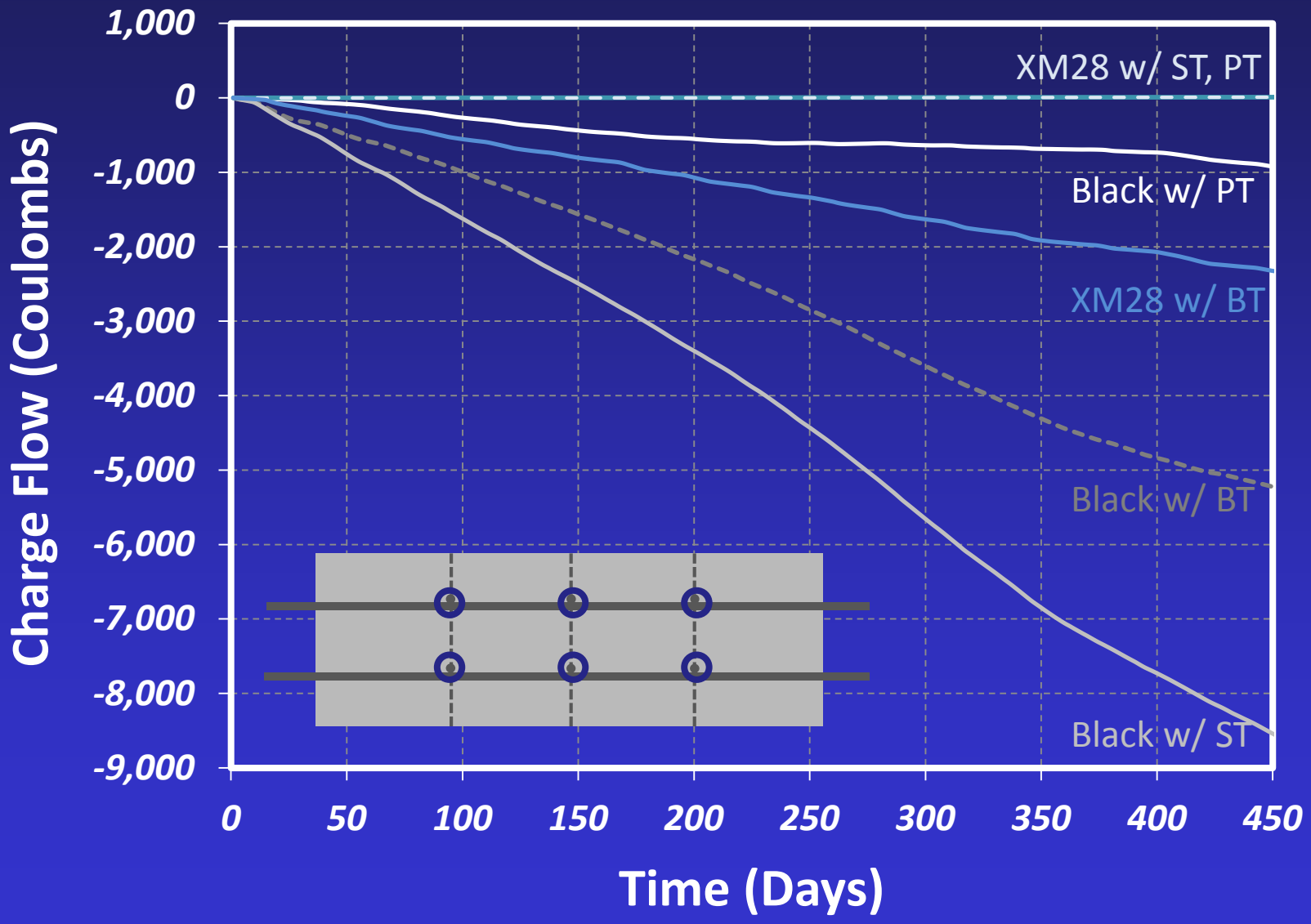
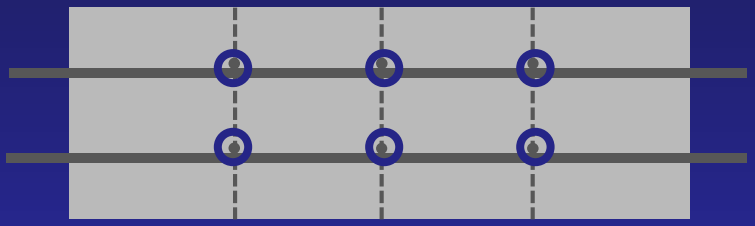
Different Tie Material



Autopsy Results

Cracked specimens with different ties

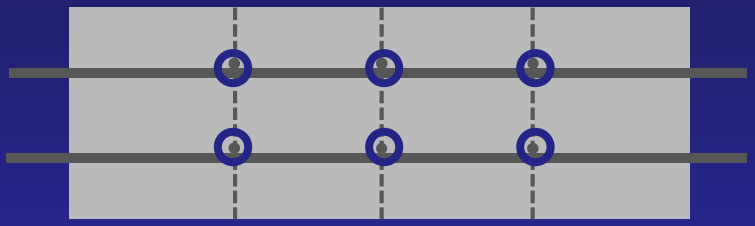


Black w/ BT

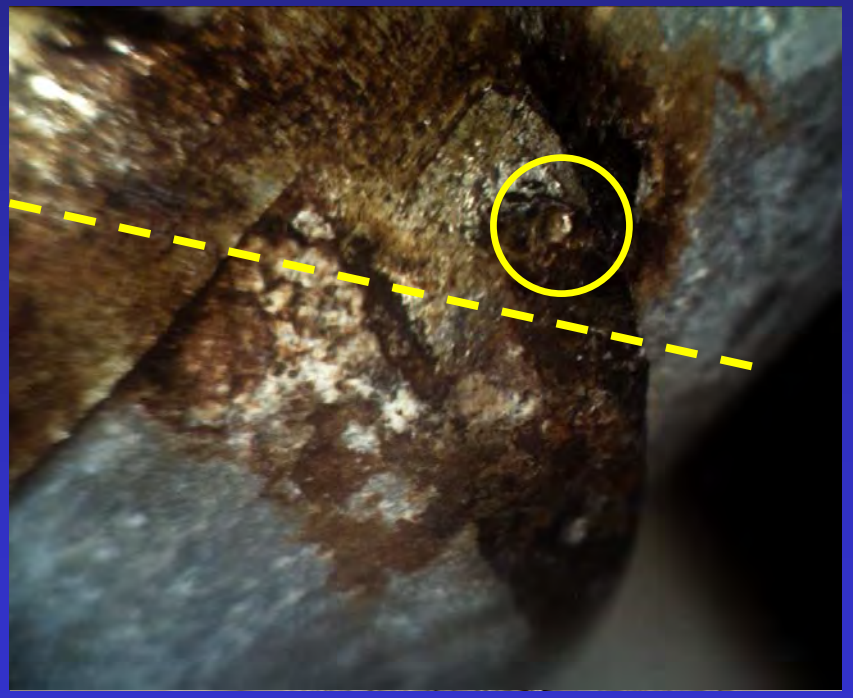
Black w/ST

Autopsy Results

Cracked specimens with different ties



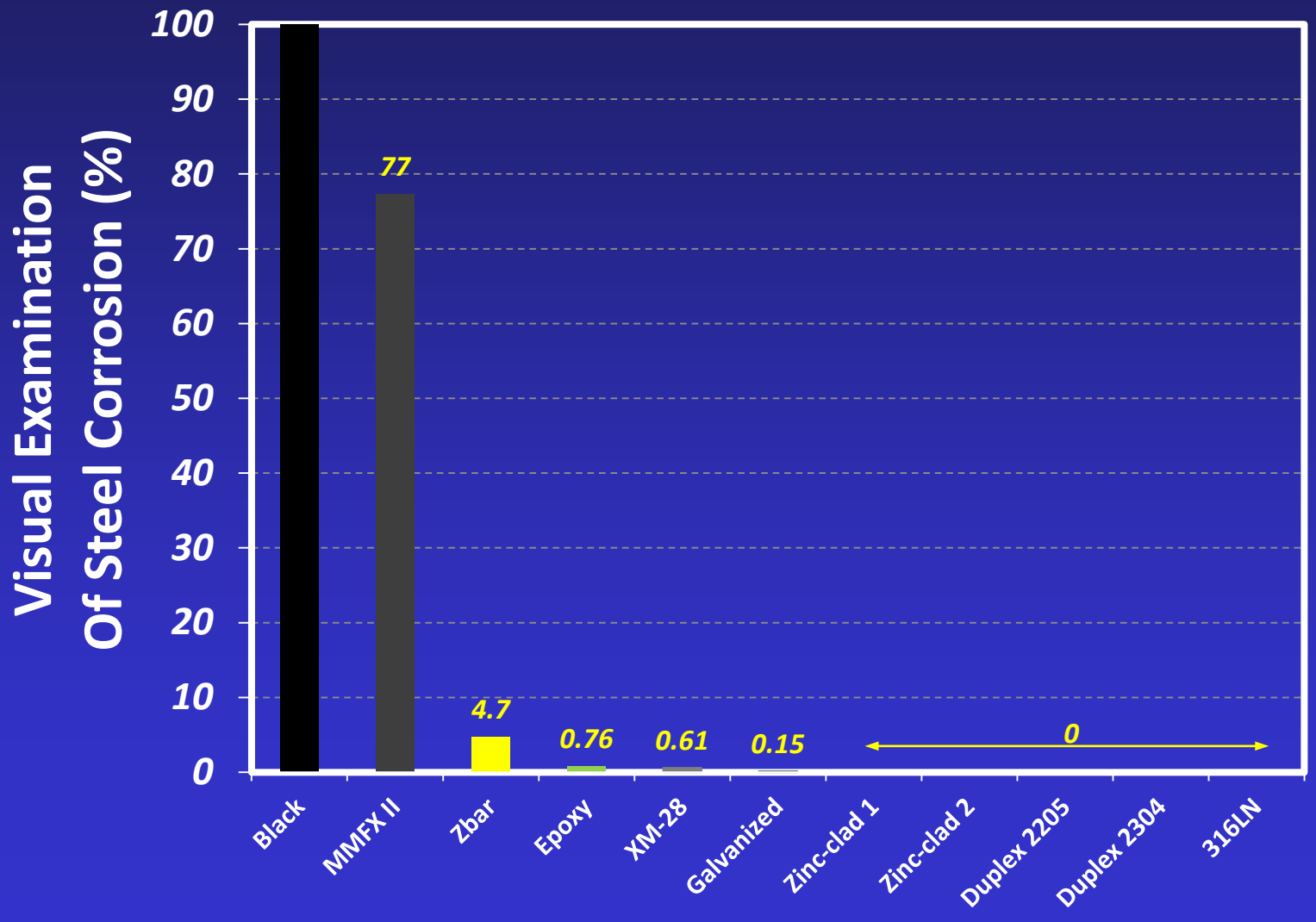
XM28 w/ BT



Microscopic View

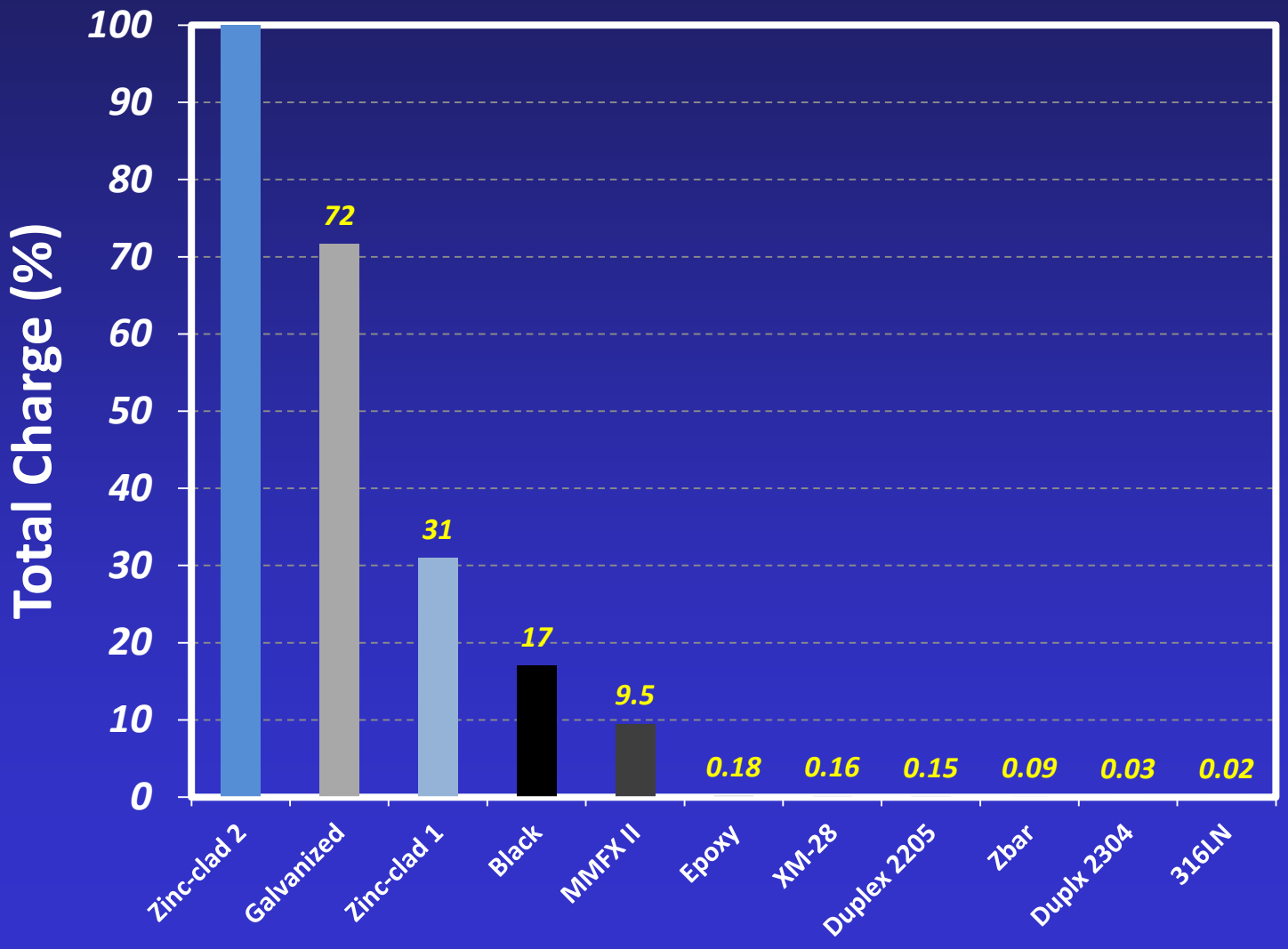
Visual Examination of Steel Corrosion

(Cracked - Identical mats)



Total Charge

(Cracked - Identical mats)



Corrosion Resistance of Reinforcing Bars

- Selection of corrosion resistant bars after 503 days of testing:

Rank	Bar Type	Corrosion Performance
1	316LN	Best
2	Duplex 2304	
3	Duplex 2205	
4	Zinc-clad	
5	Galvanized	
6	XM-28	
7	Zbar	
8	Epoxy	
9	MMFX II	
10	Black	Worst

Findings

- Dissimilar mats cause galvanic corrosion

  Use identical material

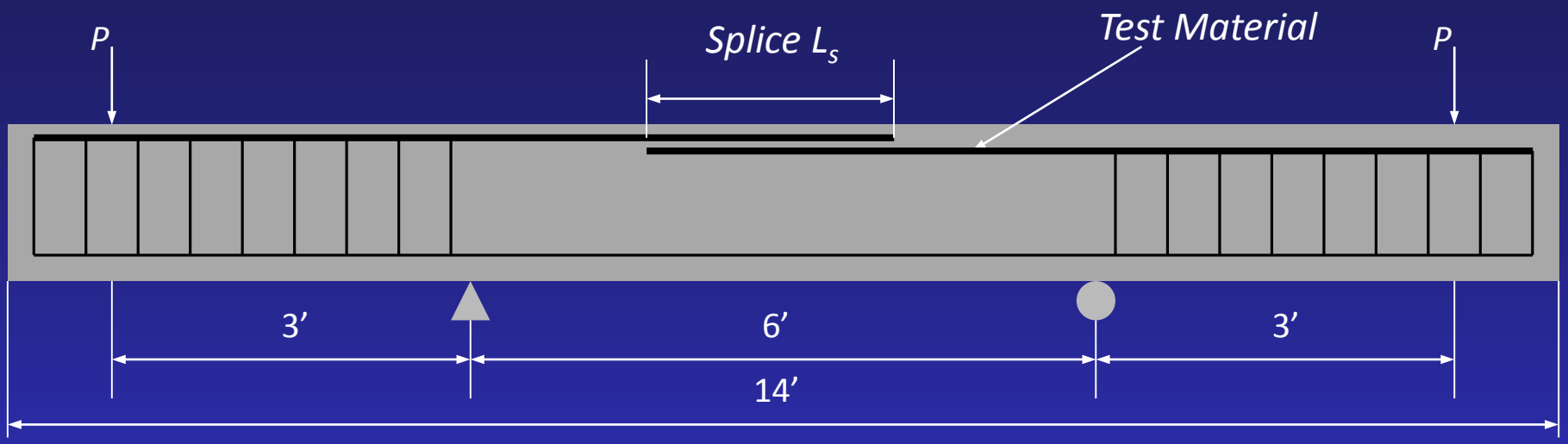
- Dissimilar metallic ties cause galvanic coupling

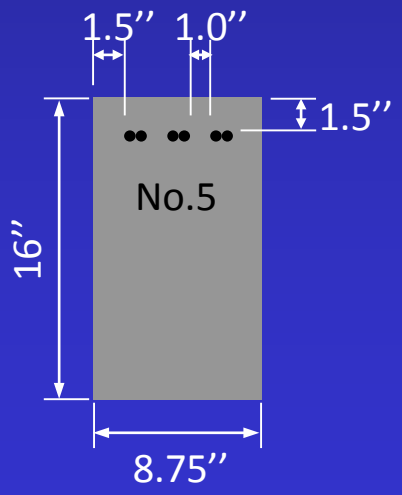
  Use inert (plastic) ties or

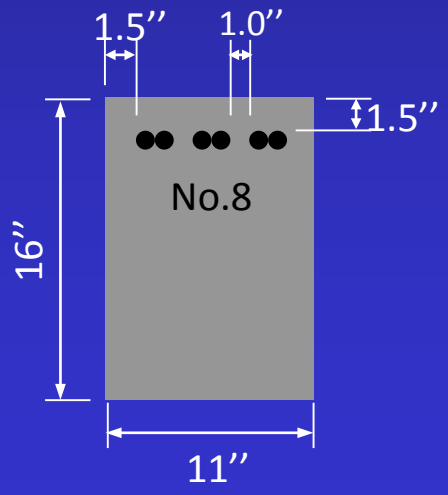
  Ties with identical material to rebar

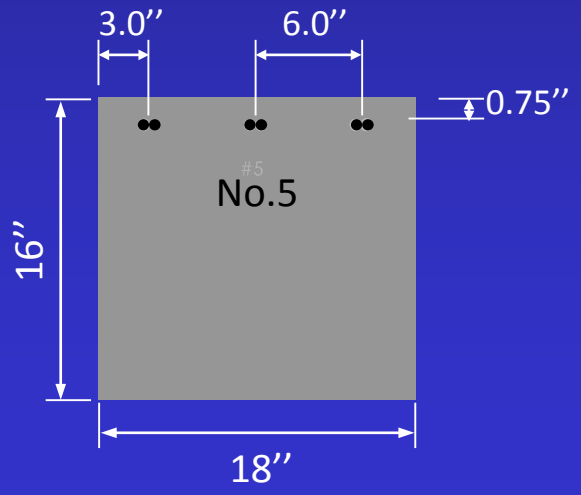
Bond Strength

Lap-splice beam specimen



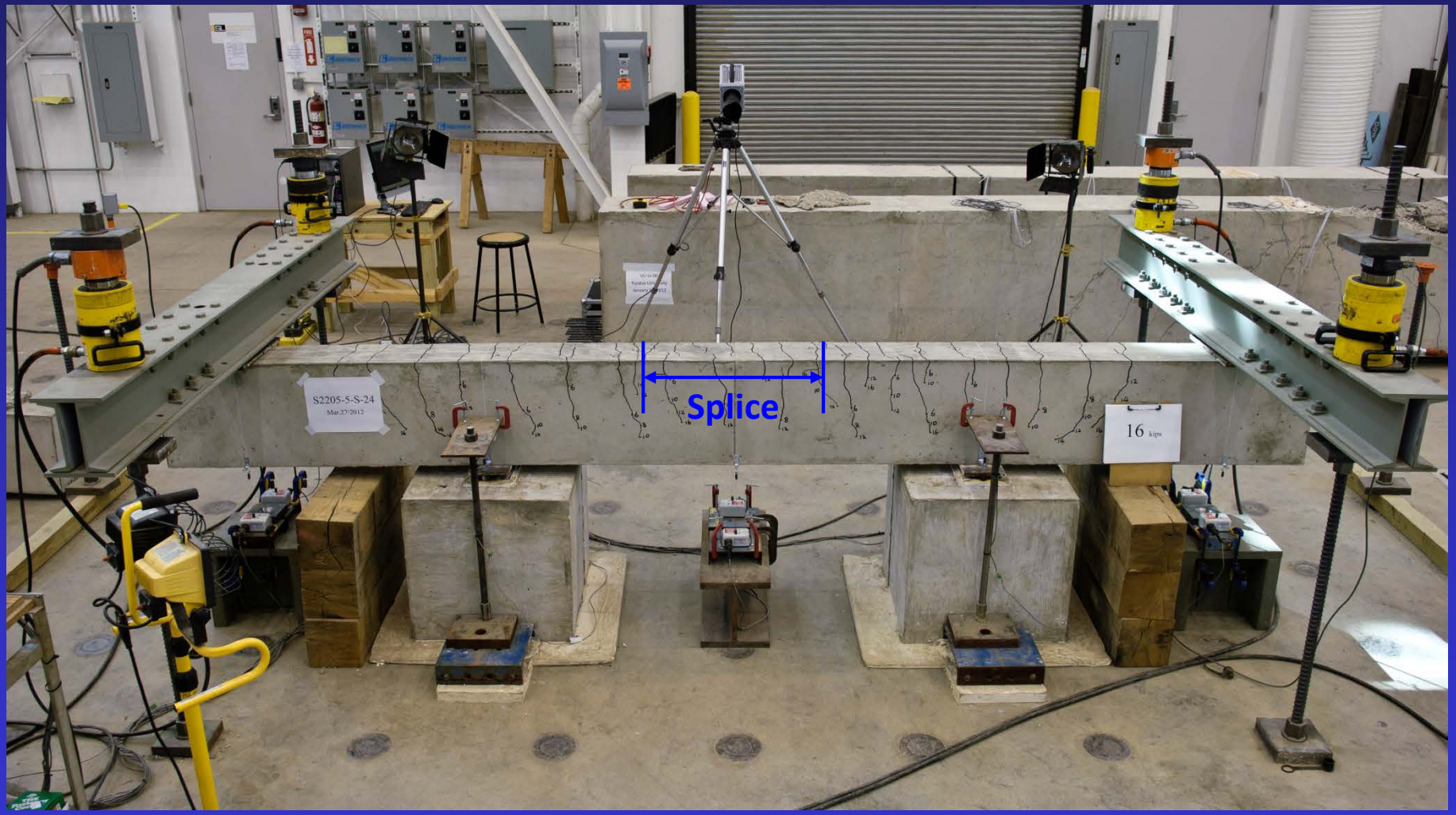




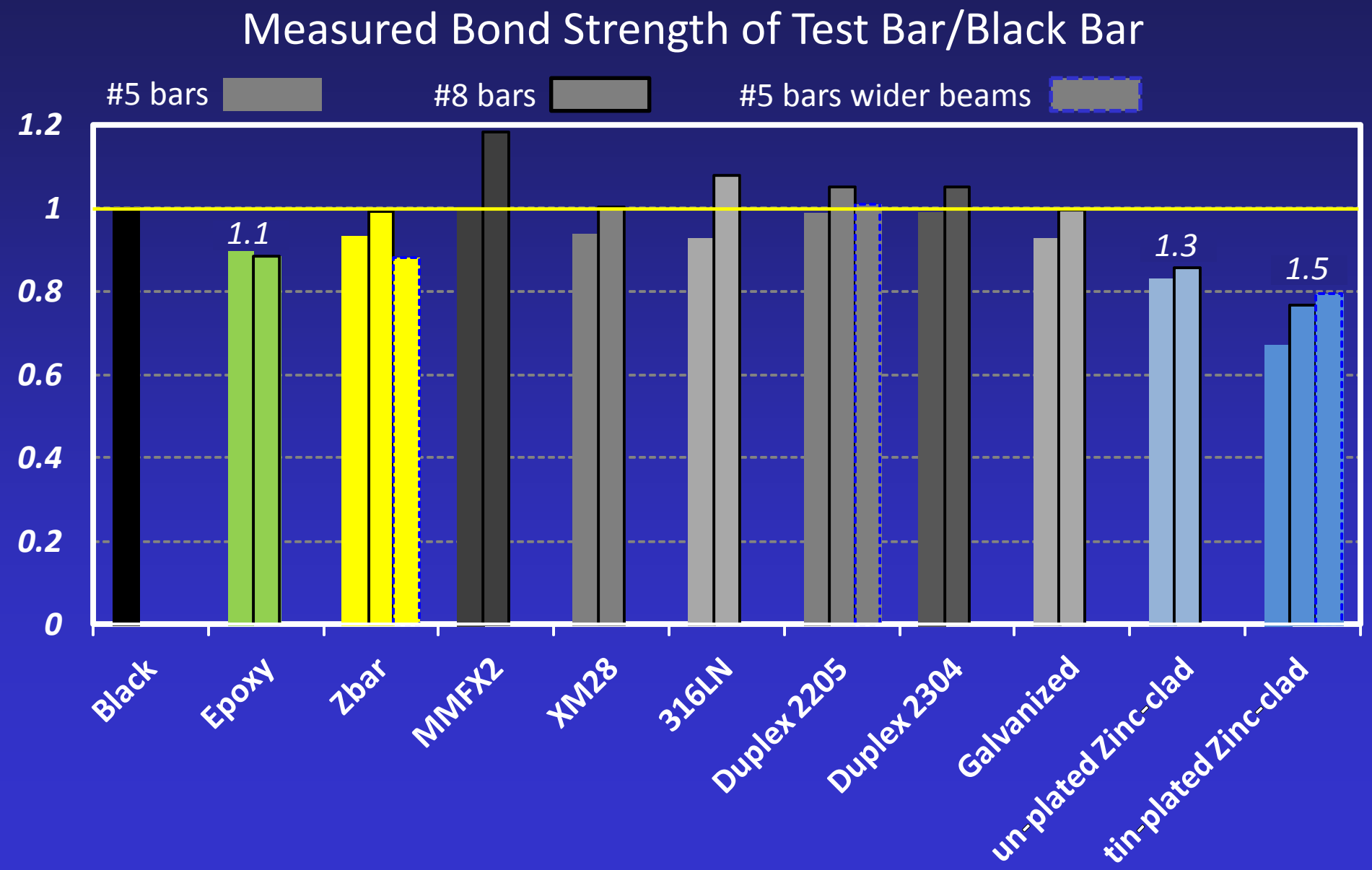


Construction of Lap-splice beams

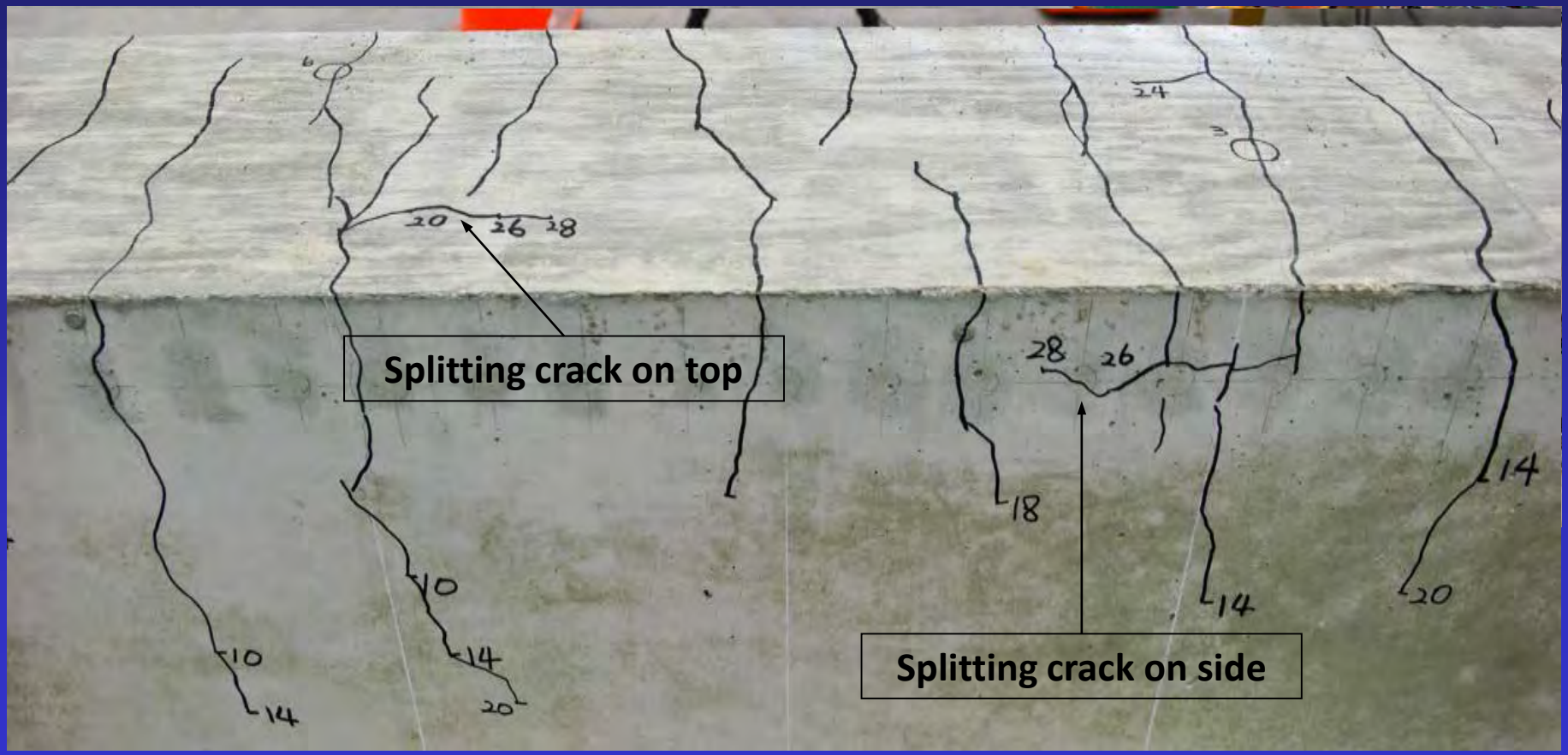
Test Set-up



Bond Ratio

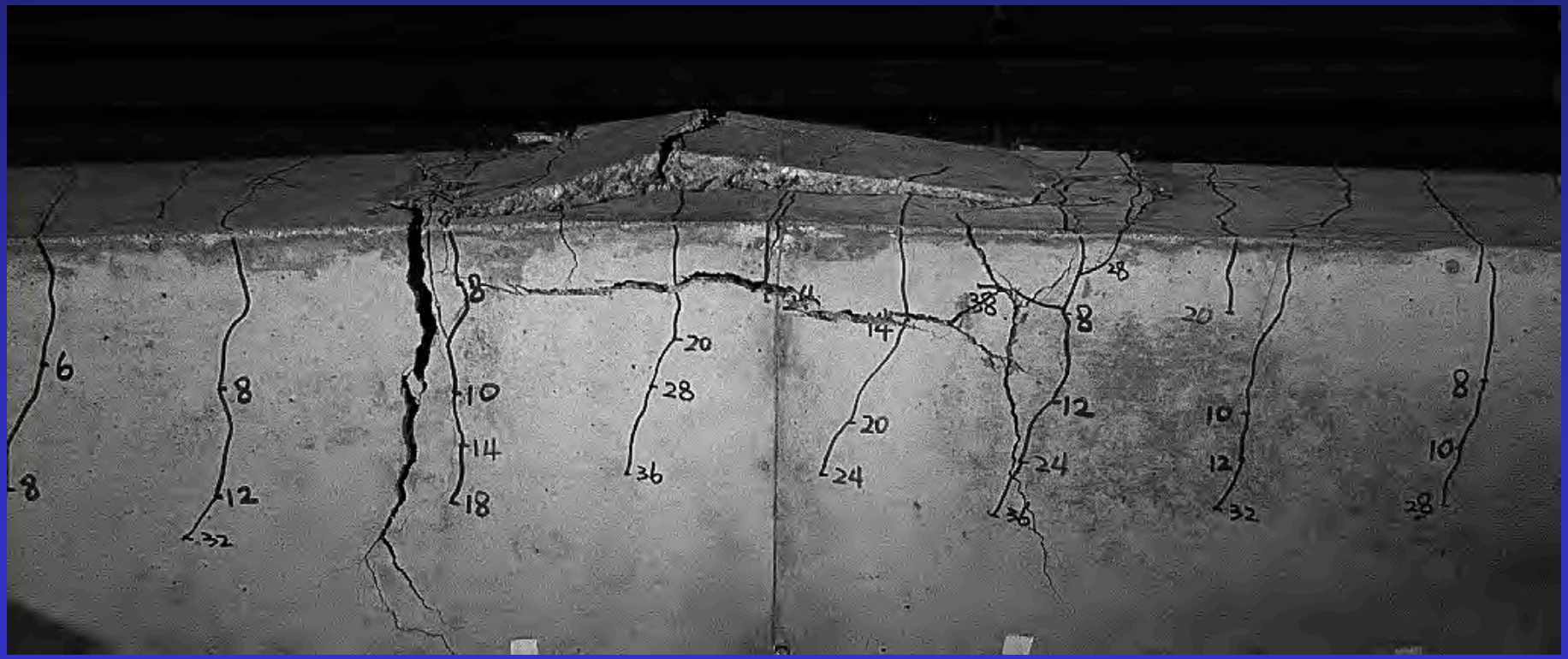

Measured Bond Strength of Test Bar/Black Bar
#5 bars
#8 bars
#5 bars wider beams
1.2
1
0.8
0.6
0.4
0.2
0
1.1
1.3
1.5
Black
Epoxy
Zbar
MMFX2
XM28
316LN
Duplex 2205
Duplex 2304
Galvanized
un-plated Zinc-clad
tin-plated Zinc-clad

Splitting Cracks prior to Failure



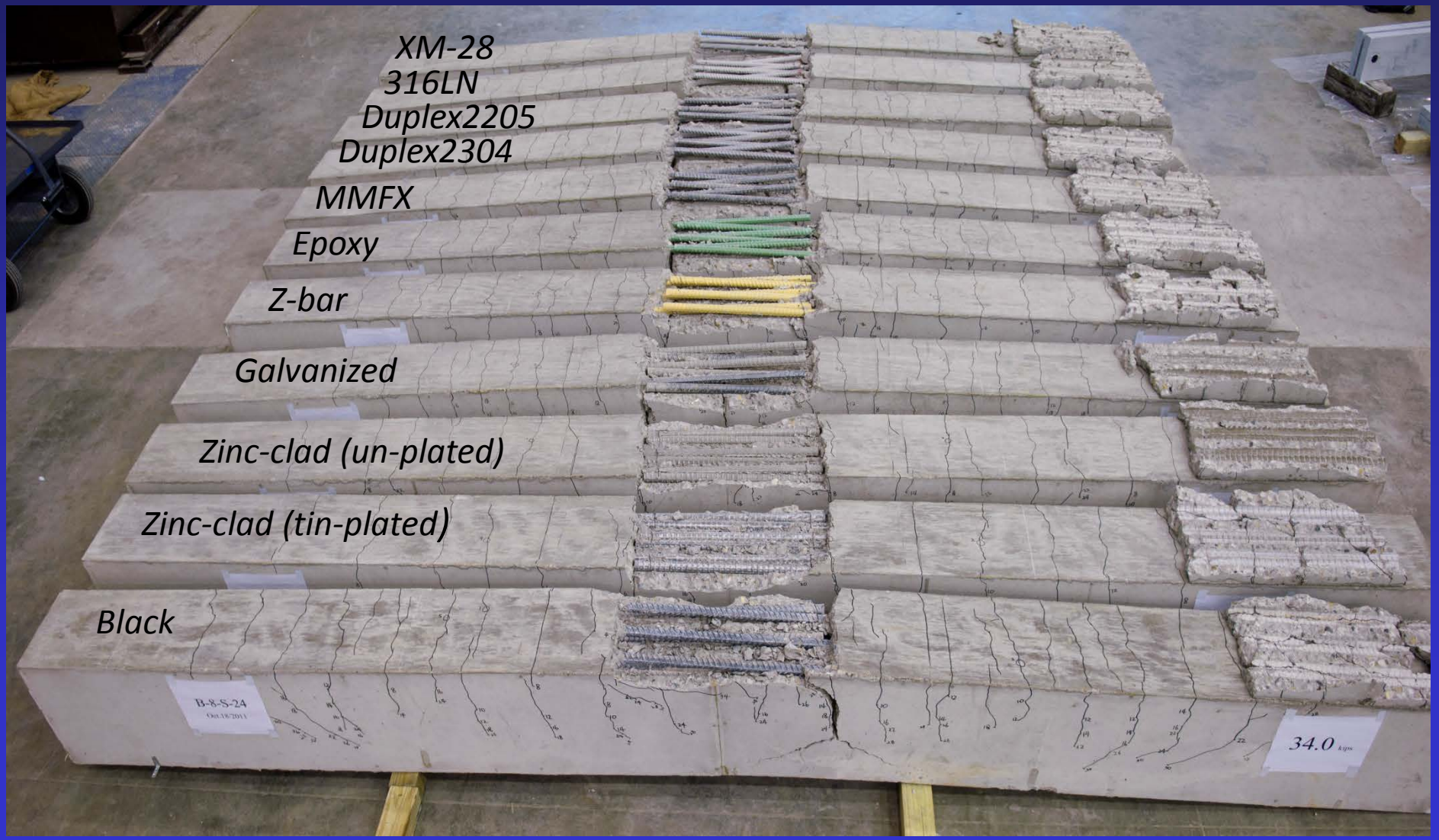
Failure Modes

Face and Side Splitting Mode (Black, #8 bars, 24 in. splice, Confined)



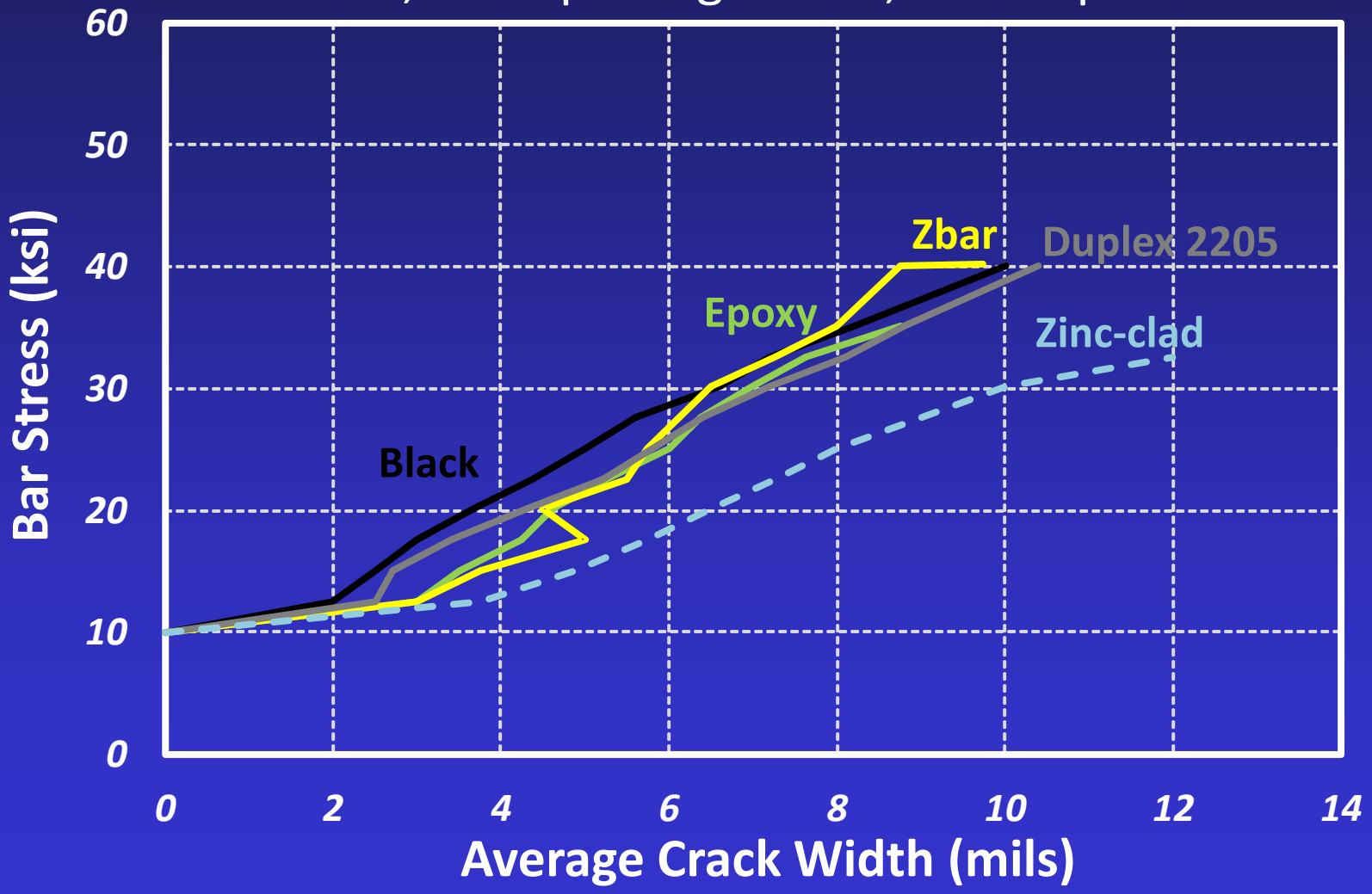
Crack Pattern

No.8, side splitting failure, 24 in. splice

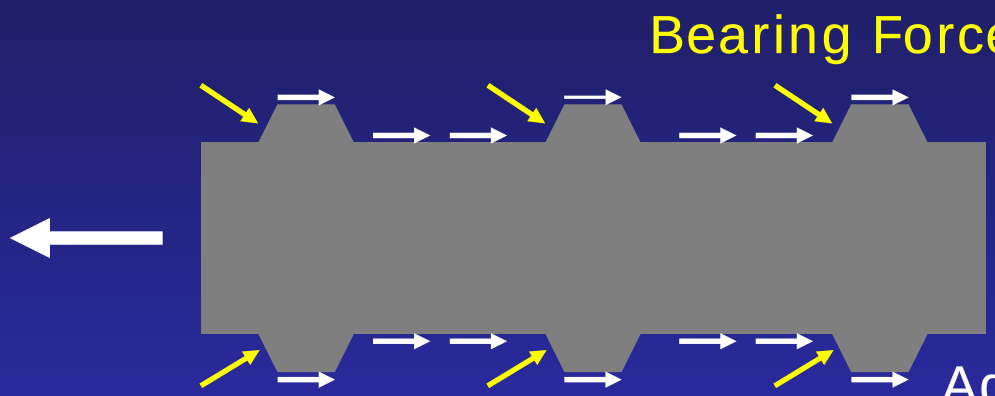


Bar stress vs. crack width

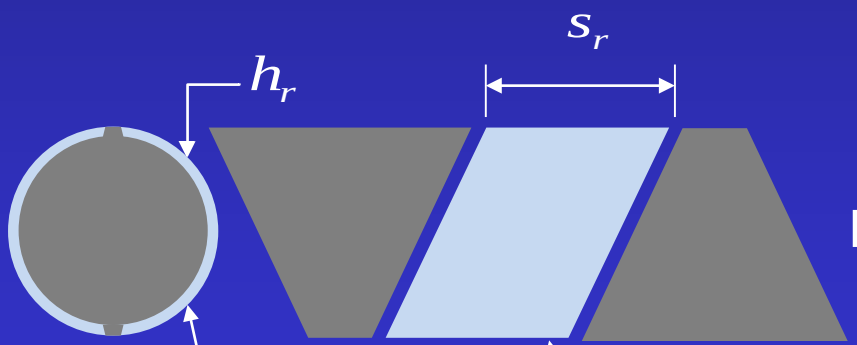
No.8, side splitting failure, 24 in. splice



Bond Force Transfer Mechanism



Adhesion and Friction Forces along the surface



Relative Rib Ratio $R_r \approx \frac{h_r}{s_r}$

Bearing Area

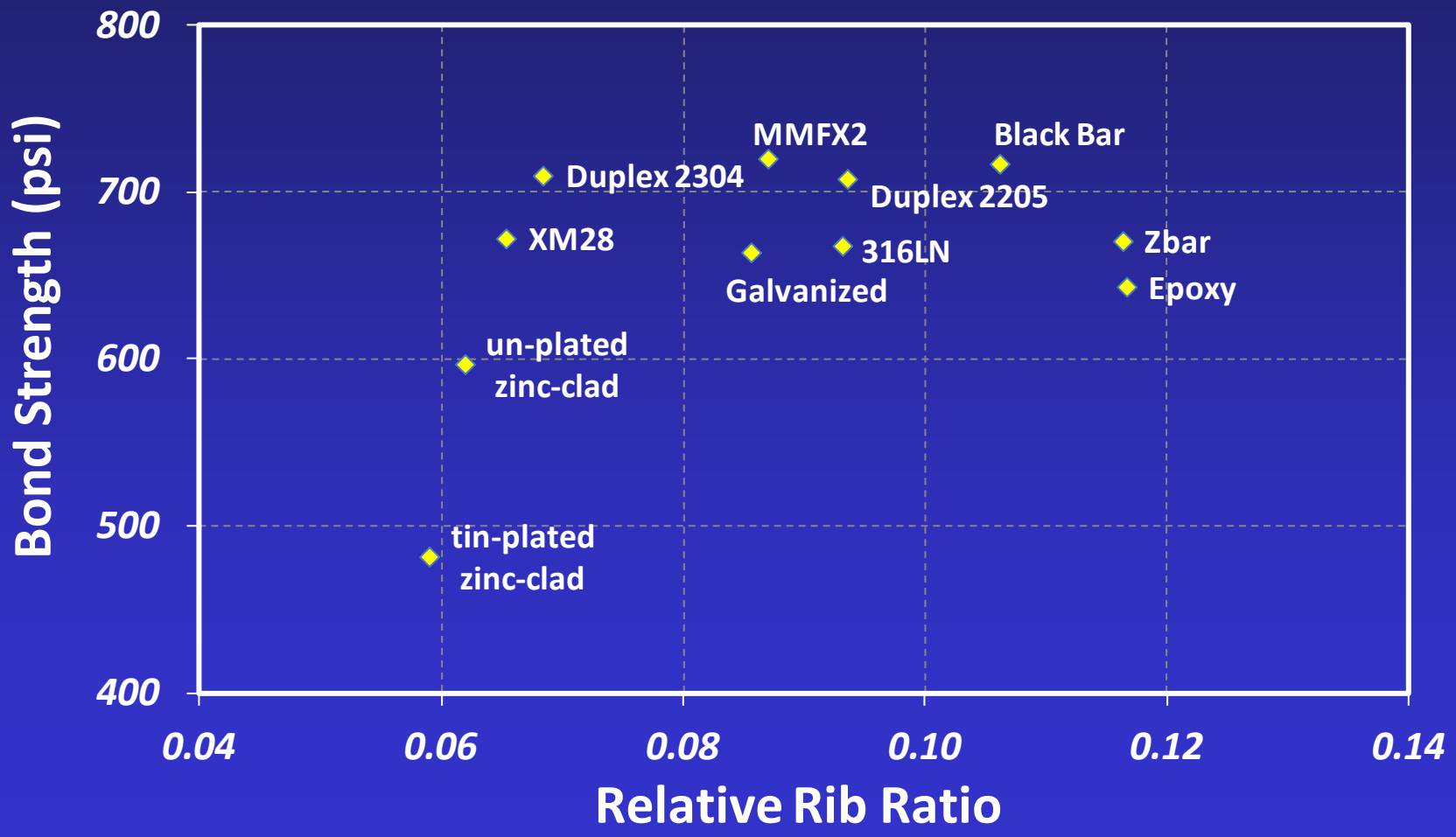
$A_r \approx h_r \pi d_b$

Shearing Area

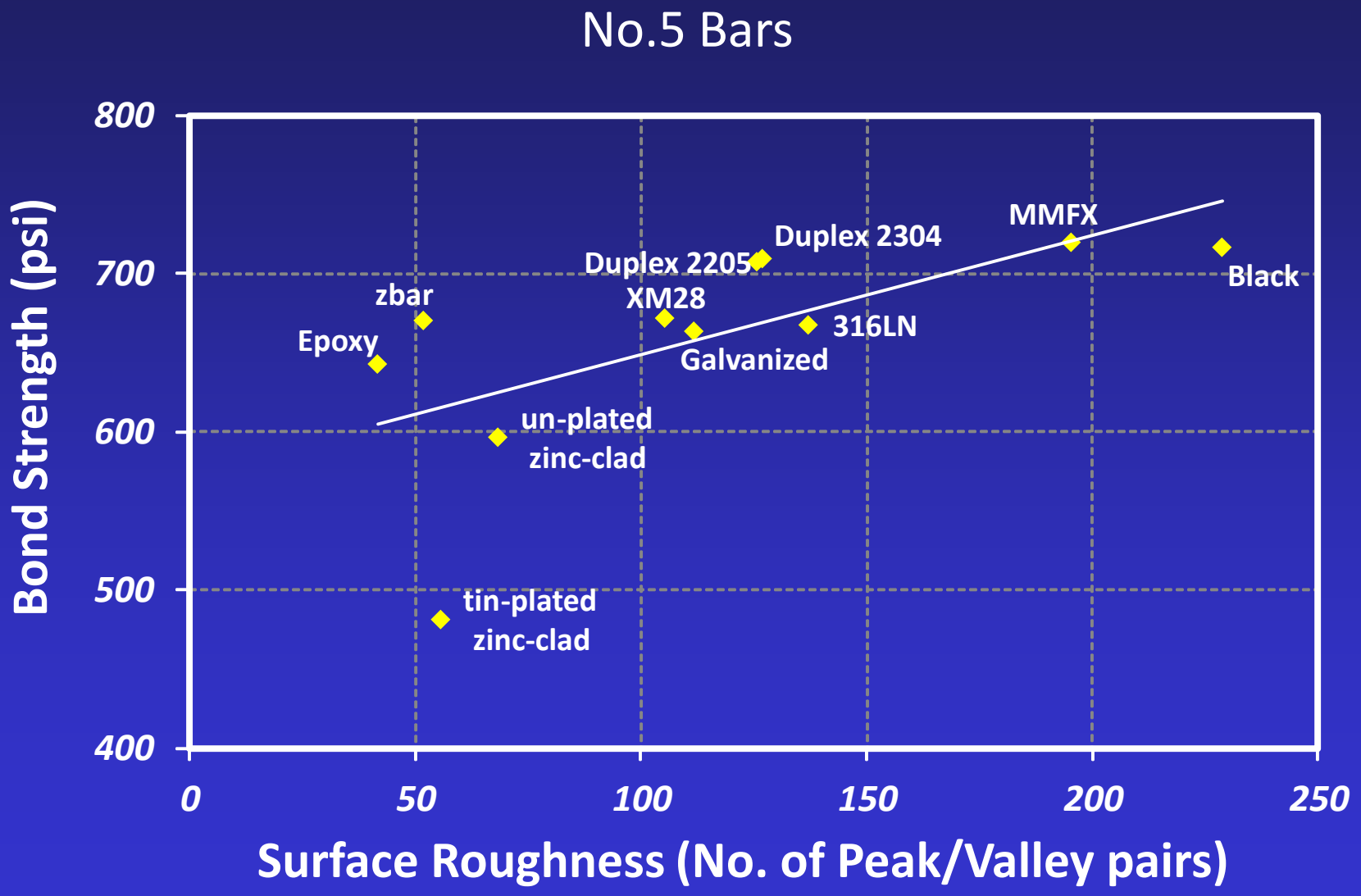
$\pi d_b s_r$

Effect of Relative Rib Ratio

No.5 Bars

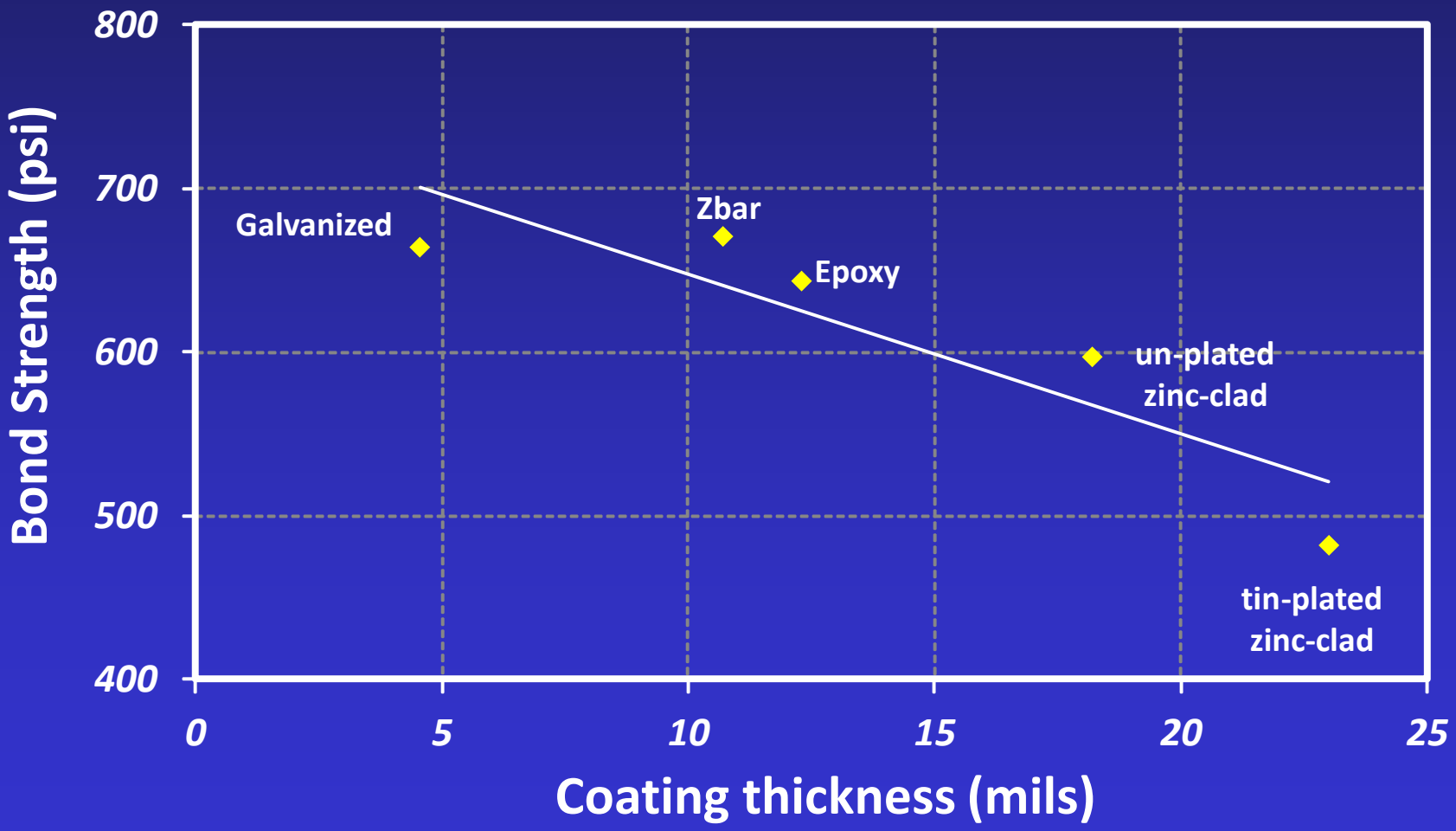


Effect of Surface Roughness



Effect of Coating Thickness

No.5 Bars



Findings

- Bond Ratio
  - MMFX2, Duplex 2205, Duplex 2304, 316LN = Black
  - Black > XM28 (97%), Galvanized (96%), Zbar (94%) > Epoxy (89%) > Zinc-clad (79%)
- Relative Rib Ratio
  - Low influential to bond strength
- Surface Roughness and Coating Thickness
  - High correlation to bond strength

Summary

- Stainless steel rebar
  - Pros: corrosion-resistant, comparable bond strength with conventional steel
  - Cons: Initial construction cost high, pitting or crevice corrosion (XM-28), galvanic corrosion
- Galvanized and Dual-coated rebar
  - Pros: corrosion-resistant, comparable bond strength, relatively lower cost than stainless steel bars
  - Cons: corrosion-resistance drops when all zinc is consumed, thicker coating will decrease bond strength

Summary

- MMFX II rebar
  - Pros: high-strength, comparable bond strength with conventional steel
  - Cons: galvanic corrosion
- Zinc-clad bar
  - Pros: corrosion-resistant
  - Cons: reduction in bond strength, relative cost compared to galvanized bar is higher
- Epoxy-coated rebar
  - Pros: cost comparable to conventional steel
  - Cons: damage in coating, debonding

Questions?

Price

- $/lb/ft
  - Carbon Steel: $0.5
  - Epoxy Coated: $0.55 (1.1 times more than black)
  - Zbar: $0.75 (1.5 more than black)
  - Galvanized: $0.75 (1.5 more than black)
  - Zinc-clad: $1.75 (3.5 more than black)
  - XM-28: $2.0 (4 more than black)
  - Duplex 2205: $2.25 (4.5 more than black)
  - Duplex 2304: $2.25 (4.5 more than black)
  - 316LN: $3 to 4 (6 to 8 more than black)