Algonquin Hotel, New Brunswick, Canada

THE DO'S & DON'TS OF CONCRETE REPAIR – PART 1 (MATERIAL SELECTION)

- Certificates will be provided via email
- All attendees will receive a copy and recording of the webinar, this may take up to a week to distribute
- We appreciate your patience

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OBJECTIVES – CONCRETE REPAIR (SPALL REPAIR)

- ✓ Understand corrosion of reinforced concrete
  - Root causes of deterioration
  - Conducting condition survey
  - Determining a repair and protection strategy
- ✓ Discuss available application methods
- ✓ Focus on material properties and benefits for proper selection

Corrosion is highly complex, time is limited, and any pricing information is only for perspective.

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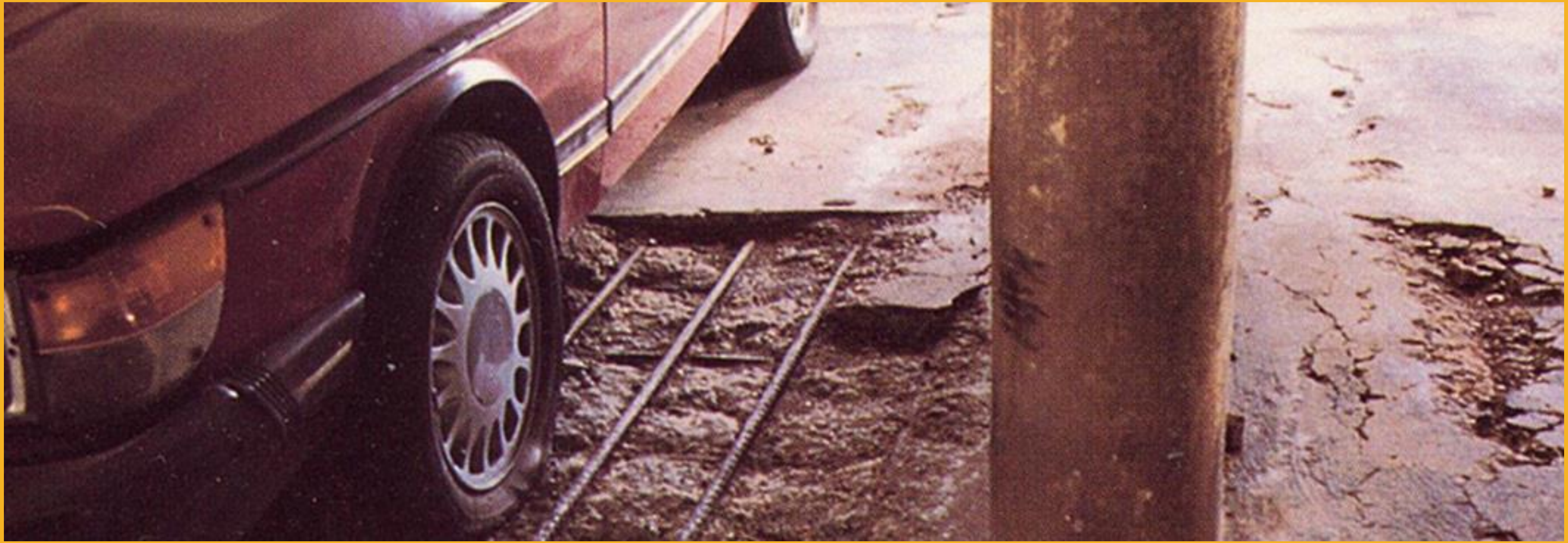

CAUSES OF DETERIORATION
CONDITION SURVEY
REPAIR AND PROTECTION STRATEGY

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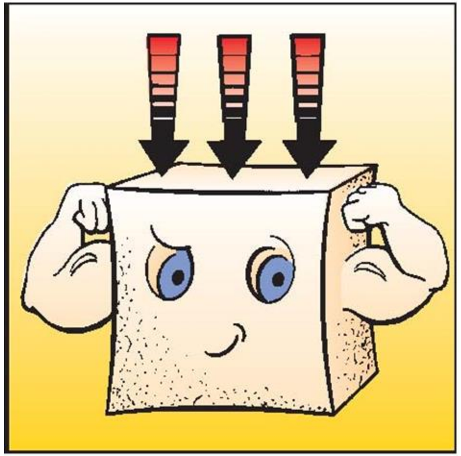
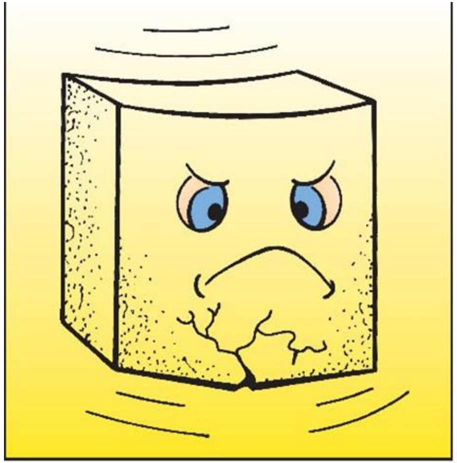
CAUSES OF CONCRETE DETERIORATION

- ✓ Impact
- ✓ Abrasion
- ✓ Freeze/thaw cycles
- ✓ Chemicals/sulfates
- ✓ Biological (micro-organisms)
- ✓ Reactive aggregates (ASR)
- ✓ Dissimilar metals
- ✓ **Steel reinforcement corrosion**

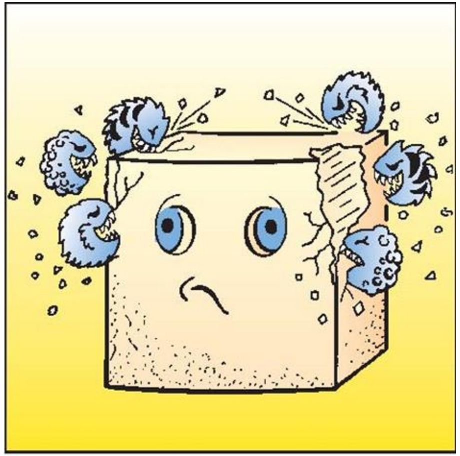
CONCRETE PROPERTIES



Concrete is Good in Compression



Concrete is Poor in Tension



Concrete is Always Under Attack

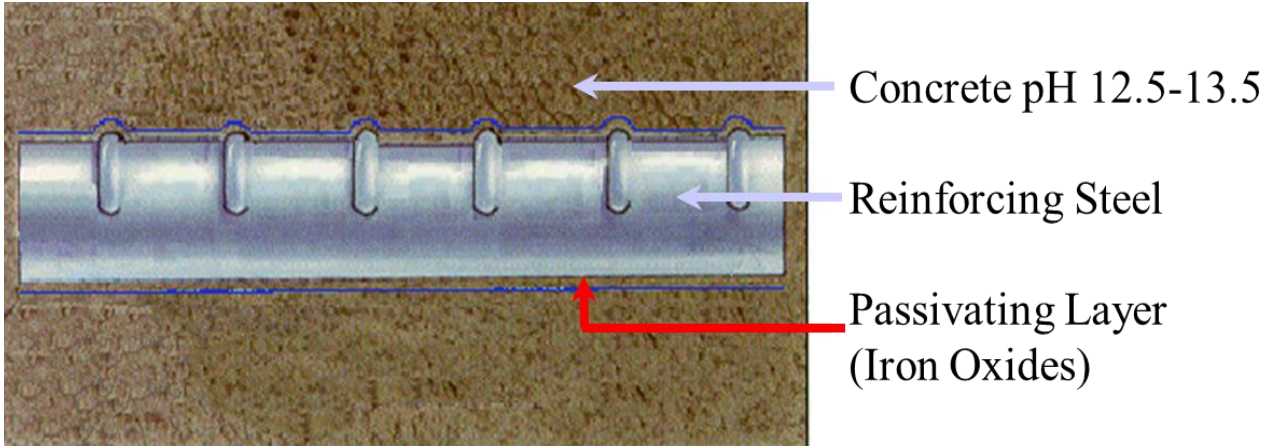
REINFORCING STEEL

- ✓ Economical method to add necessary tensile strength to concrete
- ✓ Corrodes in presence of oxygen and moisture

- ✓ Right side cleaned of corrosion
- ✓ Clearly see both anodic and cathodic areas

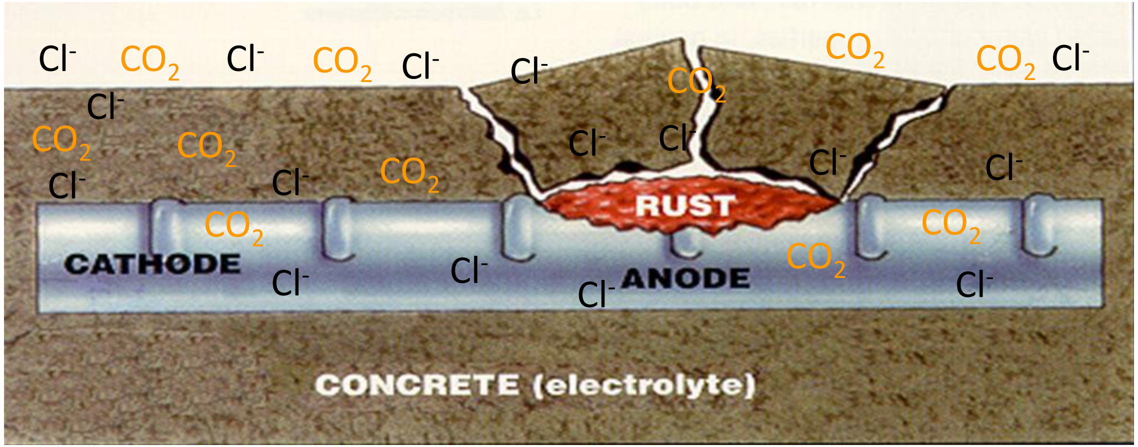
STEEL REINFORCED CONCRETE

- ✓ Concrete and steel are compatible
- ✓ Steel is passivated in concrete
- ✓ Alkaline environment protects steel from corrosion despite moisture and oxygen



ROOT CAUSES OF REINFORCEMENT CORROSION

- ✓ Chlorides and carbonation destroy the passivating layer
- ✓ Available moisture and oxygen corrode steel
- ✓ As steel corrodes it expands causing cracking and spalling of the concrete



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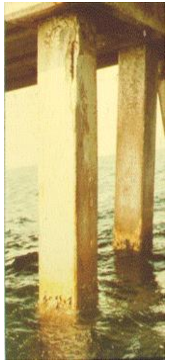
CHLORIDE-INDUCED CORROSION

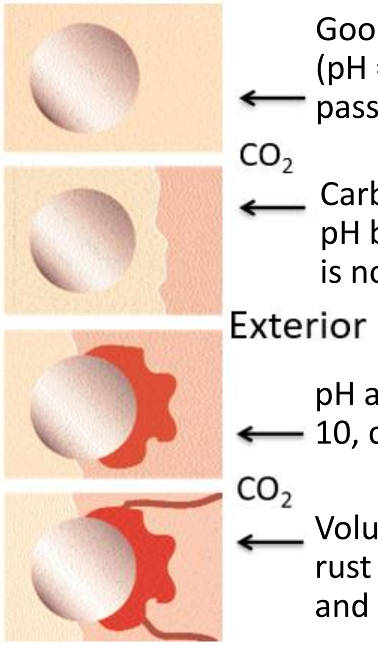
- ✓ Corrosion initiated when chlorides exceed 1.2 lb/cy = .2% by weight cement = .03% by weight concrete = 300 ppm at reinforcement








CARBONATION-INDUCED CORROSION

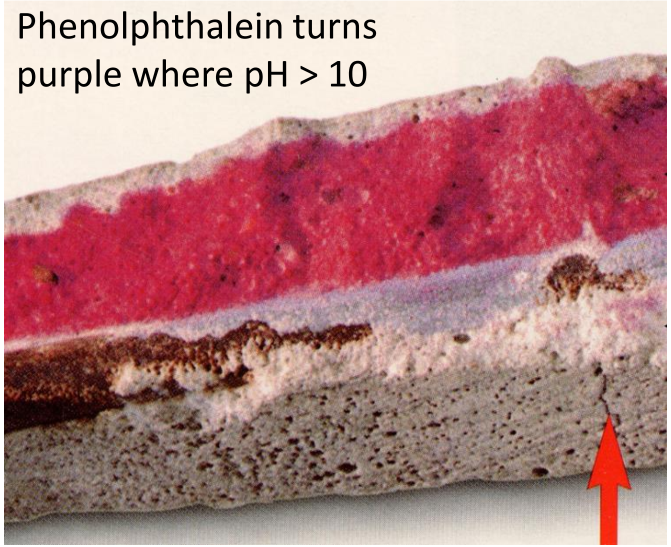


Good quality concrete (pH = 12.7-13.2) steel is passivated

Carbon dioxide enters, pH begins to drop, steel is not yet affected

pH at steel drops below 10, corrosion begins

Volume expansion of rust causes cracking and spalling



- $Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$
- RH 50-70 is optimal for carbonation
- Concrete ‘carbonated’ when pH < 10

UNDERSTANDING THE CONDITIONS

Learn the condition of the concrete

- ✓ Strengths
- ✓ Air entrainment
- ✓ Chloride content
- ✓ Carbonation depth
- ✓ Reactive aggregates

Evaluate the status of the steel

- ✓ Depth of cover
- ✓ Contaminated or uncontaminated
- ✓ Cross-sectional loss

Quantify the existing damage

- ✓ Identify spalls and delaminations

Predict the future damage

- ✓ Evaluate the latent corrosion
- ✓ Determine benefit of protection

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SELECTING A REPAIR AND PROTECTION STRATEGY

✓ Once the conditions are known, an optimal solution can be selected.

Strategy

- Remove the unsound concrete
- Clean or replace the steel
- Coat the steel
- Repair the spalls
- Repair the cracks
- Protect steel from contamination
- Protect concrete from contamination

Considerations

- Short or long-term goals
- Safety and liability
- Downtime
- Extent of latent corrosion
- Service conditions
- Aesthetics
- Budget

CONCRETE REPAIR

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CONCRETE REPAIR

- ✓ Choose method of application
- ✓ Select repair materials
  - Reinforcement coating
  - Sacrificial anode
  - Bonding agent
  - Repair mortar/concrete
- ✓ Prepare substrate and reinforcement
- ✓ Install the repair materials

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APPLICATION METHODS

Trowel
- ✓ Smaller areas
- ✓ Shallower repairs

Form and pour
- ✓ Larger volumes
- ✓ Easy to pour and enter formwork

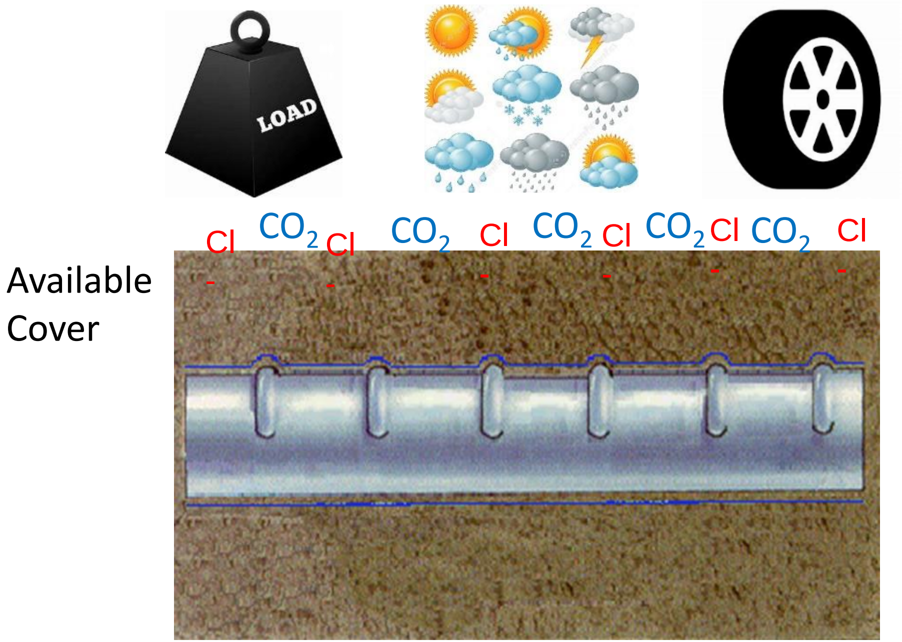
Form and pump
- ✓ When pouring is not appropriate
- ✓ Issues with access, orientation, staging

Spray **(wet/dry, high/low pressure)**
- ✓ Large volume of vertical or overhead
- ✓ Often large area but not so deep

(All methods effective when performed properly)

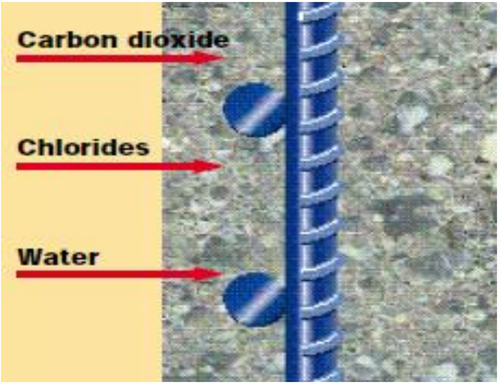
SELECTING THE REPAIR MATERIALS

- ✓ Allow for most productive installation
- ✓ Resist the causes of damage, perform in the environment
- ✓ Meet time constraints
- ✓ Consider the role in the overall repair and protection strategy



FACTORS INFLUENCING LONGEVITY OF REPAIR MATERIAL

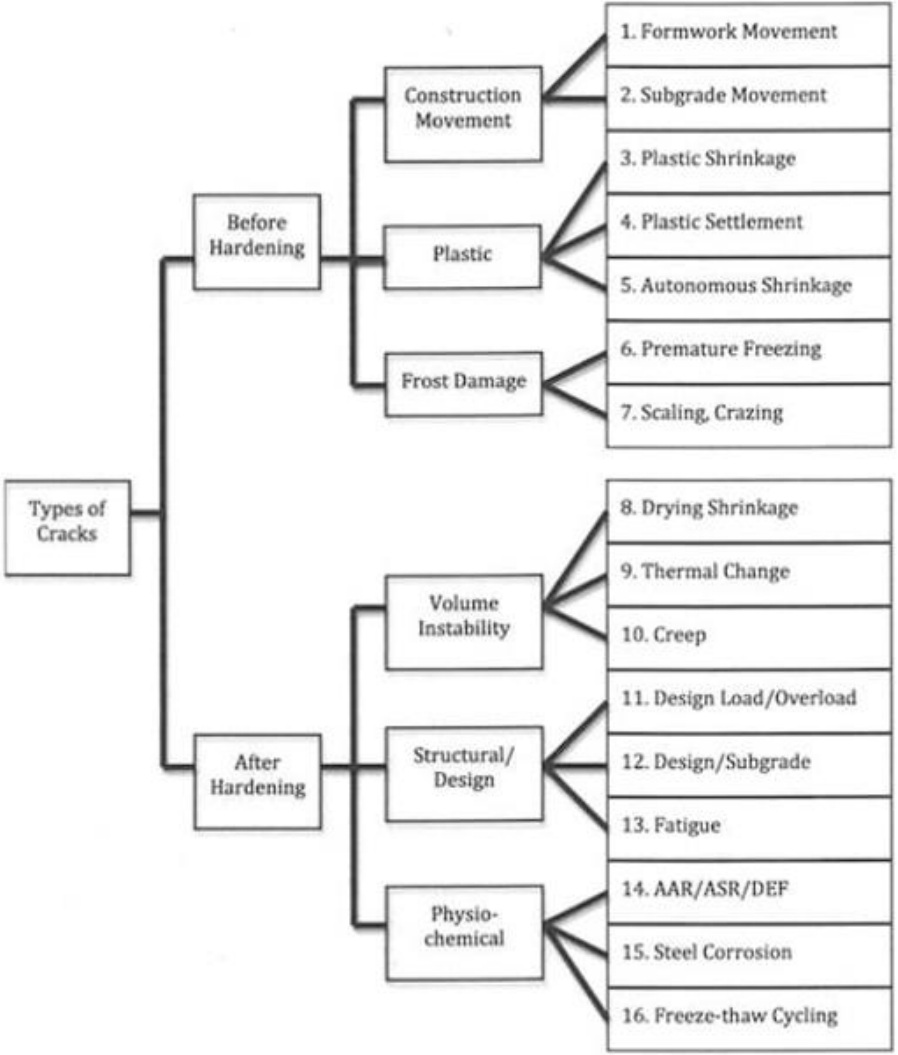
- ✓ Cracks in (and around) repair material allow quickest access of chlorides and carbonation to reach reinforcement
- ✓ Permeability of repair material determines rate of chloride and carbonation penetration through repair material to reach reinforcement
- ✓ Reinforcement coating provides substantial layer of additional corrosion protection
- ✓ Functioning corrosion inhibitor offers last line of defense against corrosion of reinforcement in and around repair material
- ✓ Compatibility of repair material with parent concrete required for long term performance
- ✓ Freeze/thaw resistance of repair material determines durability against surface deterioration in that exposure
- ✓ Strengths of repair material must meet the application criteria



CRACK CONCERNS AND TYPES

- ✓ Unsightly
- ✓ Leakage
  (ACI 224.R.72 Guideline maximum allowable width for water retaining structures is 4 mils)
- ✓ Structural
- ✓ Widen
- ✓ Corrosion
  (ACI 224.R.72 Guideline maximum allowable width for exposure to deicing chemicals is 7 mils)

[20# paper is 4 mils thick]



COMMON CRACKING IN CONCRETE REPAIR

Design - Reflective Cracking

- ✓ Installing repair material over a crack or joint in the substrate will result in the crack propagating through repair material

Avoid by

- Completely chip out cracks during surface preparation
- Epoxy inject the cracks
- Honor existing joints, create joints

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COMMON CRACKING IN CONCRETE REPAIR

Design - Stress Cracking

- ✓ Weak points increase likelihood of cracking such as at re-entrant corners and around penetrations

Avoid by

- Try to design around (core later)
- Select low shrinkage repair material
- Respect the mix
- Honor material limitations
- Use finishing aid
- Cure

COMMON CRACKING IN CONCRETE REPAIR

Design - Stress Cracking

✓ Poor geometrics

Avoid by

- Create rectangular repairs (up to 2:1)
- Select low shrinkage repair material
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COMMON CRACKING IN CONCRETE REPAIR

Shrinkage cracking

- A race between developing tensile strength versus shrinkage stress
- Shrinkage stress comes from volume decrease as water evaporates

Avoid by

- Select low shrinkage repair material
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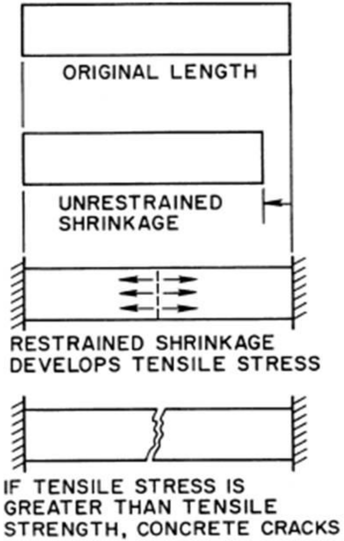
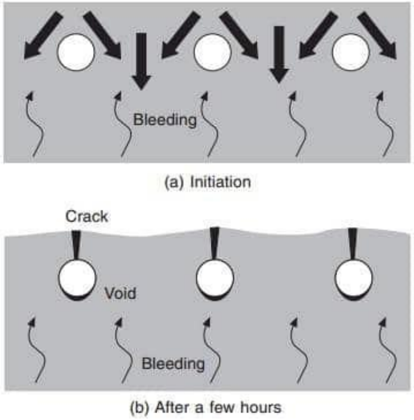
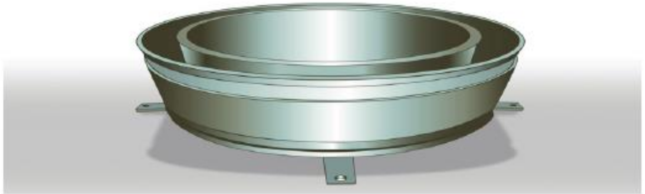
- Cure

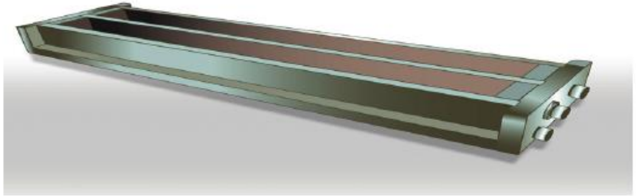




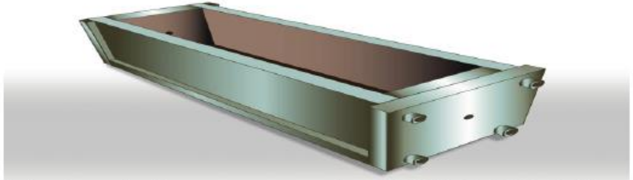
SHRINKAGE TESTING



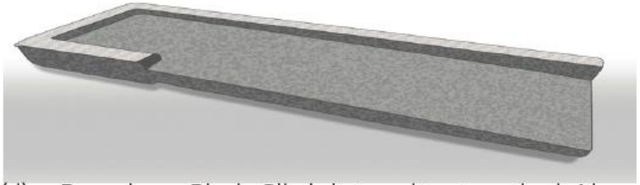
(a) ASTM C 1581/C 1581M: Ring shaped specimens used for determining age at cracking and induced tensile stress of mortar and concrete under restrained shrinkage



(b) Length change measured per ASTM C 157/C 157M modified in ICRI TDS Protocol using 3" X 3" X 11 ¼" mold



(c) Length change measured per ASTM C 157/C 157M modified in ICRI TDS Protocol using 1" X 1" X 11 ¼" mold



(d) Baenzinger Block: Sika's internal test method. Also confirmed as the optimal geometry for evaluating the sensitivity of a repair material to cracking in an independent study by the U.S. Department of the Interior, Bureau of Reclamation.

MIX WATER VERSUS WATER FOR HYDRATION

- Polycarboxylate superplasticizer replaces water used for workability

Common mix water of
8 pints

Mix water of 6.5 pints
19% reduction

Mix water of 4.5 pints
44% reduction

FINISHING AID

- ✓ Use instead of finishing water
- ✓ Slickens better
- ✓ Reduces moisture loss and crusting
- ✓ Repair materials often stickier and set faster
- ✓ Very economical
- ✓ Remove before coating or sealing

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CURING

- ✓ Start curing as soon as possible after applying finish
- ✓ Objective is to keep moisture in the repair material
- ✓ Burlap needs to remain wet
- ✓ Soakers and misters can be used
- ✓ Polyethylene needs to lay flat
- ✓ Burlene needs to lay flat

CURING

- ✓ Keep curing until at least 75% of design strength is reached
- ✓ Vertical surfaces are hard to keep in contact with burlap
- ✓ Forms can prevent moisture loss

CURING

- ✓ Curing compounds meeting ASTM C-309 are effective
- ✓ Use water-based curing compounds with materials containing polymers
- ✓ Curing compounds need to be removed before applying coatings and sealants

COMMON CRACKING IN CONCRETE REPAIR

Perimeter Separation

- ✓ Cement has weak bond to smoother saw cut surface profile (usually ½" deep)

Avoid by

- Select low shrinkage repair material
- Respect the mix
- Honor material limitations
- Use finishing aid
- Cure
- Tool and seal perimeter
- Use epoxy bonding agent

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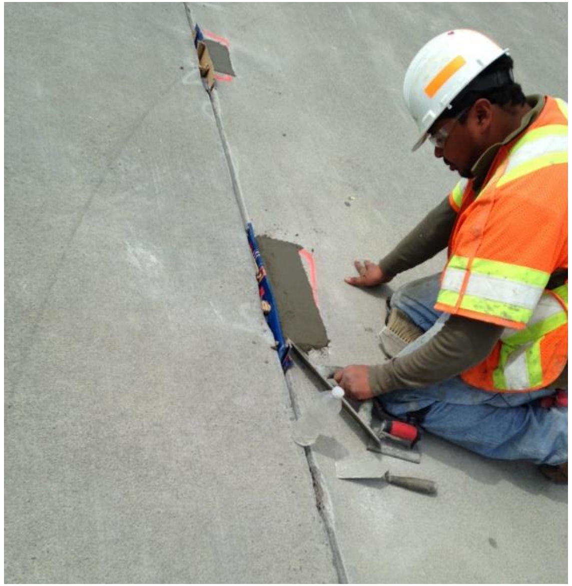

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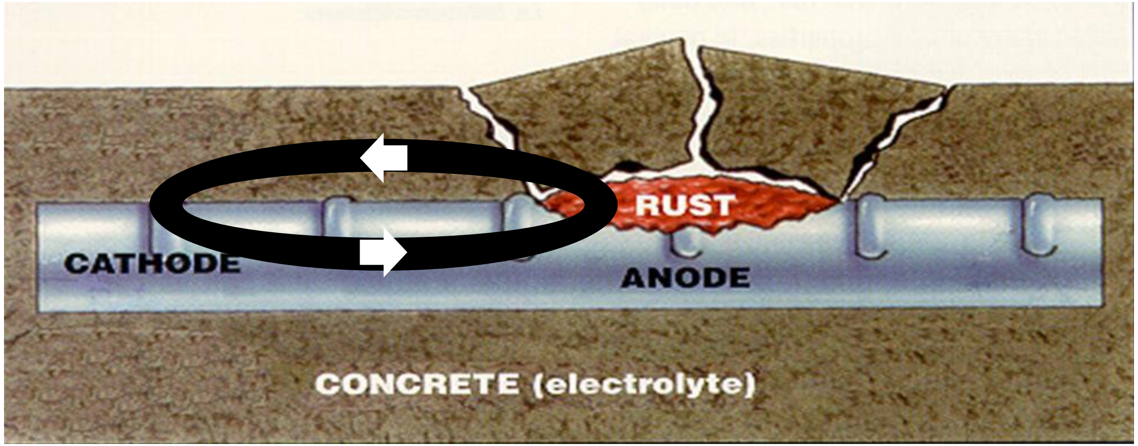
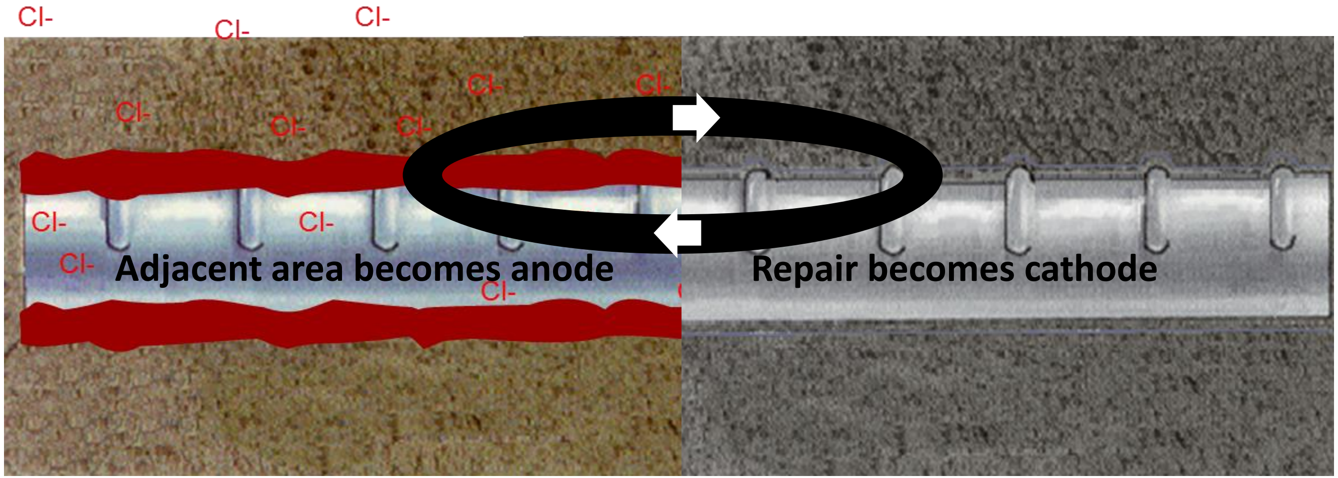
CORROSION PROCESS

- ✓ Current flows between cathode and anode through steel and concrete
- ✓ Electrical current flow is governed by Ohm's Law
- ✓ V = IR Potential Difference (V) = Current (I) x Resistance (R)
- ✓ V = IR Current (I) is the concern
- ✓ I = V/R Current (I) = Potential Difference (V) / Resistance (R)
- ✓ To lower Current (I), increase Resistance (R)



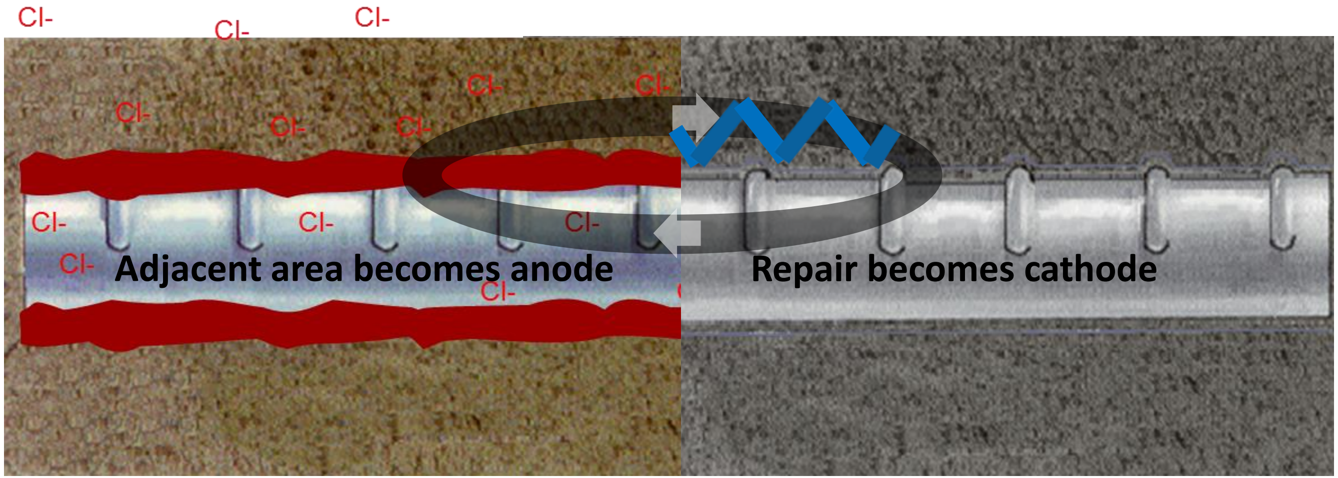
RESISTIVITY OF REPAIR MATERIALS

- ✓ Material permeability measured in coulombs, ≈ inverse of resistivity (ohm-cm)
- ✓ Typical concrete about 3,000 – 4,000 coulombs (moderate)
- ✓ A repair turns the anode to a cathode
- ✓ Increased corrosion activity around perimeter of repair referred to as ‘incipient anode’, ‘anodic ring effect’, or ‘halo effect’



RESISTIVITY OF REPAIR MATERIALS

- ✓ Increase resistance using a higher resistivity (lower permeability) repair material
- ✓ Repair materials available with < 500 coulombs (very low)
- ✓ 6 times better resistance than moderate permeability repair materials to currents and intrusion of chlorides and carbonation

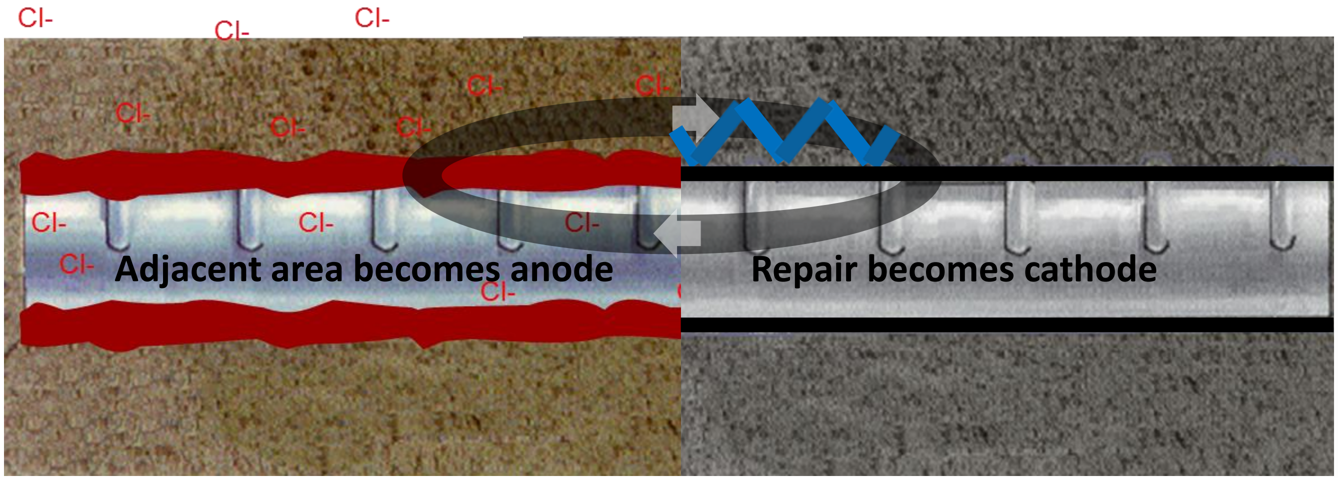


REINFORCEMENT COATING

- ✓ This epoxy coated rebar was investigated after 30 years, revealing protective value
- ✓ Using epoxy coated rebar on top mat of garage decks and uncoated rebar on bottom mat, has resulted in corrosion and spalling on the underside where chloride content is lower

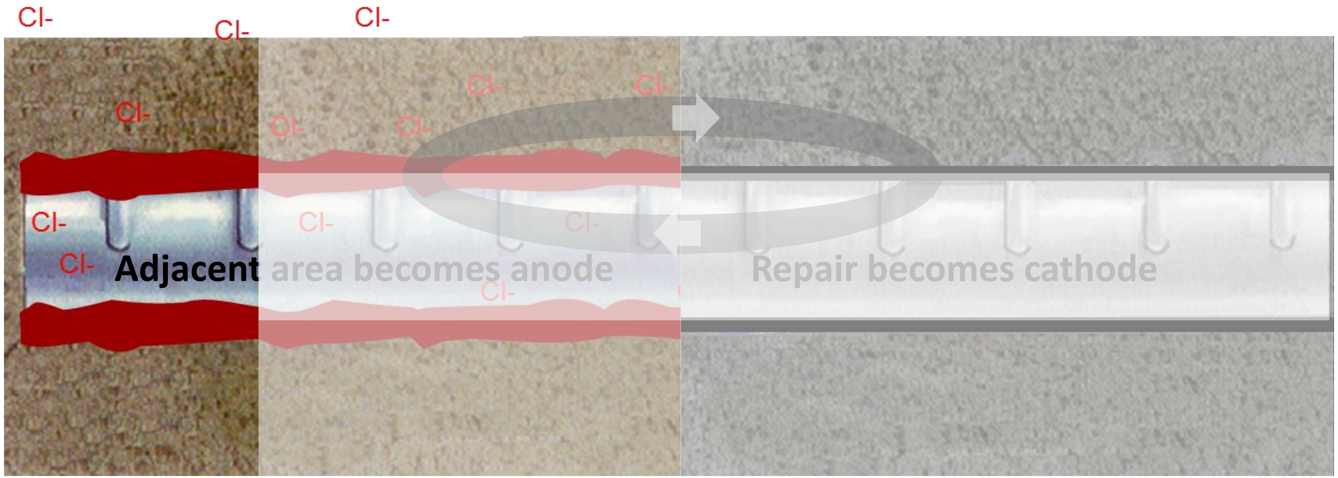
REINFORCEMENT COATING

- ✓ Reinforcement coatings add substantially more barrier properties and resistance
- ✓ Epoxy, epoxy-cement, enhanced-cement, and zinc-rich materials



INTEGRAL CORROSION INHIBITOR

- ✓ Integral corrosion inhibitor protects within the repair and migrates inches outside repair to reduce incipient anode corrosion (amino alcohol)
- ✓ Corrosion inhibitor electrochemically bonds to steel surface and excess remains in concrete to replenish itself



COMPATIBILITY WITH PARENT CONCRETE

- ✓ If mix is chiefly Portland cement and silica aggregates, then it will be thermally compatible
- ✓ Low modulus epoxy mortars are acceptably compatible up to ½” depth
- ✓ Neat epoxy and high modulus resins generally acceptable up to ¼” depth
- ✓ Interior/temperature stable environments would allow for deep epoxy mortar/concrete repairs
- ✓ Repair material can have higher compressive strength than parent concrete while having lower modulus of elasticity (latex polymer)

Material	Compressive	Elastic Modulus
Concrete	4,500 psi	4×10^6
SikaTop 111 PLUS	6,500 psi	3×10^6
Sikadur 22 Lo-Mod mortar	7,900 psi	6.6×10^4

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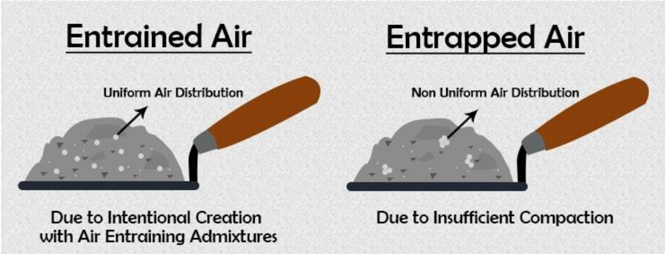
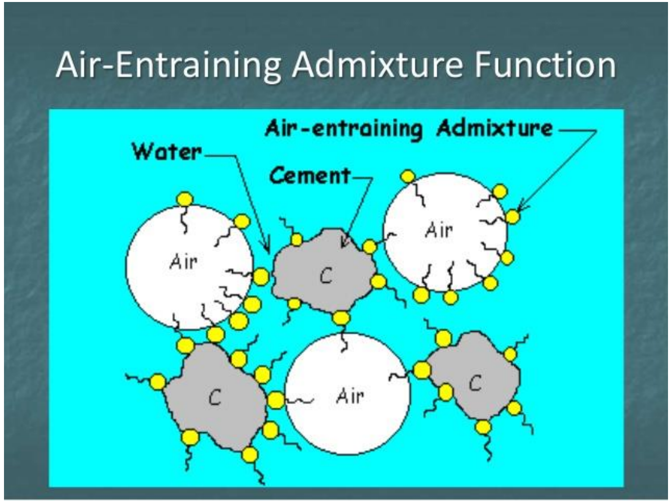
FREEZE/THAW RESISTANCE

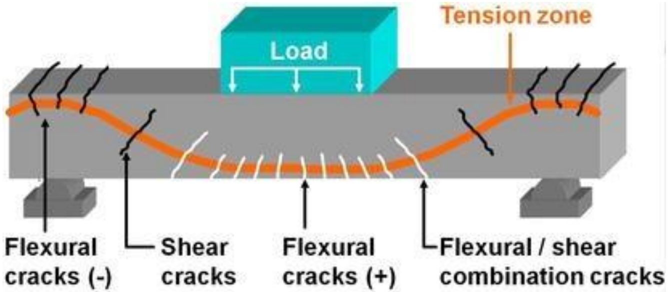
- ✓ Air entrainment (usually 4-7%) provides tiny voids (where liquid water does not enter) around pores where liquid water does enter. When the water freezes in the pores, it can expand into the air entrainment voids.
- ✓ Air entrainment can be worked out of surface from excess finishing
- ✓ Mortars inherently have more air entrainment than concretes
- ✓ Air entrainment is very good indicator of freeze/thaw resistance, but actual freeze/thaw testing is the best
- ✓ Polymer modification can greatly improve freeze/thaw resistance by reducing water absorption





STRENGTHS

- ✓ Select materials with appropriate adhesion and physical properties for the application
- ✓ Generally, similar or higher strengths than parent concrete



REPAIR MATERIAL SELECTION

Application	Premium Performance	High/Speed Performance	Quality Performance
Vertical/Overhead Trowel Mortar	SikaTop 123 PLUS Sikacrete 226 CI	SikaQuick VOH	SikaRepair 223
Pour/Pump Concrete	Sikacrete 211 SCC Plus Sikacrete 360 SCC	Sikacrete 421 CI Rapid	Sikacrete 100 CI Sikacrete 211
Pour/Pump Mortar (3/8" gravel can be added)	SikaTop 122 PLUS SikaTop 111 PLUS Sikadur 43 Patch-Pak	SikaQuick 2500 SikaQuick 1000 SikaQuick FNP	SikaRepair 222 SikaGrout 328
Leveling Mortar	SikaTop 121 PLUS SikaTop 122 PLUS Sikadur 22 Lo-Mod	SikaQuick Smooth Finish SikaQuick Resurfacer SikaQuick EZ Patch	SikaRepair 222
Spray Apply Mortar	Sikacem 133/226 CI	Sigunit L72 AF	Sikacem 103 Sikacem 103F

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Application	Premium Performance	High/Speed Performance	Quality Performance
Vertical/Overhead Trowel Mortar	SikaTop 123 PLUS Sikacrete 226 CI	SikaQuick VOH	SikaRepair 223

PERFORMANCE ANALYSIS

Property	SikaTop 123 PLUS	SikaQuick VOH	SikaRepair 223
Components	2	1	1
Compressive 28 day	7,000 psi	5,500 psi	7,500 psi
Polymer	Yes - liquid	Yes - dry	No – optional liquid
Fibers	No	Yes	No
Permeability	<500 coulombs	< 1000	No data (3000-4000)
Corrosion Inhibitor	Yes – Data (>65%)	Yes – No data	No
Applied Thickness	1/8”-2” per lift	1/8”-3” per lift	1/4”-1.5” per lift
Shrinkage	<.05%	<.05%	No data
Overcoat Time	3 day	6 hour	5 day

PRICE AND VALUE ANALYSIS (EXAMPLE)

- ✓ Example of a typical 2” vertical trowel-applied repair assuming installed price without repair material to be $50.00/SF.
- ✓ Corrosion resistance in equivalency to 3,000 coulomb concrete.

Property	SikaTop 123 Plus	SikaQuick VOH	SikaRepair 223
Price/SF at 2” Depth	$16.03	$6.31	$5.41
Installed Price/SF	$66.03	$56.31	$55.41
Corrosion Resistance	9 times more for 19% more money	3 times more for 2% more money	1
Value	Highest value	Better value	Lowest price

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Corrosion Resistance	9 times more for 19% more money	3 times more for 2% more money	1
Value	Highest value	Better value	Lowest price

- Consider the conditions and service environment
- Consider role in the project repair and protection strategy

SPECIFICATION DO'S & DON'TS – PREPACKAGED MATERIALS

DO SPECIFY PERTANENT PROPERTIES

- ✓ Strengths
  - (> 5,000 psi … ASTM C-109)
- ✓ Shrinkage
  - (< .06% ... ASTM C-157)
- ✓ Permeability
  - (< 500 coulombs … ASTM C-1202)
- ✓ Freeze/thaw resistance

  (> 97% @300 cycles … ASTM C-666)

DON'T SPECIFY A MIX DESIGN

- Water-cement ratio
- Aggregates
- Air entrainment
- Polymer modified
- Microsilica/Silica fume
- Water reducers/other admixtures
- Fibers

Prepackaged materials already have a specific mix design to deliver performance properties

AVAILABLE RELATED PRESENTATIONS

- ✓ Concrete Repair (Part 1 – Material Selection)
- ❑ Concrete Repair (Part 2 – Preparation & Installation)
- ❑ Crack Repair
- ❑ Concrete Protection
- ❑ Deck Coatings

Baltimore Design School – 2014 ICRI Sustainability Award Winner

THANK YOU FOR YOUR ATTENTION!

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