Fred Goodwin FACI, FICRI  
Chair ACI 515 Protective Systems for Concrete  
Fellow Scientist  
BASF Construction Chemicals

Agenda

• Background  
• Aggressive Substances  
• Protective Systems and Treatments  
• THE Tables  
• Notation  
• Next Steps
What is Concrete?

- Concrete is economical with a long life & low maintenance
- Concrete does not rot, corrode, or decay.
- Concrete can be molded or cast into almost any desired shape.
- Concrete is fire-safe & able withstand high temperatures.
- Concrete is resistant to wind, water, rodents, and insects.
- 12 BILLION cu meters per year globally
- ~1 cu yd / person / year in USA
- >70 Billion cu meters placed in USA since 1930
  with ~10 Billion cu meters > 20 years old

However……..

- The cost to owners for concrete repair, protection, and strengthening in US is $18 to $21B /yr (2004)
  [link]
- The cost of corrosion of concrete reinforcement is > $125B / yr
  [link]
- A 7 year infrastructure investment of $3.6 trillion is needed to return to quality of 1988 infrastructure C→D+
  [link]
How does concrete fail?

- Concrete has (compared to other building materials)
- low tensile strength (~10% of compressive strength),
- low ductility (it’s brittle),
- low strength-to-weight ratio (it’s heavy),
- responds to environment (it changes with time)
- has permeability (ingress of deleterious materials)
- is susceptible to chemical attack (acids, AAR, etc.)
- and it cracks.
- Steel corrodes
  - Chloride, carbonation, and polarization interaction
  - Rust expands, causing cracking, spalling, and eventual failure

ALL of these properties change as the concrete ages.

The Problem

- Total wholesale value of all floor coverings and coatings sold in 2011 was estimated at 22 billion dollars.
- Floor system failures estimated to cost $300 million to 1 billion dollars annually
- Most failures involve moisture in some way.

ICRI 710 draft Moisture-Related Issues with Concrete Floor Finishes

2005 Study:
- Over 1.1 billion ft.² new slabs constructed
- Additional 1 billion ft.² remodel/adaptive reuse
- < 20% tested

Lee Eliseian, President Independent Floor Testing & Inspection, Inc, SPECS 2012
ABSTRACT

- Concrete structures can be subjected to physical or chemical attacks by various substances, including water, acids, alkalis, salt solutions, and organic chemicals.
- Damage may vary in intensity from surface discoloration or roughening to catastrophic loss of structural integrity due to acid attack or reinforcing steel corrosion.
- In 2013 ACI 515 published their "Guide to Selecting Protective Treatments for Concrete"
- This document
  - Compares the extent of chemical attack for >300 chemicals on concrete
  - Suggests possible preventative surface treatments to minimize these effects.
- Many of the conditions effecting the installation of coatings on concrete such as concrete condition assessment, surface preparation, and service conditions will be forthcoming in future documents.

History of ACI 515

- 1936 Committee Founded
- 1966 Published “Guide for the Protection of Concrete Against Chemical Attack by Means of Coatings and Other Corrosion Resistant Materials”
- 1979 Published “A Guide to the Use of Waterproofing, Dampproofing, Protective, and Decorative Barrier Systems for Concrete”
- 1985-1986 Revised and Published 515.1R-79 (revised 1985) in MCP
- 2007 PCA IS001 “Effects of Substances on Concrete and Guide to Protective Treatments”, Beatrix Kerkhoff
- Restructured committee tasks, “borrowed” from PCA IS001 for “the missing link”
- 2013 Published ACI 515.2R-13 “Guide to Selecting Protective Treatments for Concrete”
- 2013 began development of additional documents
  - 515.AR: Guideline for Dialog Between the Specifier and the Owner for Protective Systems for Concrete
  - 515.ZR: Assessment, Surface Preparation, and Application Guide for Protective Systems for Concrete (Draft balloted)
515.2R-13: Guide to Selecting Protective Treatments for Concrete

• CHAPTER 1—INTRODUCTION AND SCOPE
• CHAPTER 2—NOTATION AND DEFINITIONS
• CHAPTER 3—TABLES OF CHEMICALS, THEIR EFFECTS ON CONCRETE, AND PROTECTIVE TREATMENTS
  – 3.1—Aggressive substances
  – 3.2—Treatment methods
• CHAPTER 4—PROTECTIVE TREATMENTS AND SYSTEMS DESCRIPTIONS
• CHAPTER 5—REFERENCES

3.1—Aggressive substances

• Table 3.1a—Acids
• Table 3.1b—Salts and alkalis
• Table 3.1c—Petroleum oils
• Table 3.1d—Coal-tar distillates
• Table 3.1e—Solvents and alcohols
• Table 3.1f—Vegetable oils
• Table 3.1g—Fats and fatty acids (animal)
• Table 3.1h—Miscellaneous substances

Alum \(\rightarrow\) Zinc Slag
Table 3.1a—Acids

<table>
<thead>
<tr>
<th>Acids</th>
<th>Name</th>
<th>Effect on concrete</th>
<th>Protective treatments</th>
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<tbody>
<tr>
<td>Acetic acid, less than 10 mass percent</td>
<td>a. Slow disintegreation</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
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<td>Acetic acid, 10 mass percent</td>
<td>a. Slow disintegreation</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
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</tr>
<tr>
<td>Acetic acid, 100 percent (special)</td>
<td>Slow disintegreation</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
<td></td>
</tr>
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<td>Acid water</td>
<td>b. Slow disintegretion. In porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall.</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
<td>17, 24, 25</td>
</tr>
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<td>Acid water, (pH 6.5 or less)</td>
<td>b. Natural, slightly acid water could erode surface mortar, but these actions usually stops. Disintegretion increases as pH decreases.</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
<td>17</td>
</tr>
<tr>
<td>Ammonium acid</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boric acid</td>
<td>Negligible effect</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
<td>17, 24, 25</td>
</tr>
<tr>
<td>Borate acid</td>
<td>a. Slow disintegretion</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
<td></td>
</tr>
<tr>
<td>Carbonic acid (soda water, club soda)</td>
<td>0.9 to 3 ppm of carbon dioxide dissolved in water. Disintegretion concrete slowly, and high concentration are slightly more aggressive.</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
<td></td>
</tr>
<tr>
<td>Chromic acid, 5 mass percent</td>
<td>b. None. in porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall.</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
<td>19</td>
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<tr>
<td>Chromic acid, 50 mass percent</td>
<td>b. None. in porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall.</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
<td>19</td>
</tr>
<tr>
<td>Formic acid, 10 mass percent</td>
<td>a. Slow disintegretion</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
<td>17, 24, 25</td>
</tr>
<tr>
<td>Formic acid, 90 mass percent</td>
<td>a. Slow disintegretion</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
<td>17</td>
</tr>
<tr>
<td>Hydrazine acid</td>
<td>a. Slow disintegretion. (aggressiveness depends on bacterial type.)</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII)</td>
<td>25</td>
</tr>
<tr>
<td>Hydrochloric acid, 30 mass percent</td>
<td>Rapid disintegretion, including steel.</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII, VII, VIII)</td>
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<td>17, 24, 25</td>
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<tr>
<td>Hydrochloric acid, 80 mass percent</td>
<td>Rapid disintegretion, including steel.</td>
<td>2, 7, 8, 9, 10, 11, 12, 13, 14 (II, III, V, VI, VII, VIII, VII, VIII)</td>
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<td>17, 24, 25</td>
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</tbody>
</table>
Notes
Special notation characters are referenced in Tables 3.1a through 3.1h to provide further clarification of specific chemicals and are shown as letters in the column headed “Notes.”

<table>
<thead>
<tr>
<th>Character</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>sometimes used in food processing or as food or beverage ingredient; ask for advisory opinion of Food and Drug Administration (FDA) regarding coatings for use with food ingredients.</td>
</tr>
<tr>
<td>b</td>
<td>water with a pH higher than 6.5 may be aggressive if it also contains bicarbonates; natural water is usually of pH higher than 7.0 and seldom lower than 6.0, though pH values as low as 0.4 have been reported (Nordstrom et al. 2000); for pH values below 3, protect as for dilute acid.</td>
</tr>
<tr>
<td>c</td>
<td>frequently used as a deicer for concrete pavements. If the concrete contains too little entrained air, a poor-quality air-void system, or has not been aged more than 1 month, repeated application may cause surface scaling; for protection under these conditions, refer to deicing salts.</td>
</tr>
<tr>
<td>d</td>
<td>carbon dioxide dissolves in natural waters to form carbonic acid solutions; when it dissolves to an extent of 0.9 to 3 ppm, it is destructive to concrete.</td>
</tr>
<tr>
<td>e</td>
<td>frequently used as deicer for airplanes; heavy spillage on runway pavements containing too little entrained air may cause surface scaling.</td>
</tr>
<tr>
<td>f</td>
<td>in addition to the intentional fermentation of many raw materials, much unwanted fermentation occurs in the spoiling of foods and food wastes, also producing lactic acid.</td>
</tr>
<tr>
<td>g</td>
<td>contains carbonic acid, fish oils, hydrogen sulfide, methyl amine, brine, and other potentially reactive substances.</td>
</tr>
<tr>
<td>h</td>
<td>water used for cleaning coal gas; compositionally, coal-washing gas can contain gases based on hydrogen sulfide, ammonia, carbon dioxide, and carbon monoxide (Kohl and Neilsen 1997); the reported pH can range from as low as 5.7 to as high as 8.5.</td>
</tr>
<tr>
<td>j</td>
<td>in those limited areas of the United States where concrete is made with reactive aggregates, reactive aggregate reaction products can cause disruptive expansion.</td>
</tr>
<tr>
<td>k</td>
<td>composed mostly of nitrogen, oxygen, carbon dioxide, carbon monoxide, and water vapor; also contains unburned hydrocarbons, partially burned hydrocarbons, oxides of nitrogen, and oxides of sulfur. Nitrogen dioxide and oxygen in sunlight may produce ozone, which reacts with some of the organics to produce formaldehyde, peracetylnitrites, and other products.</td>
</tr>
<tr>
<td>l</td>
<td>contains chromium trioxide and a small amount of sulfate or nearly saturated ammonium chromic sulfate, and sodium sulfate.</td>
</tr>
<tr>
<td>m</td>
<td>many types of solutions are used, including (a) sulfate—contains copper sulfate and sulfuric acid (b) cyanide—contains copper and sodium cyanides and sodium carbonate (c) rochelle—contains these cyanides, sodium carbonate, and potassium sodium tartrate (d) others such as fluoborate, pyrophosphate, amine, or potassium cyanide</td>
</tr>
<tr>
<td>n</td>
<td>contains lead fluosilicates and fluosillicic acid.</td>
</tr>
<tr>
<td>p</td>
<td>reference to combustion of coal, which produces carbon dioxide, water vapor, nitrogen, hydrogen, carbon monoxide, carbohydrates, ammonia, nitric acid, sulfur dioxide, hydrogen sulfide, soot, and ashes.</td>
</tr>
<tr>
<td>q</td>
<td>molten paraffin absorbed by porous concrete that is subsequently immersed in water can cause concrete disintegration from sorptive forces.</td>
</tr>
<tr>
<td>r</td>
<td>contains nickelous chloride, nickelous sulfate, boric acid, and ammonium ion.</td>
</tr>
<tr>
<td>s</td>
<td>may contain various mixtures of blood, fats and oils, bile and other digestive juices, partially digested vegetable matter, urine, and manure, with varying amounts of water.</td>
</tr>
<tr>
<td>v</td>
<td>usually contains zinc sulfate in sulfuric acid; sulfuric acid concentration may be low—approximately 6 mass percent in low current density process—or higher, approximately 22 to 28 mass percent in high current density process.</td>
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### Table 3.1—Acids

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<td>a</td>
<td>Slow disintegration</td>
<td>9, 10, 14, 16 (II, III, V, VI, VII)</td>
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<tr>
<td>Acetic acid, 100 percent (glacial)</td>
<td></td>
<td>Slow disintegration</td>
<td>9, 10, 14, 16 (II, III, V, VI, VII)</td>
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<tr>
<td>Acetic anhydride</td>
<td></td>
<td>Slow disintegration</td>
<td>1, 2, 5, 6, 9, 10, 11, 12, 13, 16 (II, III, V, VI, VII, VIII) 17, 24, 25</td>
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<td>Acetic anhydride (pH 6.5 or less)</td>
<td>b</td>
<td>Natural; slightly acid waters could dissolve surface acetic acid but does not cause noticeable damage</td>
<td>2, 3, 5, 6, 8, 9, 10, 11, 13, 16 (II, III, V, VI, VII, VIII, VIII) 17</td>
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<td>Acetic acid, 50 mass percent</td>
<td>b</td>
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<td>Rapid disintegration, including steel</td>
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<td>Hydrochloric acid, 17 mass percent</td>
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<td>Rapid disintegration, including steel</td>
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</table>
CHAPTER 4
PROTECTIVE TREATMENTS AND SYSTEMS DESCRIPTIONS

- 4.1—Magnesium fluosilicate or zinc fluosilicate
- 4.2—Alkali silicates, sodium silicate (water glass), potassium silicate, lithium silicate
- 4.3—Drying oils
- 4.4—Coumarone-indene resin
- 4.5—Styrene-butadiene (SBR) copolymer resin
- 4.6—Chlorinated rubber
- 4.7—Chlorosulfonated polyethylene (hypalon)
- 4.8—Vinyls and latex-based materials
- 4.9—Bituminous paints, mastics, and enamels
- 4.10—Polyester and vinyl ester materials
- 4.11—Polyurethane/urethane
- 4.12—Epoxy
- 4.13—Neoprene
- 4.14—Polysulfide
- 4.15—Coal tar and coal-tar epoxy
- 4.16—Chemical-resistant masonry units, mortars, grouts, and concretes
- 4.17—Sheet rubber
- 4.18—Resin sheets
- 4.19—Lead sheet
- 4.20—Glass
- 4.21—Acrylics, methyl methacrylate (MMA), and high molecular-weight methacrylate (HMWM)
- 4.22—Silane, siloxane, and silicones (organosilicon compounds)
- 4.23—Metalizing
- 4.24—Crystalline coatings and admixtures
- 4.25—Polyurea
- 4.26—Adjunct additives

Aggressive Substances
+ Protective Treatments
≠ Solution

However...
Concrete Protective System Selection

Surface Constraints
Application Constraints
Service Conditions
Treatment Options
Owner Expectations

Concrete Protective System Selection

Concrete Quality
Exposure Before Installation
Orientation

Orientation
Horizontal
Sloped
Vertical
Overhead

On Grade
Vapor Barrier Present
No Vapor Barrier

Over Granular Fill
Under Granular Fill
Concrete Protective System Selection

- Surface Constraints
- Application Constraints
- Service Conditions
- Treatment Options
- Owner Expectations

Concrete Protective System Selection

- Application Constraints
- Regulations
  - USDA
  - FDA
  - DOA
  - OSHA
  - Other
- Specifications
  - Composition
  - Properties
  - Performance
- Return To Service Requirements
  - Installation Area
- Application Ambient Conditions
  - Brush
  - Roll
  - Spray
  - Roll and Spray
  - Lay and Orient
  - Deposit
- Cost
- Spillage
- Gage Rate
Surface Preparation Mechanism

- Cleaning
- Erosion
- Impact
- Pulverization
- Chemical Reaction
- Expansive Pressure
- Low pressure water
- Detergent scrubbing
- Grinding
- Bush Hammers
- Scabblers
- Scarifiers
- Abrasive Blasting
- Shotblasting
- Hydrodemolition
- Flame Scarification
- Emulsification
- Needle Scaling
- WET SUBSTRATE

Different Surface Preparation Methods Achieve Different Profile Ranges

<table>
<thead>
<tr>
<th>Surface Preparation Method</th>
<th>Separate Surface Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abrasive blasting</td>
<td></td>
</tr>
<tr>
<td>Low pressure water</td>
<td></td>
</tr>
<tr>
<td>Detergent scrubbing</td>
<td></td>
</tr>
<tr>
<td>Grinding</td>
<td></td>
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<tr>
<td>Bush Hammers</td>
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</tr>
<tr>
<td>Scabblers</td>
<td></td>
</tr>
<tr>
<td>Scarifiers</td>
<td></td>
</tr>
<tr>
<td>Abrasive Blasting</td>
<td></td>
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<tr>
<td>Shotblasting</td>
<td></td>
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<tr>
<td>Hydrodemolition</td>
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<tr>
<td>Flame Scarification</td>
<td></td>
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<tr>
<td>Emulsification</td>
<td></td>
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<tr>
<td>Needle Scaling</td>
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Bruising/Micro-Cracking, Microfracturing

Table: Surface Preparation METHODS and ACHIEVED PROFILE RANGES

- Abrasive blasting
- Low pressure water
- Detergent scrubbing
- Grinding
- Bush Hammers
- Scabblers
- Scarifiers
- Abrasive Blasting
- Shotblasting
- Hydrodemolition
- Flame Scarification
- Emulsification
- Needle Scaling

Bruising/Micro-Cracking, Microfracturing

Bruising and Micro-Cracking appearance of the profile depends on the concrete strength, the size and type of aggregate, and the type of the concrete surface. The sound substrate, if it is already sufficiently adhered to, remains adhered to the reinforced CSP substrate. As the depth of removal increases, the profile of the prepared section will be increasingly dominated by the size and type of the coarse aggregate.
Different Surface Profile Ranges Are Required for Different Materials

<table>
<thead>
<tr>
<th>Material to be applied</th>
<th>CSP 1</th>
<th>CSP 2</th>
<th>CSP 3</th>
<th>CSP 4</th>
<th>CSP 5</th>
<th>CSP 6</th>
<th>CSP 7</th>
<th>CSP 8</th>
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<td>0 to 3 mils (0 to 0.075 mm)</td>
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<td>4 to 10 mils (0.041 to 0.256 mm)</td>
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<td>High-build coatings</td>
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<td>1/8 to 1/4 in (3.0 to 6.4 mm)</td>
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<td>Self-leveling toppings</td>
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<td>5/64 in to 1/16 in (1.2 to 3 mm)</td>
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<td>Polymer overlays</td>
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<td>1/8 to 1/4 in (3.0 to 6.4 mm)</td>
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<td>Concrete overlays and repair materials</td>
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Factors of Durability of Concrete:
- Physical/Chemical Parameter
- Optimum Fineness
- High Strength
- High Soundness
- Lower Heat of Hydration
- Low Impurities
- Lower Permeability

Owner Expectations

Concrete Protective System Selection

THE BOTTOM LINE

Cost
- Appearance
- Durability
- Maintenance & Inspection Program
- Warranty/Guarantee
SELECTING PROTECTIVE CONCRETE TREATMENTS IS AN INFORMED COMPROMISE
BASF Construction Chemicals

Fred Goodwin, Fellow Scientist