Achieving Durability In Concrete Repair

Peter Emmons
Agenda

- Causes of Deterioration
- Surface Preparation
- Repair Materials
- Placement Techniques
  - Hand trowel
  - Horizontal Placement
  - Formed
  - Shotcrete
- Quality Assurance/Control
Repair Performance
An Industry Problem

- Good
- Fair
- Poor
- Failed!
Cause & Effect

Defect, damage or deterioration

• Leakage
• Settlement
• Deflection
• Wear
• Spall
• Disintegration
• Crack

Surface Repair

• Spalling
• Disintegration
Embedded Metal Corrosion

Cause: Chloride Penetration

- Oxygen
- Chlorides
- Moisture

Crack
Embedded Metal Corrosion

The Effects of Chlorides

- Expansion of rebar (spall)
- Loss of strength
- Conduit for more corrosion
- Loss of deformations (lose interlock)

Rebar
Embedded Metal Corrosion
Embedded Metal Corrosion

Slab Soffit Spall
Embedded Metal Corrosion

Cause: Carbonation

Carbon dioxide + moisture → pH decreases

pH 13 → pH 10 → Corrosion
Embedded Metal Corrosion

Detecting Carbonation

Acrylic coating
Stucco
Crack
Embedded Metal Corrosion

Detecting Carbonation
Repair Techniques

Surface Preparation
Concrete Repair Process

**Effect:** Concrete spall
Surface Repair

The Process

- Condition
- Removal
  - Surface prep
- Material selection
  - Placement technique
Surface Repair

Improper Surface Preparation

Before 1989
Why Here,

Not Here?
Surface Repair

Repair Geometry

Delaminated, cracked areas

Incorrect layout

Recommended layout
Surface Repair

Repair Geometry

beam section

slab or wall section

damaged edge section
Proper surface preparation

ICRI Guideline 310.1R-2008
www.icri.org
Concrete Removal

Chipping Hammer for Reinforcing Steel Detail Work

15# Hammer, No bigger than 30#
60-90 # Breakers for Full Depth Demolition Only
◆ Substrate Microfracture
◆ Reinforcing Steel Bond Effects
◆ Edge Spalling
Video of Hydro Demo 2:25
Reinforcing Steel Repair & Protection
Reinforcing Repair

Natural Protection

High pH Creates Passivating Layer On Steel
Reinforcing Repair

Surface Preparation of Bars

- Cleaning required to remove bond inhibiting materials
- Heavy mill scale removed
- Heavy rust layers removed
- All oxide does not need to be removed
- Sandblasting preferred method
- Degree of blasting??
Surface Repair

Proper surface preparation

90°

3/4"
Reinforcing Repair

Cleaning with wire wheel
Corrosion of Steel in Concrete

Diagram showing the process of corrosion in concrete with key components labeled:
- Cathode
- Anode
- Crack
- Current Flow
- Rebar
Patches and Ring Effect
Reinforcing Repair Choices for Protection

- Nothing Additional
- Alkaline slurry
- Inhibitor Treatment
- Zinc
- Zinc on surface
- Impressed current
- Epoxy Encapsulation
Reinforcing Repair

Epoxy Coating of Bars

- No undercutting to expose bars
- Uneven chemical environment will cause rapid repair failure
Reinforcing Repair

Field Applied Epoxy Bar Coating

- Electrical insulation
- Hard to protect full bar
- Impossible at bar intersections
- Is this a good method??
Reinforcing Repair

Zinc Rich Primer Protective Layer

- Cathodic protection
- Not recommended in aggressive environments i.e. cast-in chlorides
Repair of Corroded Bars

Lost Cross Section
Deteriorated Reinforcement
Sawcutting, Too Much of a Good Thing
Reinforcing Repair

Lap Splice

Required Lap

Supplemental Bar

Required Lap

Affected Length
Reinforcing Repair

Rebar Splicing

- Swedged
- Stick Weld
- Threaded Coupling

* Lap length shall be determined in accordance with ACI 318; also refer to AASHTO and CRSI Manuals.
Material Selection
Drying Shrinkage
Moisture Loss

Evaporation

Absorbed Water

Autogenous Volume Changes
Drying Shrinkage Cracking

Specify low shrinkage materials
C-157 less than .05%
Shrinkage Test Results
Repair Materials

- Low Shrinkage
- Moderate Shrinkage
- High Shrinkage

Increased tendency to crack

Shrinkage, %

Concrete
Repair Material Choices

- **Portland Cement Concrete**
  - *Ready Mix Concrete*
  - *Bagged*

- **Modified Portland Cement Concrete**
  - Silica Fume
  - Polymer (Acrylic, Latex)
  - Corrosion Inhibitors
  - Flowing Agents- HRWR, SCC
  - Non Sag Fillers
  - Fibers
  - *Bagged – Proprietary*
  - *Ready Mixed*

- **Special Cements**
  - Magnesium Phosphate

- **Polymer Cement Mortars**
  - **Epoxy Binder**
Silica Fume Characteristics

- 7% silica fume replacement of cement
- Approximately 2M particles of silica fume for each grain of cement
- Very high strengths or very high levels of durability or both
What is Polymer-Cement Concrete/Mortar?

- Organic polymers (SBR most common) dispersed in water combined with portland cement and aggregate combined during mixing
- Spheres 0.05-0.20 microns in diameter
- 1-in. cube of dried film would contain about 200M particles
- Polymer modification
  - Hydration of cement
  - Coalescence of polymer
Formation of Polymer Film
Simplified Model

- Flocculation of latex particles
- Formation of close-packed structure of latex particles
- Drainage of water between particles
- Coalescence of latex particles
- Cement hydrates enveloped with latex films or membranes
Bagged Repair Materials

“a two component polymer modified cement based, fiber reinforced concrete waterproof repair mortar.”
Bagged Repair Materials

- XXXXX repair mortar is a one-component rheoplastic,
- shrinkage-compensated,
- fiber-reinforced product that
- contains an integral corrosion inhibitor.
- It contains silica fume
- to offer high strength and superior performance for structural concrete repairs. XXXX can be applied vertically or overhead by low-pressure spraying or hand troweling
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Shrinkage?
### Typical Data Sheet

**Typical Data (Material and curing conditions @ 73°F (23°C) and 50% R.H.)**

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Shrinkage? Cracking Resistance?
1. Developing protocol for selection of material with defined test methods and commentary
Shrinkage Reduction

Addition of Stone to Mortar reduces shrinkage 70%
Introduction to Placement Methods
Placement

- Moisture Conditioning
- Bonding Repair Mat’l to Substrate
- Placement Techniques
- Quality Assurance
Achieving Bond

Bond Mechanisms

- Mechanical Interlock
- Absorption into Pores

Tensile Bond

Shear Bond
Surface Repair

Bonding Mechanism: Open Pores

After chipping

Existing

After repair

New

Existing
Moisture Conditioning

Dry Substrate?

Wet Substrate?

SSD?
Placement Process

- Moisture Conditioning
- Bonding Agents
- Material Placement
- Material Curing
Achieving Bond

Bonding Agents

- Are they necessary?
- Types
- Problems
Sand Cement Slurry Broomed into Prepared Substrate
Achieving Bond Quality Assurance

- Field Mockups
  - Evaluate Methods
  - Evaluate Materials
  - Evaluate Results
Core
Repair
Substrate
Achieving Bond
Quality Assurance

◆ Visual Evaluation

Full Depth Core
References Direct Tensile Pulloff Testing

◆ New ASTM Standard 1583
  - Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)

◆ ICRI Guideline 210.3-2004
  - Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of Concrete Surface Materials
Design
- Type of bonding agent
- Repair material volume change vs. substrate
- Freeze-thaw behind repair material

Field Workmanship
- Application of bonding agent
- Surface prep around reinforcing steel
- Surface prep of deteriorated concrete
- Placement of repair material

Achieving Bond

Bond Failure

Causes:
Pavement Repair

No Preparation
Bond Failure

- Incomplete Surface Preparation
  - Bruising
  - Microfracture
Achieving Bond

Bond Failure

- Bruising
Achieving Bond

Bond Failure

Cured Bonding Agent Prior to Placement of Repair Material
Achieving Bond

Bond Failure

- Interlayer Adhesion
- Multiple Bond Lines
- Durability?
Achieving Bond

Bond Failure

Reimulsifible Bonding Agent (PVA)

Exterior Application Wetting and Drying
Placement Process

- Bonding Agents
- Moisture Conditioning
- Material Placement
- Material Curing
Placement Method Considerations

- Encapsulate Reinforcing Steel
- Uniform Material Delivery
  - NoSegregation
- Complete Filling of Cavity
Intimate Contact

New Material to Substrate
Placement Techniques

- Dry Packing
- Hand Layup (Trowel)
- Full Depth
- Overlays
- Partial Depth
Hand Lay Up

Achieving Bond

- Intimate Contact by Hand Pressure
Achieving Bond

Bond Failure

◆ Interlayer Adhesion

◆ Multiple Bond Lines

◆ Durability?
Hand Applied Issues

Drying
Shrinkage
Cracks in this thick application
>3”
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Modulus? Shrinkage?
Trowel Applied- best uses

- Thin Applications
- When reinforcement not involved
Rebar
Existing concrete
Void
Rebar

BEAUTY IS ONLY SKIN DEEP.
Ugly goes clear to the bone.
Placement Techniques

- Dry Packing
- Hand Layup (Trowel)
- Full Depth
- Overlays
- Partial Depth
Thin Overlay Polymer Cement

- Water
- Latex particles
- Unhydrated cement
- Flocculation of latex particles
- Cement gel & hydrates
- Drainage of water between particles
- Coalescence of latex particles
- Latex film
- Cement hydrates
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<td>Application Time</td>
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**Flexural Strength (ASTM C-293)**
- 28 days: 1,500 psi (10.3 MPa)

**Splitting Tensile Strength (ASTM C-496)**
- 28 days: 700 psi (4.8 MPa)

**Bond Strength* (ASTM C-882 modified)**
- 28 days: 2,500 psi (17.2 MPa)

**Compressive Strength (ASTM C-109) (mortar)**
- 1 day: 2,500 psi (17.2 MPa)
- 7 days: 5,500 psi (37.9 MPa)
- 28 days: 7,000 psi (48.3 MPa)

**Permeability (AASTHTO-277)**
- 28 days: Approx. 500 Coulombs

**Electrical resistivity (ohm-cm)**
- 35,000

**Freeze/Thaw Resistance (ASTM C-666)**
- 300 cycles: 98%
Advanced Placement Techniques

- Form and Pour
- Form and Pump
- Shotcrete- Dry and Wet Mix
- Precast
Surface Repair

Form & pour before...
Surface Repair

Form & pour formed...
Surface Repair
Form & pour after...
Form and CIP

Formwork Construction
- Liquid Pressure of Concrete
- Design per ACI formwork Guidelines
- Chutes / Access to Place Material
- Fill Cavity Completely

Vertical & Overhead Applications
Form and CIP

Keys to Success

- Formwork Construction
- Surface Conditioning
- Material Selection
  - Flowable
  - Non-Segregating
  - Low Shrinkage
- Placement Selection
  - Pump
  - Gravity Feed
- Curing
  - Forms in Place
Achieving Bond

- Vibration
  - Internal
  - External

- Final Drypack as Required
Advanced Placement Techniques

- Form and Pour
- Form and Pump
- Shotcrete- Dry and Wet Mix
- Precast
Surface Repair
Form & Pump
Form and Pump Advantages

- Repair Material Selection
  - Fine to Coarse Aggregates
- Uniformity of Material Delivered
- Encapsulation of Reinforcing Steel
- Formwork Pressurization & Bond
- Formwork Curing
Form and Pump Procedure

- Surface Preparation
- Surface Conditioning
- Formwork Erection
- Port Locations
  - 3 - 4 Ft. on Center
- Pressure Gauges
- Proper Venting
Form and Pump Procedure

- **Cavity Filling**
- **Vertical Repairs**
  - Fill From Lowest Points
- **Pump from Port to Port**
- **Monitor Pressure**
Form and Pump Procedure

Achieving Bond
- Expel Entrapped Air
- Form Pressurization
  - Gauge Pressure
  - Formwork Design Pressure
  - Communication
- Formwork Failures
Tensile Anchor Attachment
Compression
Shoring
Attachment
Flowable Self Leveling Repair Materials

Self-Consolidating Concrete (SCC) can be consolidated without vibration and fills formwork by means of its own weight without segregation.

An Admixture
Cone Test
SCC Admixture
Advanced Placement Techniques

- Form and Pour
- Form and Pump
- Shotcrete - Dry and Wet Mix
- Precast
Surface Repair

Shotcrete

Dry-mix
or wet-mix
What is Shotcrete?

“mortar or concrete pneumatically projected at high velocity onto a surface”
Mortar or Concrete

air injection ring
housing
air ring
Grooved
"O" ring seal

control valve
street elbow
nozzle tip
clamp
ACI 506 Specimens
ACI 506 Specimens
Surface Repair
Shotcrete
Concentrated or large bars...
Surface Repair

**Shotcrete**

...lack of consolidation around rebar

Existing concrete

Void

Rebar

Rebar

Shotcrete...
Dry Mix Shotcrete
Wet Mix Shotcrete
Wet Mix Shotcrete
Quality Control of Materials
Additional Information

- www.Fixconcrete.org
  - 1500 videos from ICRI & ACI Technical Mtgs
  - Free

- Repair Manual 2000 Pages
  - ICRI
  - ACI
  - $125
Thank You!

Any Questions?

Peter Emmons