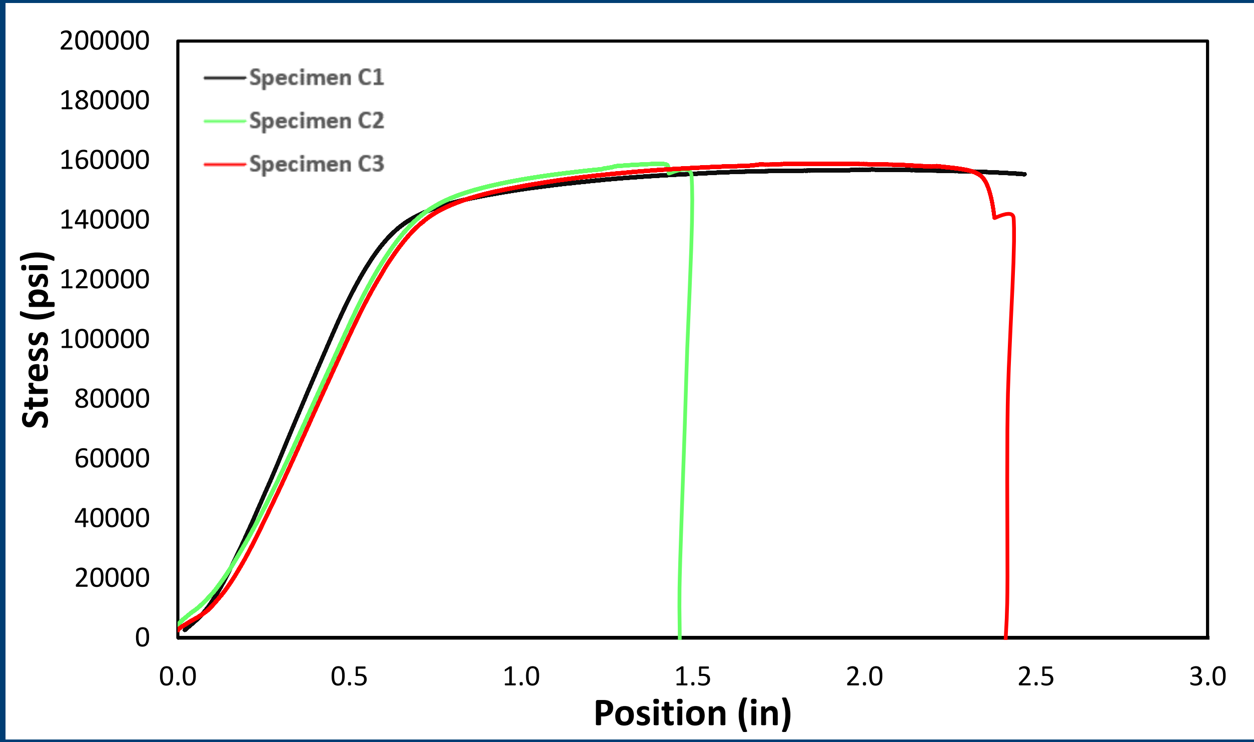
Tension Test with Coupler ‘C’

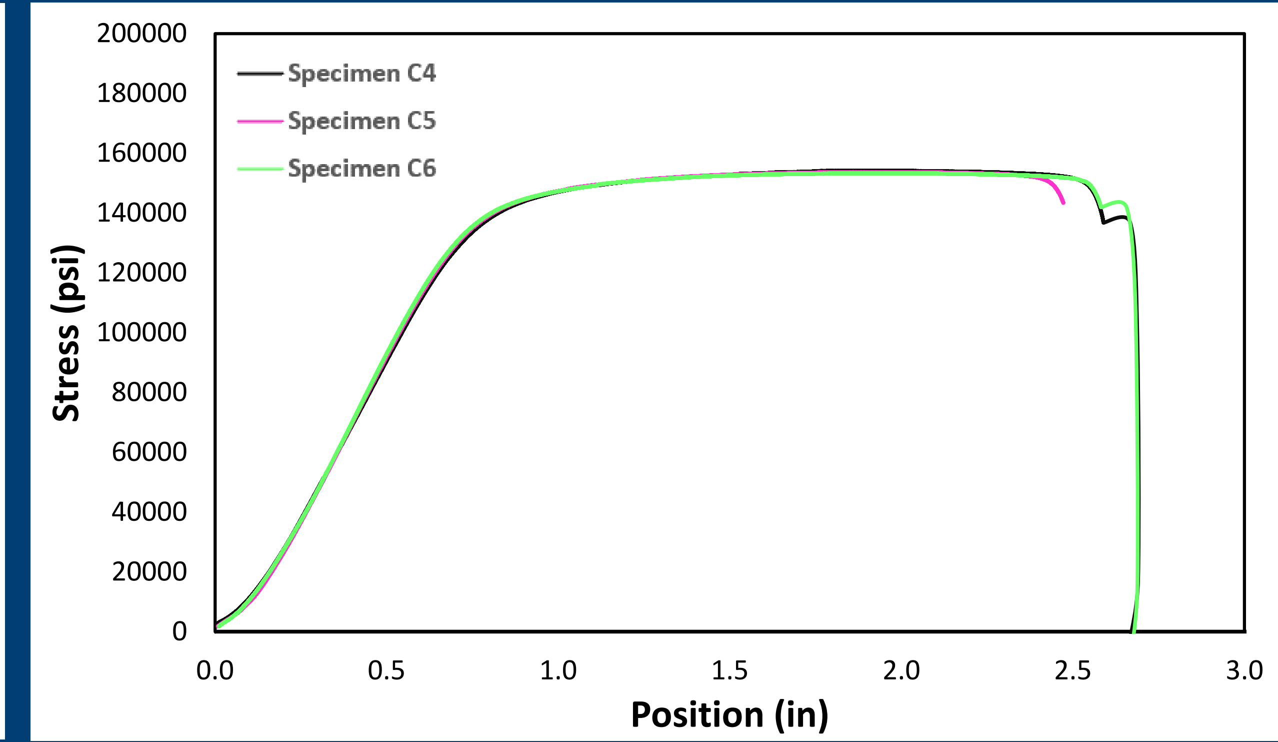
- Appropriate and acceptable for splicing pseudo-threaded TiABs
- AASHTO LRFD-Specimens should achieve > 125% of yield strength of the bar (Only 120% achieved) – This is acceptable
- Normal steel used to make coupler material goes to strain hardening. TiABs and Steel has different strain hardening
- TiABs do not carry large overstrength (strain hardening) factor compared with normal or high-strength rebars
- TiABs have an elastic-perfectly plastic type of behavior under tensile loads. Overstrength factor is generally about 1.1 compared with 1.5 or similar for normal rebars

Tension Test with Coupler 'C'



Tension Test with Coupler 'C'





Conclusions

- To keep the quantity of TiABs limited (because of higher cost), tensile tests on spliced TiABs were performed to identify and explore suitability of some available splicing systems for TiABs
- Coupler 'C' (uses cold swaged steel sleeve and is thicker) produced by Producer 'X' seemed to be appropriate mechanical coupler for splicing pseudo-threaded TiABs because testing was successful in pushing failure away from splice.
- Results of testing show that TiABs have good potential for applications in civil infrastructure. But, further investigation into the use of TiABs in concrete is still needed.

Acknowledgements

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Thank you

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