Prepare, Repair, and Prepare Concrete and Cementitious Surfaces Prior to Topcoating with High-Performance Linings: *The dirty little secret about cementitious repair mortars used in wastewater repairs*

Vaughn O' Dea,
Tnemec Company, Inc.

PRESENTATION OVERVIEW

- Protecting Concrete
- Substrate Preparation
- Mortar Repairs
- Cementitious Mortar Preparation

Why Protect Concrete in Wastewater Systems?

PROTECTING CONCRETE

High-Performance Protective Coatings are commonly employed to protect concrete:

- Provide a surface that is resistant to immersion, splashes, spills, and vapors from corrosive solutions
  - Acid attack
  - Alkali attack
  - Sulfates
- Protect structural rebar from corrosion
  - Chlorides
- Protect and enhance concrete integrity
  - Mechanical damage and wear

PROTECTING CONCRETE

Required per Code:

- ACI 350 Code Requirements for Environmental Engineering Concrete Structures:

"Protective coatings & linings are to be used when concrete is in contact with chemical or corrosive gases which attack the cement mortar matrix or embedded steel."

§4.7.1

"[W]here protective coatings or liners shall be used to prevent contact of chemical solutions or gases which concrete surfaces, they shall be impervious and shall exhibit good bond."

[Ibid]

PROTECTING CONCRETE

ACI 350:

- Group 2 (sulfates)
  - Ferric sulfate
  - Copper sulfate
- Group 3 (corrosive chemicals): (*partial list)*
  - Alum
  - Aluminum sulfate
  - Calcium hypochlorite
  - Chlorine
  - Ferric chloride
  - Hydrogen sulfide gas
  - Ozone gas
  - Sodium hydroxide
  - Sodium or potassium salts
  - Sulfuric acid

PROTECTING CONCRETE

ACI 350: *(§4.5.11) (partial list)*

- Facilities and structures such as the following are to be protected when exposed to chemical attack:
  - Domestic and industrial wastewater treatment plants
  - [W]astewater pump stations
  - Conduits, sewers, manholes, and junction chambers
  - Hazardous materials containment structures

PROTECTING CONCRETE

Example: Secondary Containment (acid) Exposure

PROTECTING CONCRETE

Example: Ferric Chloride Exposure

PROTECTING CONCRETE

Example: Aluminum Sulfate Exposure

PROTECTING CONCRETE

Example: Sulfate & Chloride Exposures

PROTECTING CONCRETE

Example: Chlorine Exposure

PROTECTING CONCRETE

Biogenic Sulfide Corrosion:

- Deterioration of wastewater collection & treatment systems
  - a.k.a., microbiologically influenced corrosion (MIC), biogenic sulfuric attack (BSA)
  - Headspace (vapor phase) environments above flow of the waste stream
  - Typified by elevated levels of hydrogen sulfide (H_2S), carbon dioxide (CO_2) and methane (CH_4)
    - Acid gases (i.e., H_2S = thiosulfuric acid, CO_2= carbonic acid)

PROTECTING CONCRETE

- Biogenic Sulfide Corrosion:
  - Biological oxidation of H_2S to H_2SO_4 within headspace areas of enclosed wastewater structures

$$H_2S + 2O_2 \xrightarrow{\textit{Thiobacillus}\ \text{SOB}} H_2SO_4$$

  - H_2SO_4 attacks the matrix of the concrete above the waterline *(i.e., pipe crowns, walls, soffits)*



PROTECTING CONCRETE

Example: Severe Wastewater Headspace Exposure

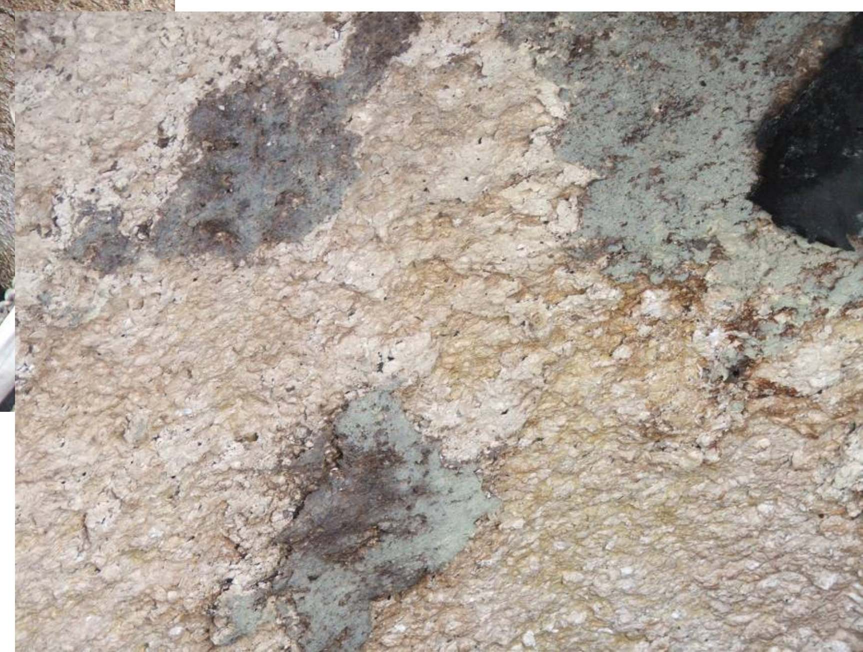
PROTECTING CONCRETE

Example: Severe Wastewater Headspace Exposure

PROTECTING CONCRETE

Example: Severe Wastewater Headspace Exposure

PROTECTING CONCRETE



Example: Severe Wastewater Headspace Exposure

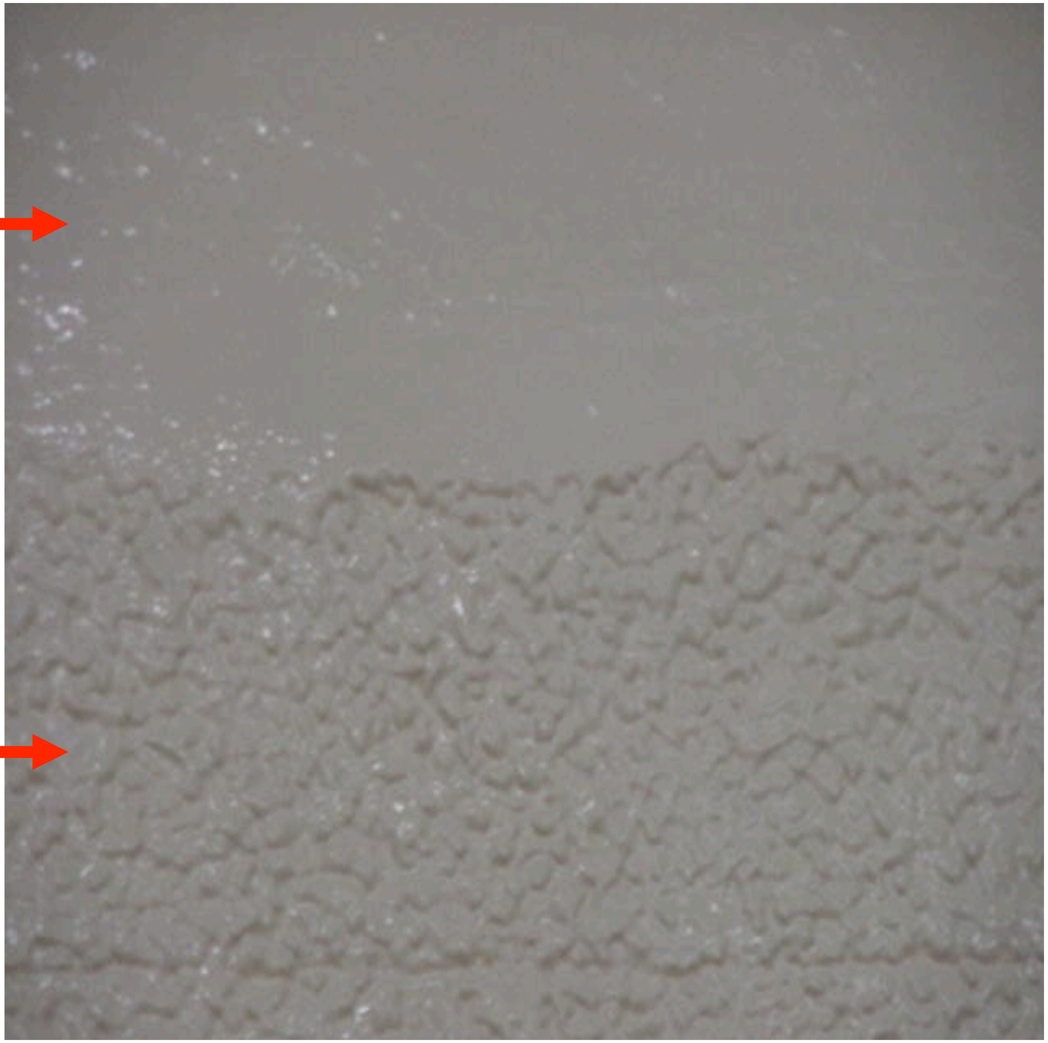
PROTECTING CONCRETE

Substrate Repair:

- Establishes a "paintable surface"
  - Film integrity
  - Monolithic lining
  - Chemically-resistant lining
- Considered part of the protective lining system
  - Optimum Adhesion/Bond
  - Optimum Performance
- EPA's Clean Water and Drinking Water Infrastructure Sustainability Policy
  - Asset Management philosophy

PROTECTING CONCRETE

- Concrete repair (above) followed by high-performance protective coating
- Improper concrete repair (below) followed by high-performance protective coating
  - heterogeneous film
  - thin areas
  - pinholes



PROTECTING CONCRETE

Typical headworks structures, equalization basins, digesters

PROTECTING CONCRETE

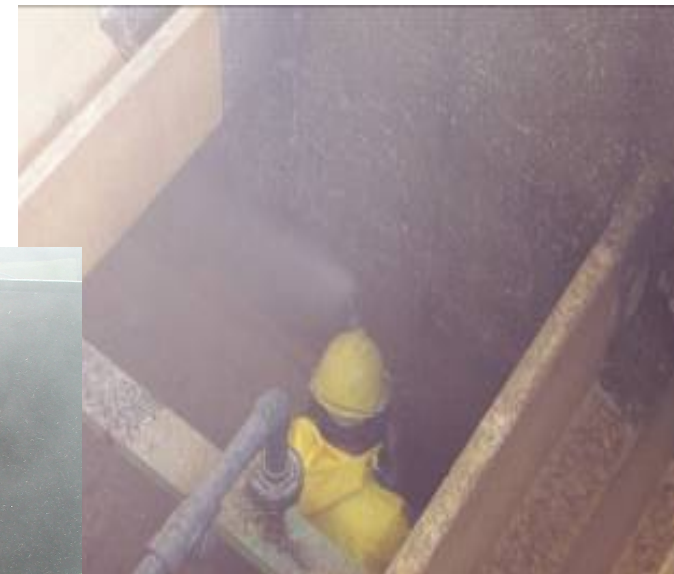
Typical Concrete Secondary Containment Systems

Preparing Concrete Substrate for Repair Mortar

SUBSTRATE PREPARATION

- ACI
  - 546R-04, *Concrete Repair Guide*
  - RAP Bulletin 3, *Spall Repair by Low Pressure Spraying*
  - RAP Bulletin 6, *Vertical and Overhead Spall Repair by Hand Application*
  - RAP Bulletin 12, *Concrete Repair by Shotcrete Application*
- ICRI
  - 310.1R-2008, *Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion*
- *General Tenets*: Removal of deteriorated, damaged or defective concrete back to a sound, symmetrical, roughened (profiled) surface.

SUBSTRATE PREPARATION



SUBSTRATE PREPARATION

Concrete Substrate Repair

SUBSTRATE REPAIR

- Level substrate for topcoating
- Rebar cover/structural integrity
- Rebar passivity

SUBSTRATE REPAIR

- Cementitious mortars commonly used for wastewater repairs are based upon hydraulic binders such as:
  - Portland or blended cement-based mortars
  - Calcium aluminate cement-based mortars
  - Acrylic polymer cement-based mortars
  - Epoxy polymer cement-based mortars

SUBSTRATE REPAIR

Hydraulic Repair Mortars

SUBSTRATE REPAIR

Example: Hydraulic repair mortar w/ trowel/float finish

SUBSTRATE REPAIR

Examples: Hydraulic repair mortar w/ broom finish

Ready to Topcoat?
Not so fast…

High-performance protective linings require:
- Removal of laitance layer (if present)
- Removal of membrane curing compound (if used)
- Provide surface profile for mechanical adhesion

MAY REQUIRE…

Additional Surface Preparation

Cementitious Repair Mortar Preparation?

CEMENTITIOUS MORTAR PREPARATION

Failure of a protective liner due to insufficient removal of laitance from a cementitious repair mortar

CEMENTITIOUS MORTAR PREPARATION

Failure of a protective liner due to insufficient removal of laitance from the cementitious repair mortar

CEMENTITIOUS MORTAR PREPARATION

Optimum Bond Strength:

- Good bonding relates to the ability of the materials within the system to act as one
- Bond strength (adhesion) is the resistance of the repair material to separation from:
  - concrete substrate
  - reinforcing steel
  - other material for which it is contact (including topcoats)
- Protective Coatings Industry recommends bond strength greater than tensile strength of sound concrete substrate
  - Approximately 350-500 psi

CEMENTITIOUS MORTAR PREPARATION

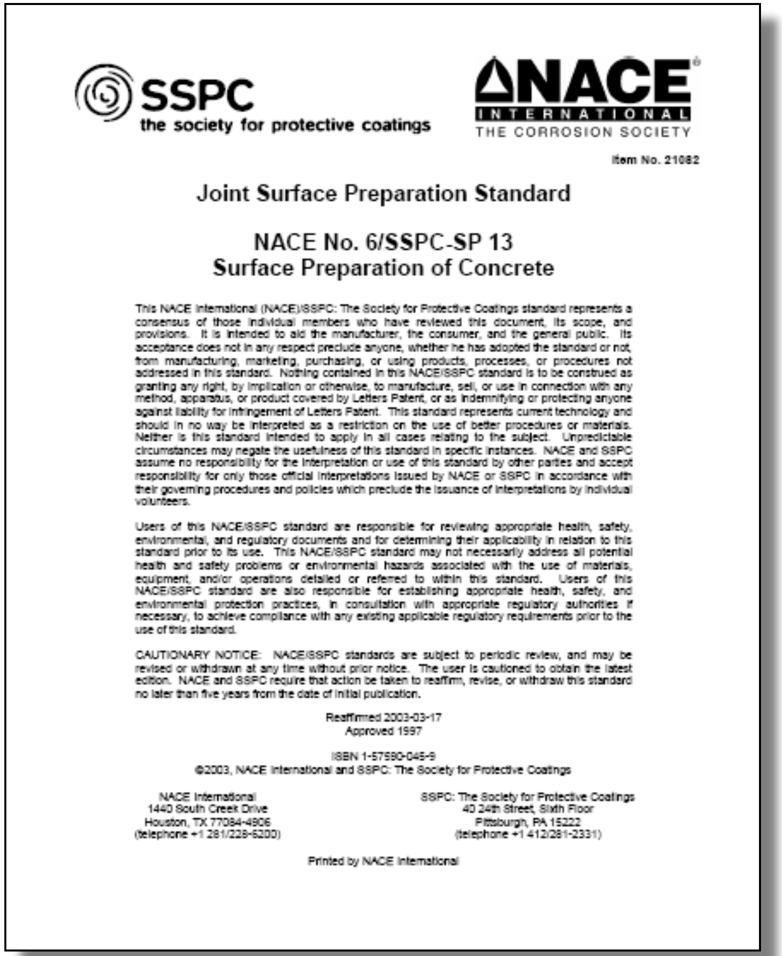
Optimum Bond Strength, *cont:*

- Cementitious mortars may form a weak surface layer (laitance) from:
  - Too high a w/cm
  - Exudation of fines with bleed water
  - Overworking during finishing
  - Improper curing of mortar
- Removal paramount for the long-term adhesion performance of protective linings
- Protective Coatings Industry created surface preparation standards

CEMENTITIOUS MORTAR PREPARATION

SSPC-SP13/NACE No. 6 *Surface Preparation Of Concrete*

- SSPC: The Society for Protective Coatings
  www.sspc.org
- NACE International
  www.nace.org
- Preparation of cementitious surfaces prior to application of protective linings
  - Laitance layer
  - Membrane curing compounds
  - Provide sound surface



SSPC the society for protective coatings

NACE INTERNATIONAL THE CORROSION SOCIETY

Item No. 21082

Joint Surface Preparation Standard

NACE No. 6/SSPC-SP 13
Surface Preparation of Concrete

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CEMENTITIOUS MORTAR PREPARATION

Example of removal of laitance and weak concrete to expose subsurface voids and to produce a sound concrete surface with adequate profile and porosity

Pre-preparation *Post-preparation*

CEMENTITIOUS MORTAR PREPARATION

The Dilemma:

- Many unsubstantiated claims for the suitability and successes of some cementitious materials
  - Curing requirements *(inconsistent/non-existent)*
  - Finishing/Topcoating recommendations
- Prompted an investigation to assess the adhesion of a high-performance protective lining over various cementitious repair mortars
  - Un-Blasted vs. Blasted vs. Broom Finish

BOND STRENGTH TESTING

Testing Matrixes

- Surveyed specifications on 100 municipal wastewater infrastructure rehabilitation projects
- Identified the 4 common cementitious repair composites:
  1. Epoxy-modified cementitious mortars
  2. Acrylic-modified cementitious mortars
  3. Portland-based cementitious mortars
  4. Calcium aluminate-based cementitious mortars
- Represent a wide range in composition and material properties

BOND STRENGTH TESTING

Testing Matrixes, *cont.*

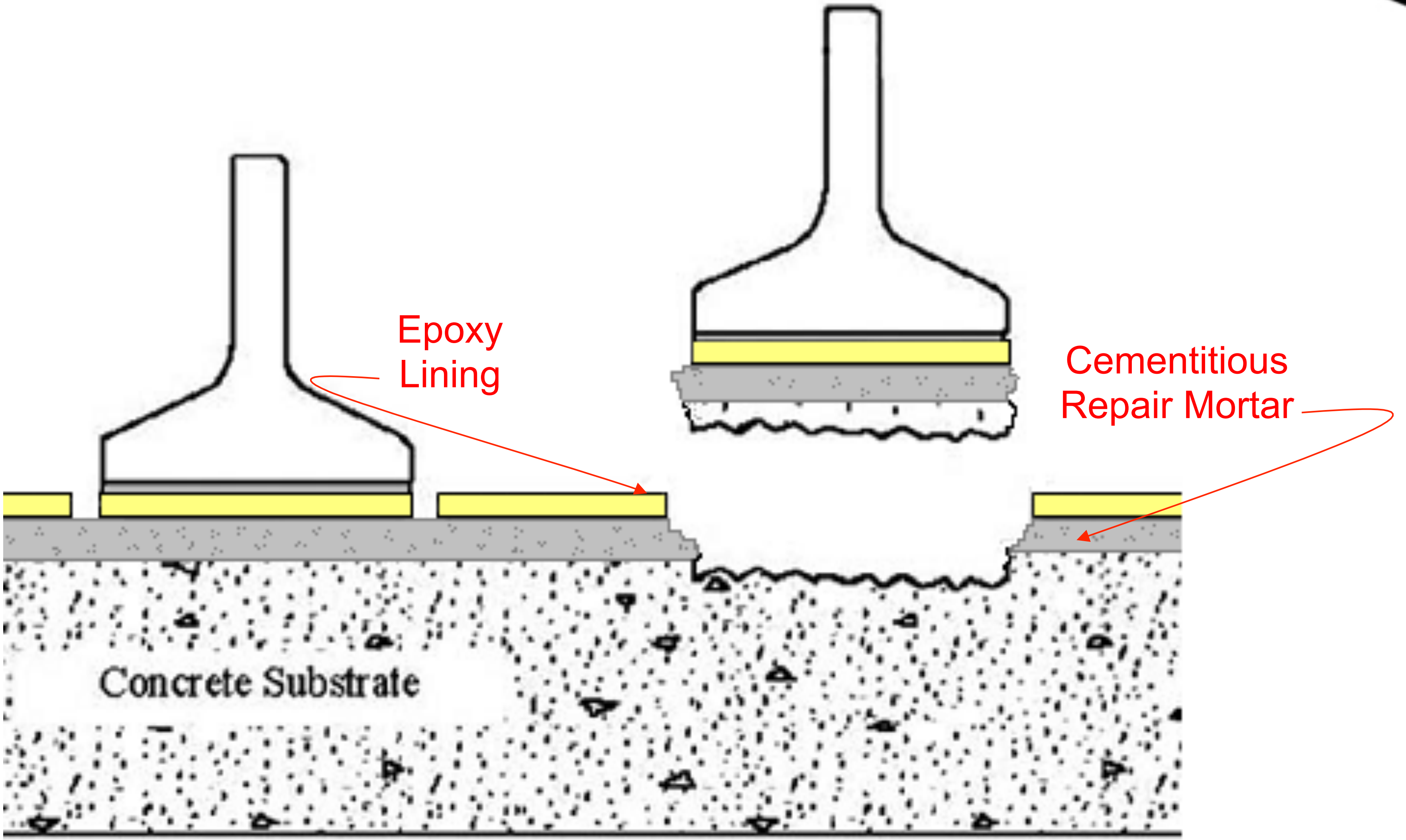
- Surface tensile properties of the 12 mortars when applied at their minimum recommended thicknesses with:
  - Un-Blasted Surface
  - Blasted *(mechanically profiled)* Surface
  - Broom Finished Surface
- Topcoated with a high-performance protective lining
- Bond strength properties assessed in accordance with ASTM D 7234
  - Assesses the near surface adhesion between the coating and concrete (cementitious repair mortar) substrate

BOND STRENGTH TESTING

Direct Tensile Strength: *ASTM D 7234*

- Determines normal stress, σ
- DeFelsko Corp. Self-aligning PosiTest Pull-Off Adhesion Tester
- 50 mm (2 in) dollies
- Peak force = 560 psi

BOND STRENGTH TESTING



Tensile Strength Testing per ASTM D 7234

BOND STRENGTH TESTING

Concrete Substrate Panels

- High-Strength 5,500 psi Portland Type I design mix
- Cast 24”x 24”x 2” panels for common substrate slabs *(non-reinforced)*
- Membrane cured for 28 days per ACI 308R
- Top surfaces mechanically prepared to SSPC-SP13/NACE No. 6 surface condition, achieving a ICRI-CSP5 surface profile

BOND STRENGTH TESTING

Epoxy Coating (topcoat)

- A high-build, 100% SBV, two-component, high-functionality amine epoxy was used as a representative high-performance lining
  - Commercially available high-performance lining is recommended for use over concrete & steel in highly corrosive wastewater environments
- Applied at 30 mils DFT

BOND STRENGTH TESTING

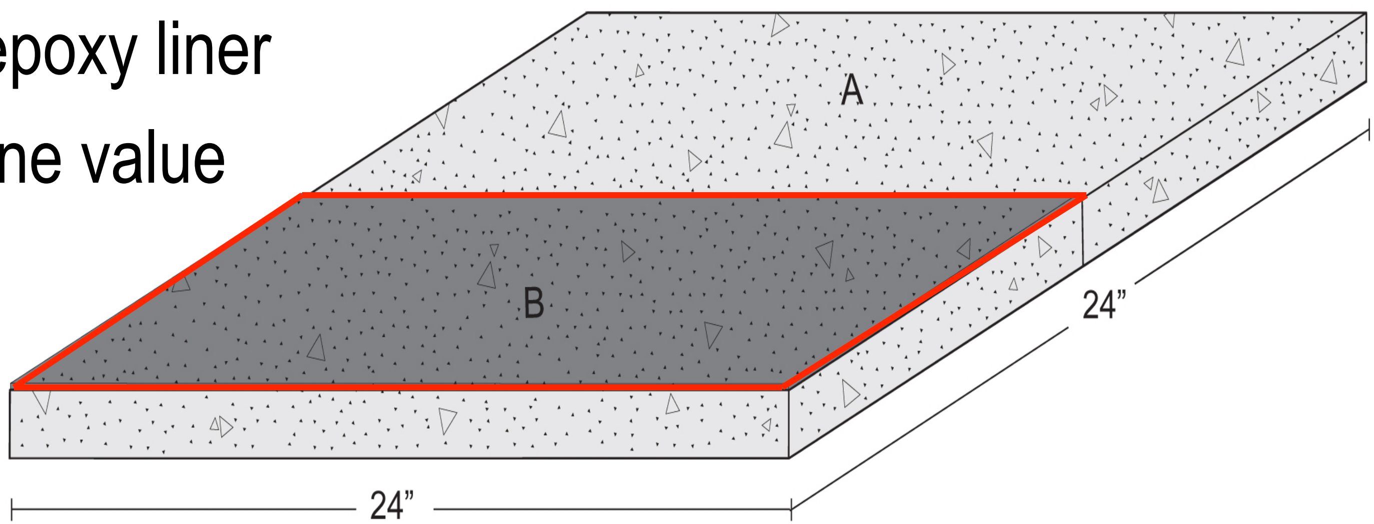
Concrete Control Panel (CCP)

- Development and maintenance of a sound bond between the topcoat and substrate is necessary to achieve durable repairs and long-term protection
- Bond strength testing:
  - Topcoat cohesive failure should not occur
  - Adhesive failure between topcoat and repair mortar should be a rare occurrence
  - Cohesive failure of repair mortar is not desirable
  - Cohesive failure in the concrete is preferred
- Single panel withheld as the control substrate (baseline)
  - ASTM D 7234

BOND STRENGTH TESTING

Concrete Control Panel (CCP)

- Upper half (denoted A) remained unchanged from prepared surface
- Lower half (denoted B) was topcoated with 30 mils DFT of a high-build epoxy liner
- Derive baseline value

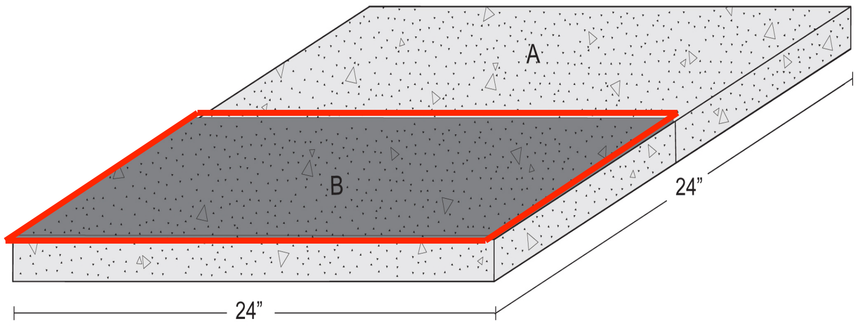


BOND STRENGTH TESTING

Concrete Control Panel (CCP), cont.

- Results (baseline):

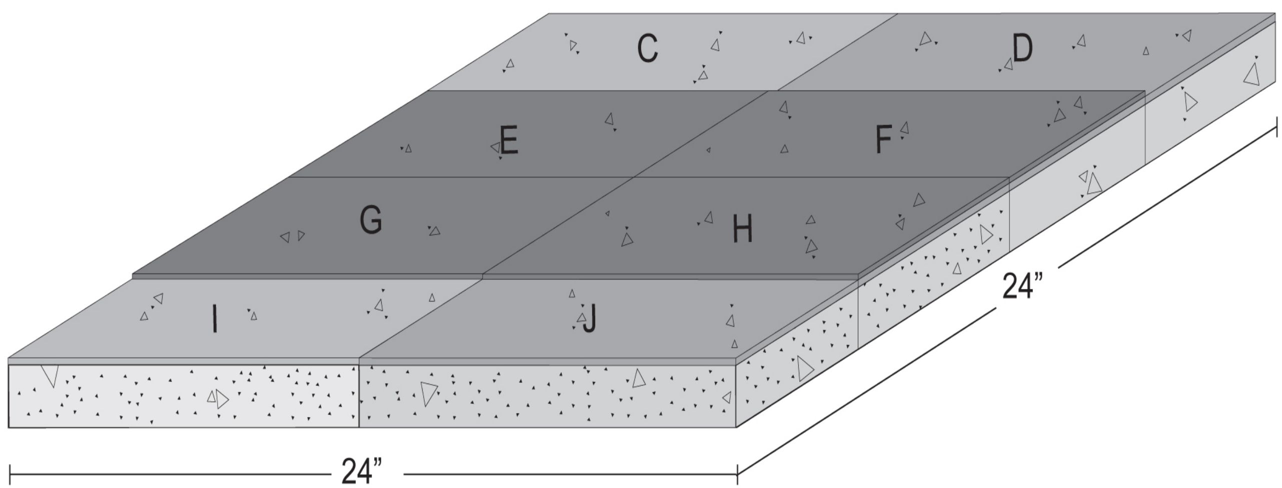
CCP Section	System	Surface Preparation	Average Tensile Strength (psi)	Failure Mode *(Pull 1)*	Failure Mode *(Pull 2)*	Failure Mode *(Pull 3)*
A	Concrete	SSPC-SP13/NACE No. 6, ICRI-CSP5	**521**	100% A	100% A	100% A
B	Concrete/100% solids EP	SSPC-SP13/NACE No. 6, ICRI-CSP5	**538**	100% A	100% A	100% A



BOND STRENGTH TESTING

Un-blasted v. Blasted Surface Matrix

- Eight quadrants
- Determined bond strength by evaluating influences of:
  - Un-cured v. Cured *(ACI 308R)*
  - Un-blasted v. Blasted *(SSPC-SP13/NACE No. 6, ICRI CSP-3)*
  - Un-topcoated v. Topcoated *(epoxy lining)*



BOND STRENGTH TESTING

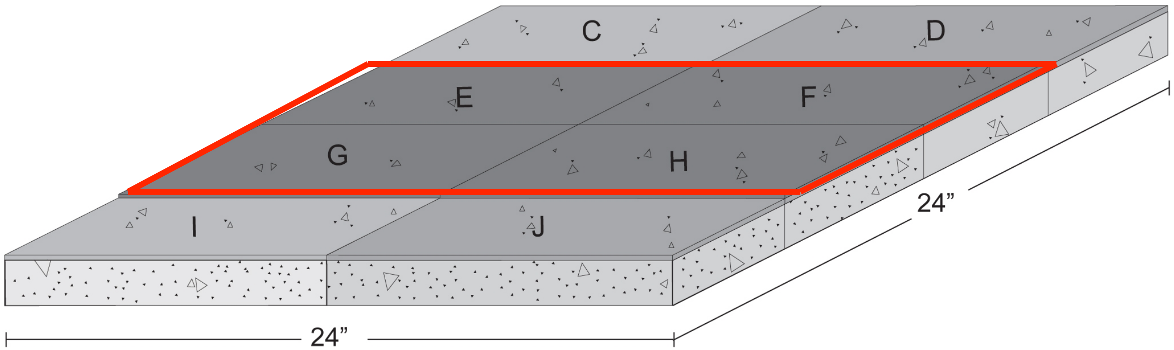
Un-blasted v. Blasted Surface Matrix, cont.

- Concrete substrate panels SSPC-SP13/NACE No. 6, ICRI CSP5 profile
- Concrete substrate panels received SSD condition
- Each mortar:
  1. Bond (scrub) coat
  2. Application to minimum recommended thickness with float
  3. Trowel finished

BOND STRENGTH TESTING

Un-blasted v. Blasted Surface Matrix, cont.

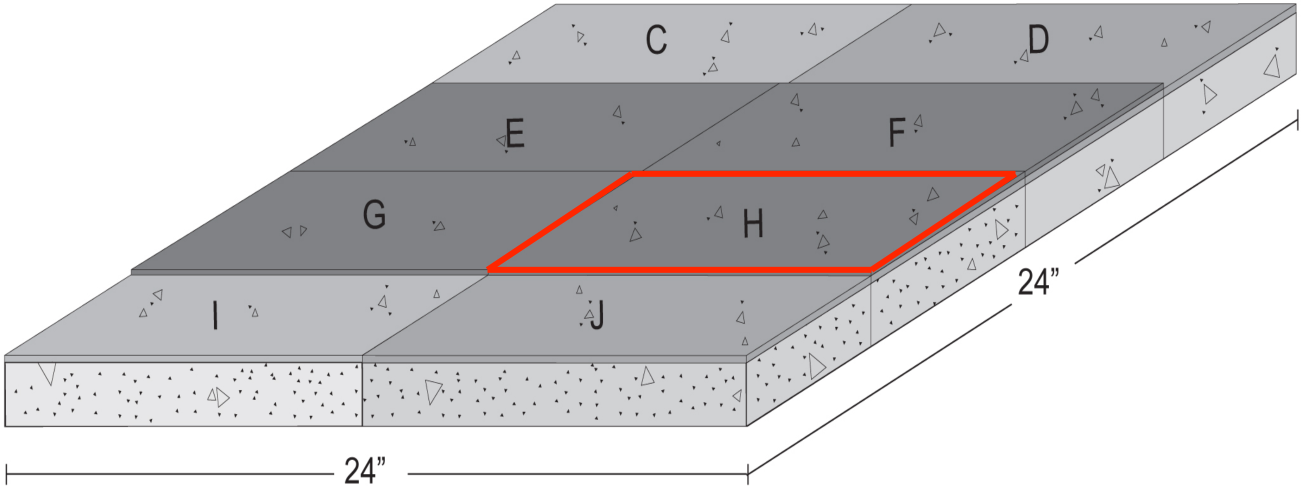
- Left half received no external curing
- Right half cured with acrylic curing compound
- Lower half was abrasive blasted to ICRI-CSP3 to remove curing compound and laitance layer
- Middle Sections received application of high-performance epoxy topcoat and cured for 7 days



BOND STRENGTH TESTING

Un-blasted v. Blasted Surface Matrix, cont.

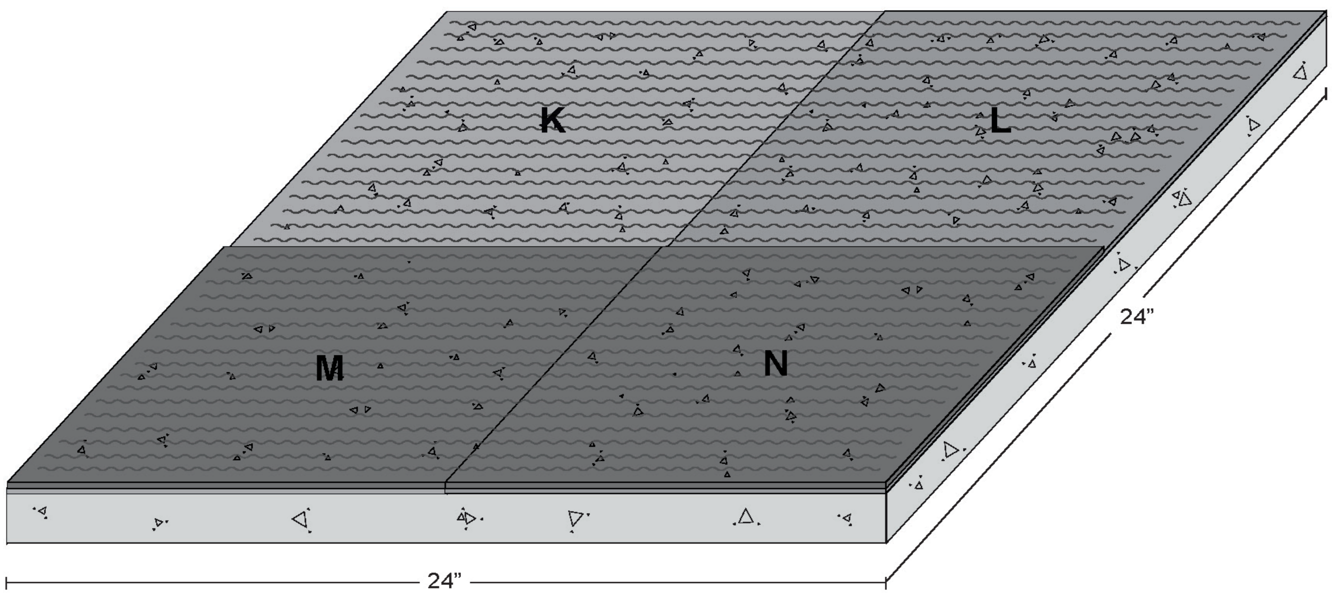
- Panel Section H (cured/blasted) yielded maximum surface bond strength
  - *Properly cured*
  - *Removal of laitance layer (when present)*
  - *Removal of curing compound*



BOND STRENGTH TESTING

Broom Finished Surface Matrix

- Four quadrants
- Determined bond strength by evaluating influences of:
  - Un-cured v. Cured *(ACI 308R)*
  - Un-topcoated v. Topcoated *(epoxy coating)*



BOND STRENGTH TESTING

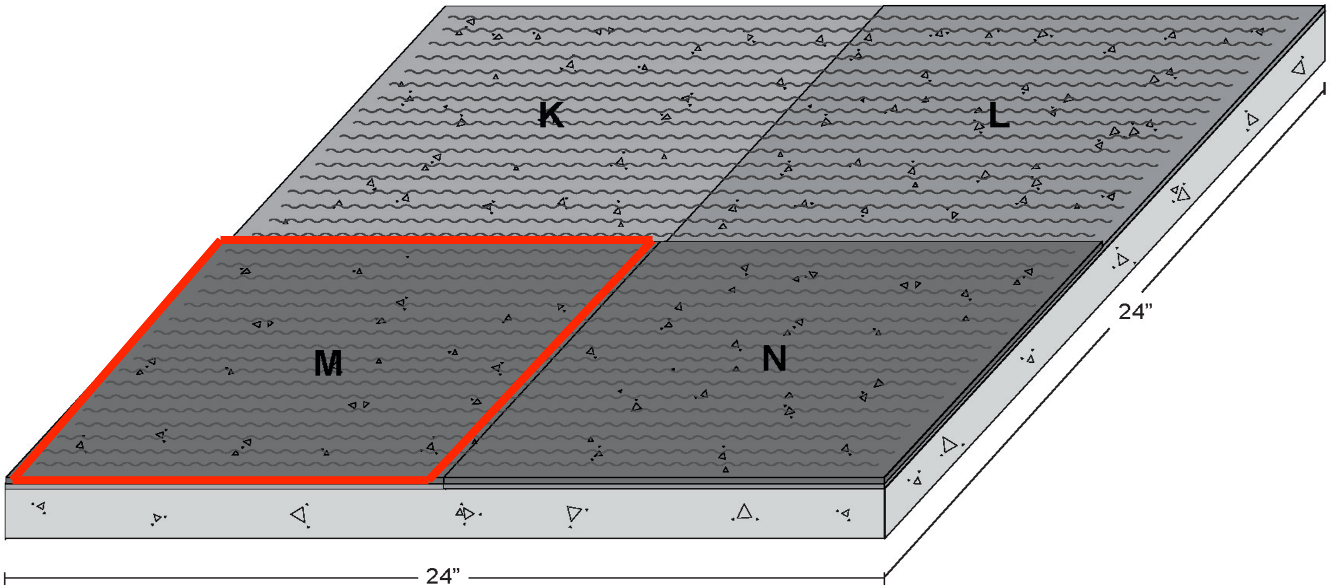
Broom Finished Surface Matrix, cont.

- Concrete substrate panels SSPC-SP13/NACE No. 6, ICRI CSP5 profile
- Concrete substrate panels received SSD condition
- Each Mortar:
  - Bond (scrub) coat
  - Application to minimum recommended thickness with float
  - Broom finished using masons brush

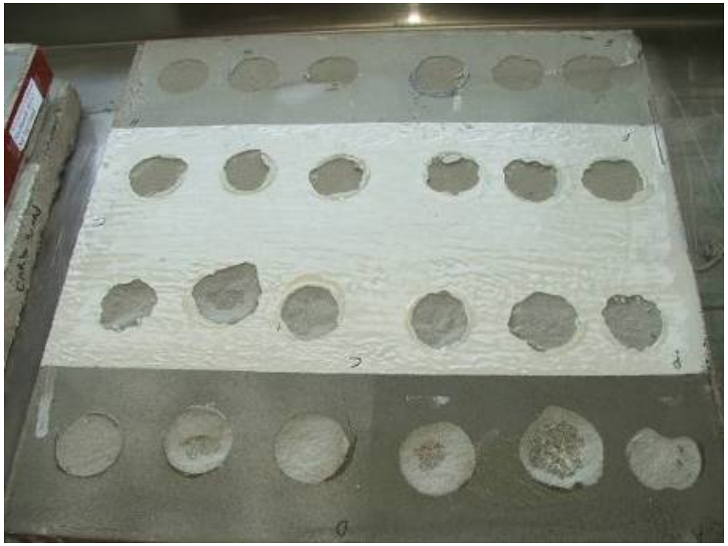
BOND STRENGTH TESTING

Broom Finished Surface Matrix

- Left half received no external curing
- Right half cured with acrylic curing compound
- Lower sections received a high-performance epoxy liner and cured for 7 days
- Panel Section M achieved the maximum surface bond strength

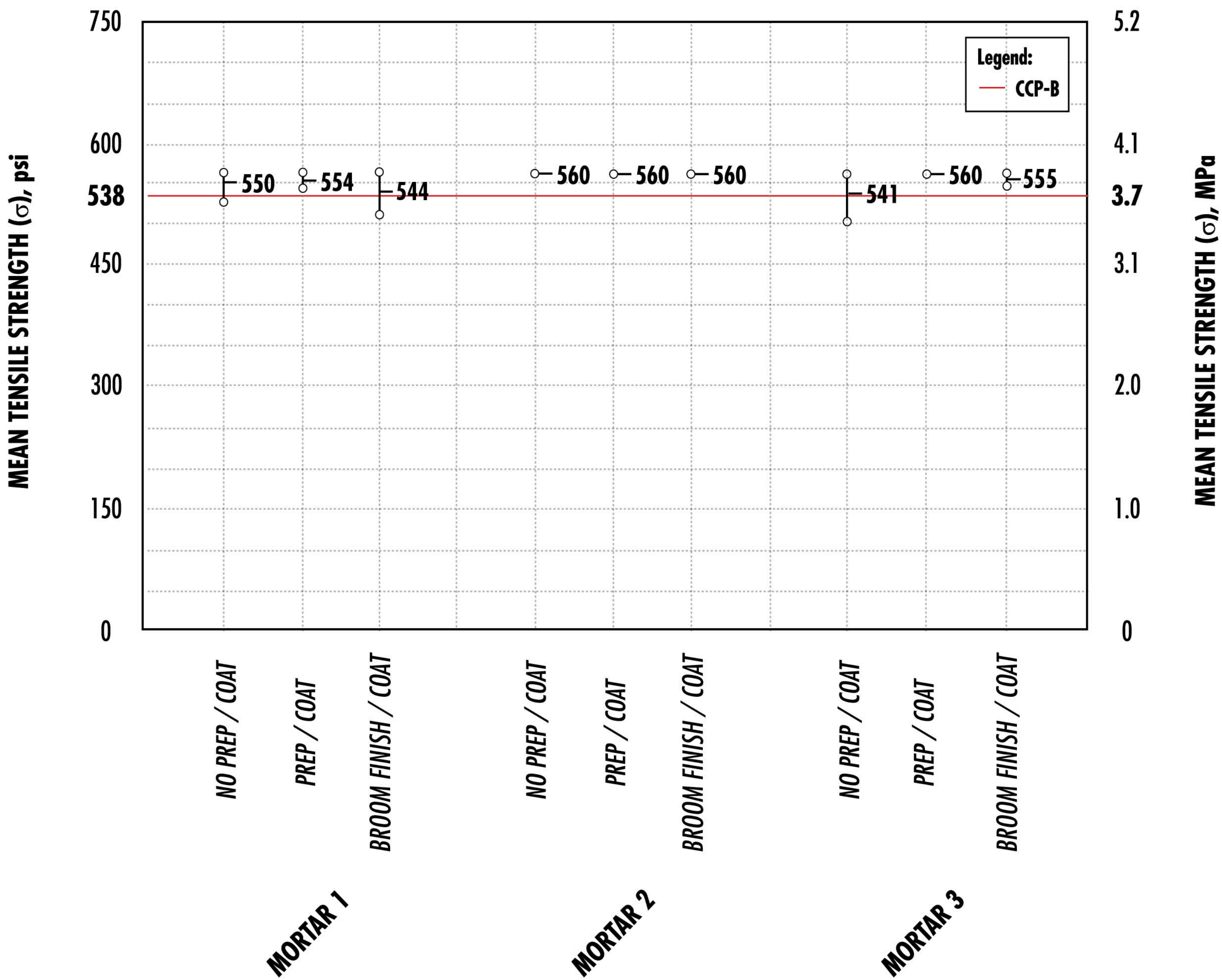


Bond strength testing in accordance with ASTM D7234 using self-aligning PosiTest Pull-Off Adhesion Tester with 50 mm dollies.

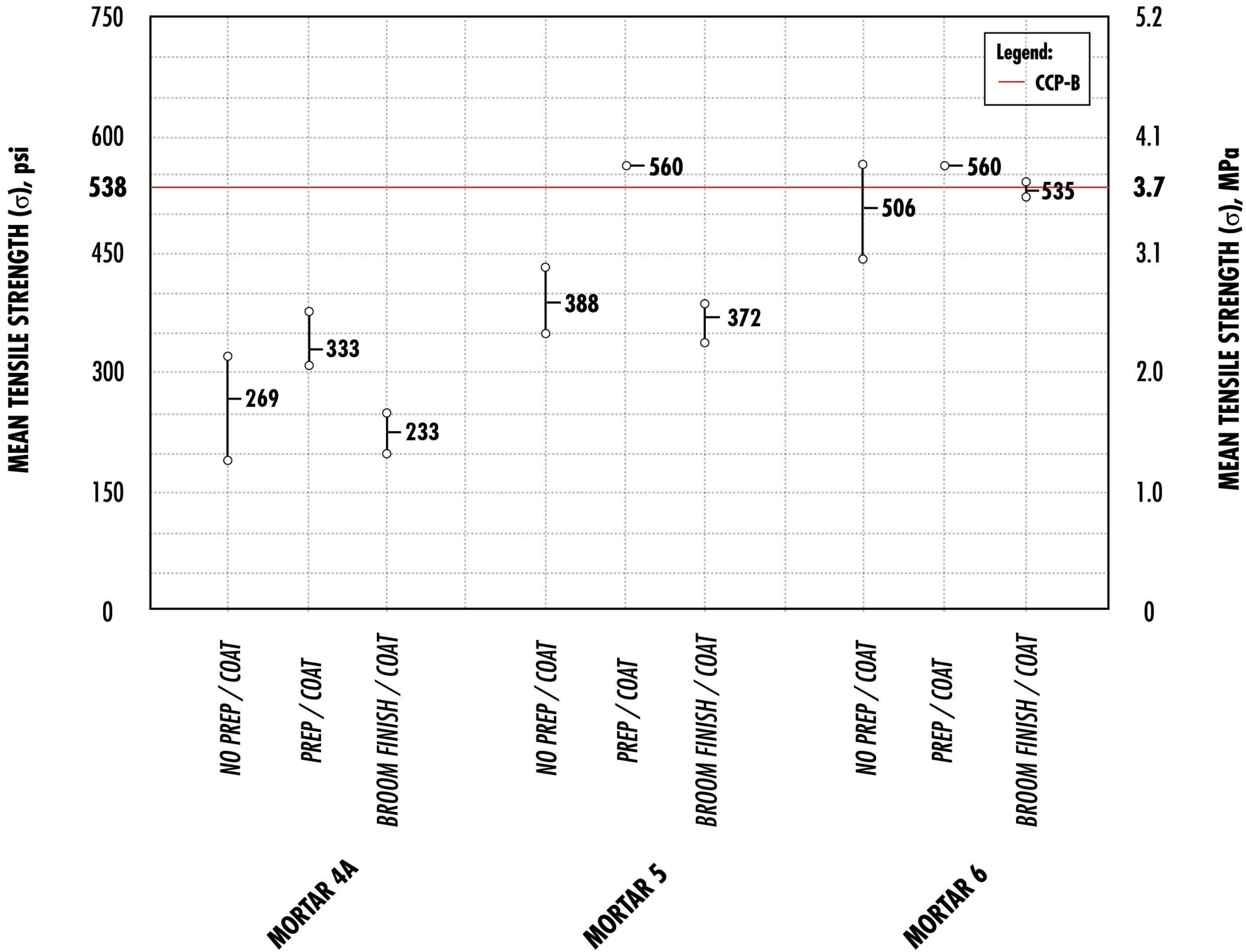


Bond strength testing in accordance with ASTM D7234 using self-aligning PosiTest Pull-Off Adhesion Tester with 50 mm dollies.

EPOXY-MODIFIED CEMENTITIOUS MORTARS

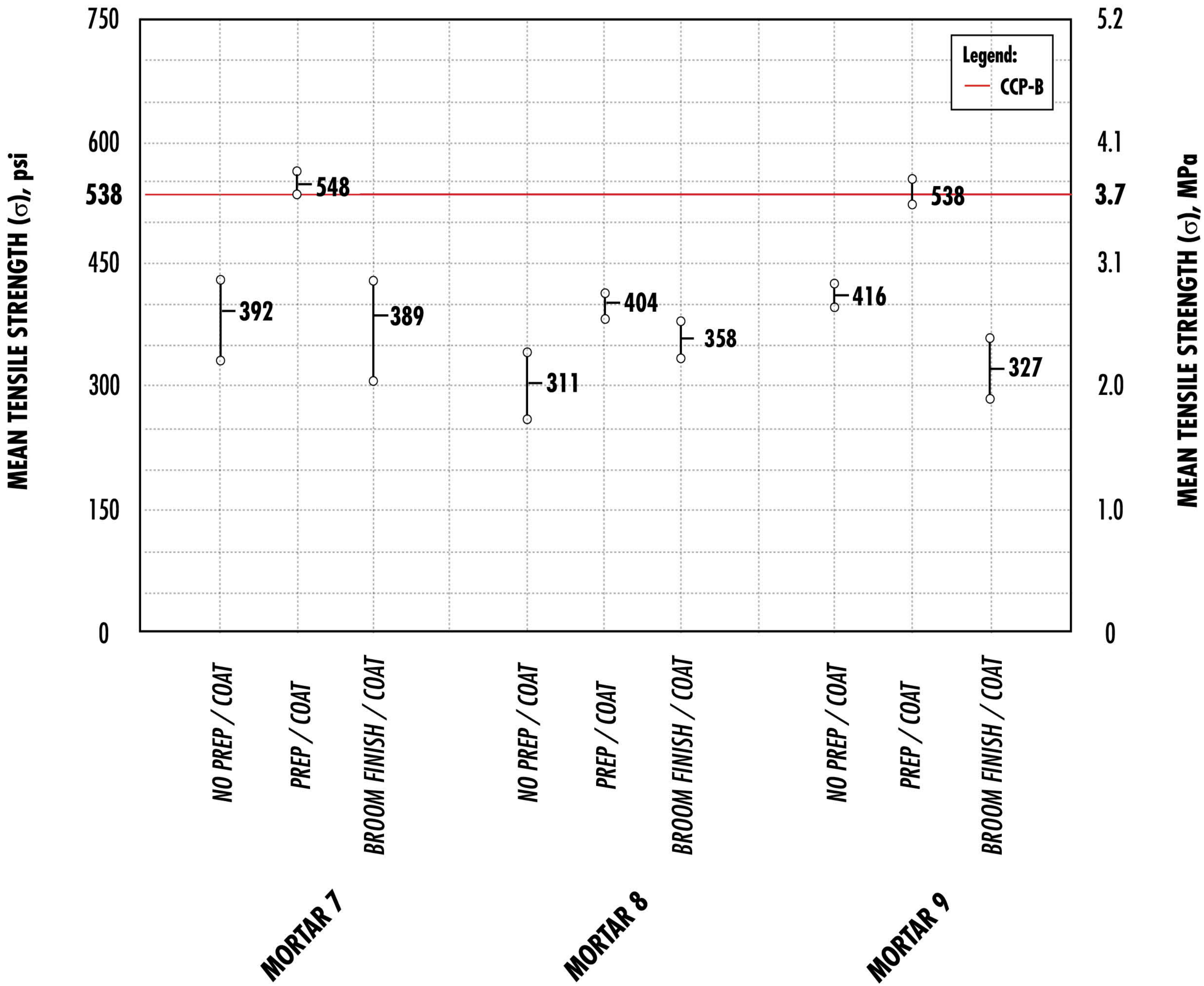


ACRYLIC-MODIFIED CEMENTITIOUS MORTARS

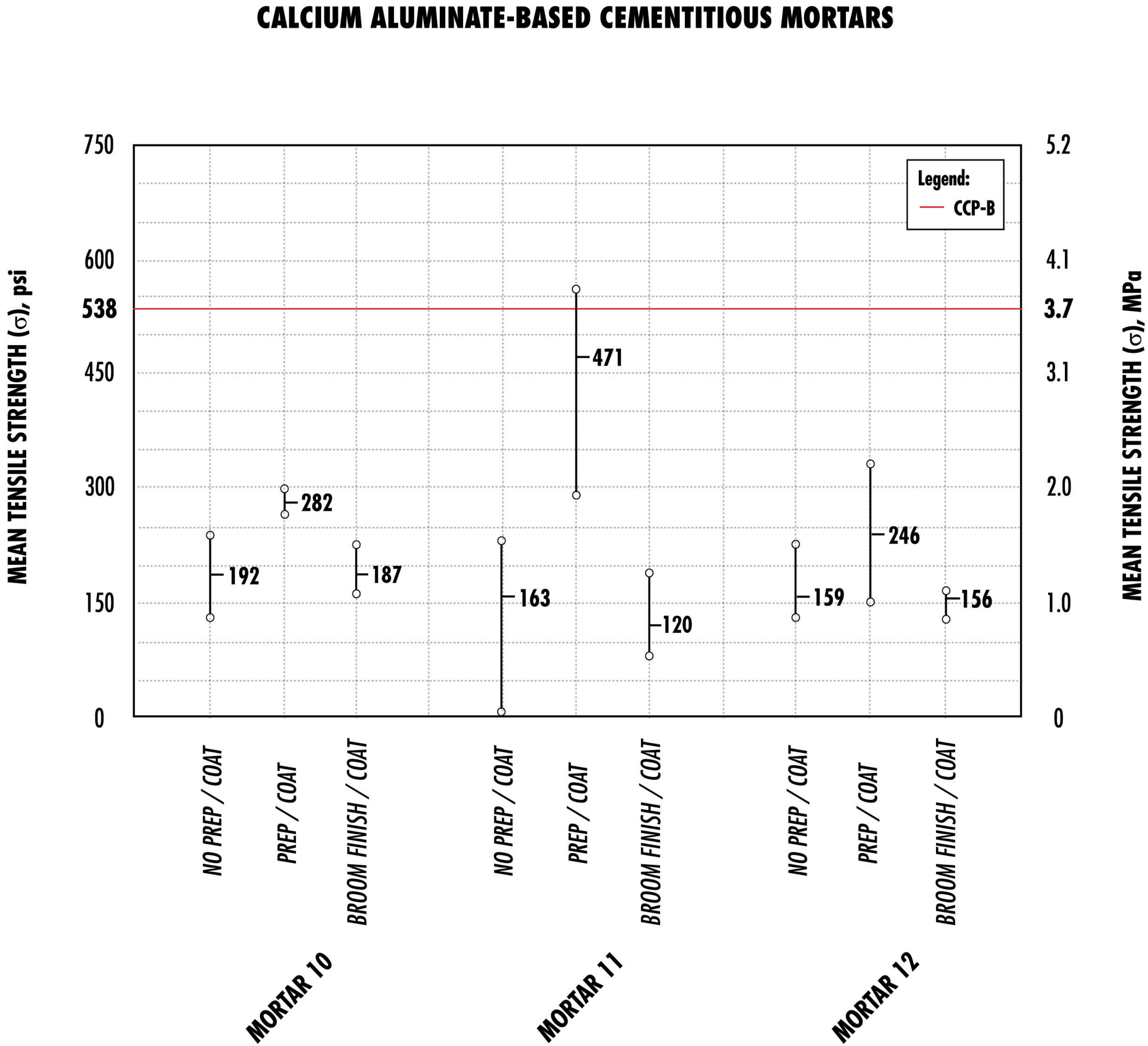


ANALYTICS

PORTLAND-BASED CEMENTITIOUS MORTARS



ANALYTICS



CALCIUM ALUMINATE-BASED CEMENTITIOUS MORTARS
MEAN TENSILE STRENGTH (σ), psi
MEAN TENSILE STRENGTH (σ), MPa
750
600
538
450
300
150
0
5.2
4.1
3.7
3.1
2.0
1.0
0
Legend:
CCP-B
192
282
187
163
471
120
159
246
156
NO PREP / COAT
PREP / COAT
BROOM FINISH / COAT
NO PREP / COAT
PREP / COAT
BROOM FINISH / COAT
NO PREP / COAT
PREP / COAT
BROOM FINISH / COAT
MORTAR 10
MORTAR 11
MORTAR 12

BOND STRENGTH TESTING

Conclusions

- Necessary to properly prepare hydraulic mortars—with exception of epoxy modified—when topcoating with high-performance protective linings
  - Develop a weak surface layer *(too high a w/cm, overworking during finishing, the exudation of fines with bleed water, or due to improper curing of the mortar)*
- Broom finish forms a weak upper surface layer on majority of cementitious repair mortars
  - Exception of epoxy modified cementitious

BOND STRENGTH TESTING

Conclusions, cont.

- Blasted (mechanically prepared) cementitious repair mortars offer superior surface tensile strength over broom finished mortars
- Criterion is echoed by surface preparation standards set forth by the protective coatings industry

CEMENTITIOUS MORTAR PREPARATION

BUYERS BEWARE!

- Manufacturers submit laboratory testing to substantiate surface finishing and preparation requirements when topcoated with high-performance lining systems
- Manufacturers test compatibility of the entire system, including repair mortars *(with recommended finish)*
- Perform bond testing on onsite mock-ups of candidate systems
- Industry needs to promulgate proper concrete restoration-topcoating and bridge knowledge gap

PREPARE, REPAIR, AND PREPARE CONCRETE AND CEMENTITIOUS SURFACES PRIOR TO TOPCOATING WITH HIGH-PERFORMANCE LININGS

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BIOGRAPHY

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Vaughn O' Dea is responsible for strategic sales, marketing and technical initiatives for Tnemec's Water & Wastewater market. O' Dea is a NACE Certified Coatings Inspector and Corrosion Technician, as well as SSPC Protective Coatings Specialist.

Vaughn is a member of NACE International (NACE), SSPC: The Society for Protective Coatings (SSPC), American Water Works Association (AWWA), International Concrete Repair Institute (ICRI), American Concrete Institute (ACI), National Association of Sewer Service Companies (NAASCO), American Public Works Association (APWA), ASTM International (ASTM) and Water Environment Federation (WEF). Vaughn is the chairman of ASTM Subcommittee WK33537 Operating the Severe Wastewater Analysis Testing Apparatus, Chairman of NACE Task Group 141 Coatings and Linings over Concrete for Chemical Immersion and Containment Service, Vice-chairman of NACE Task Group 417 Surface Preparation of Concrete, and is active in other NACE, SSPC, ICRI, ASTM and ACI technical committees.

O' Dea has authored numerous technical reports and articles for publication including Journal of Protective Coatings and Linings, Materials Performance, Inspect This!, Coatings World, Public Works Magazine, Concrete Surfaces, Concrete Repair Bulletin, and WaterWorld. Vaughn was the recipient (with his co-authors) of the JPCL Editors' Award 2008 and 2010, and is Contributing Editor for the *Journal of Protective Coatings and Linings.*