Amine Based, Migrating Inhibitors for New Construction, Restoration & Specialty Applications

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December 2018

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Cortec Corporation

ENVIRONMENTAL ISO 14001 CERTIFIED SYSTEM REGISTERED

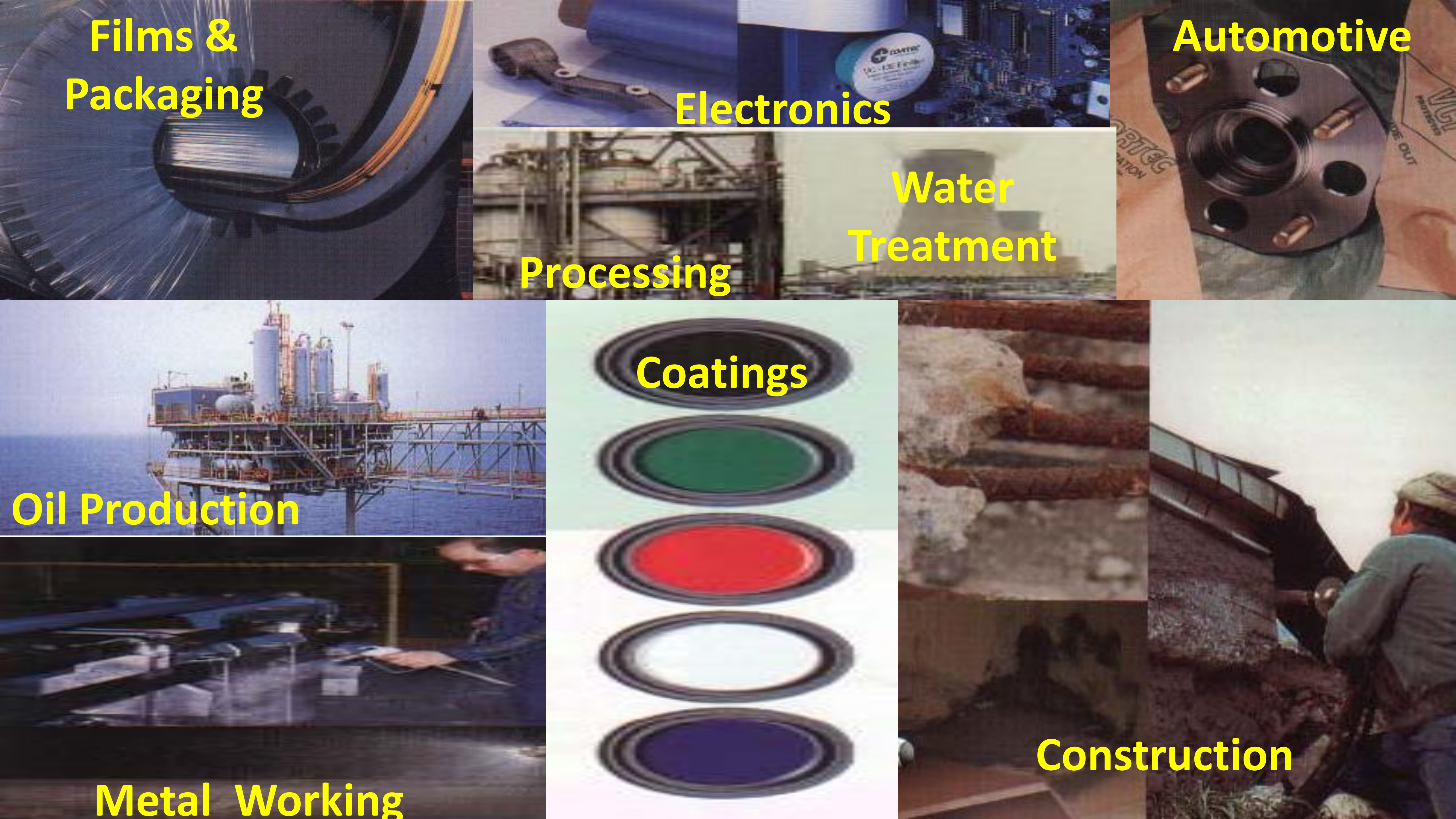
ISO 9001 CERTIFIED QUALITY SYSTEM REGISTERED

ISO/IEC-17025 LABORATORY TESTING CERTIFIED

MCI®

MIGRATING CORROSION INHIBITORS

FROM GREY TO GREEN


Films &
Packaging
Electronics
Automotive
Water
Treatment
Processing
Oil Production
Coatings
Metal Working
Construction

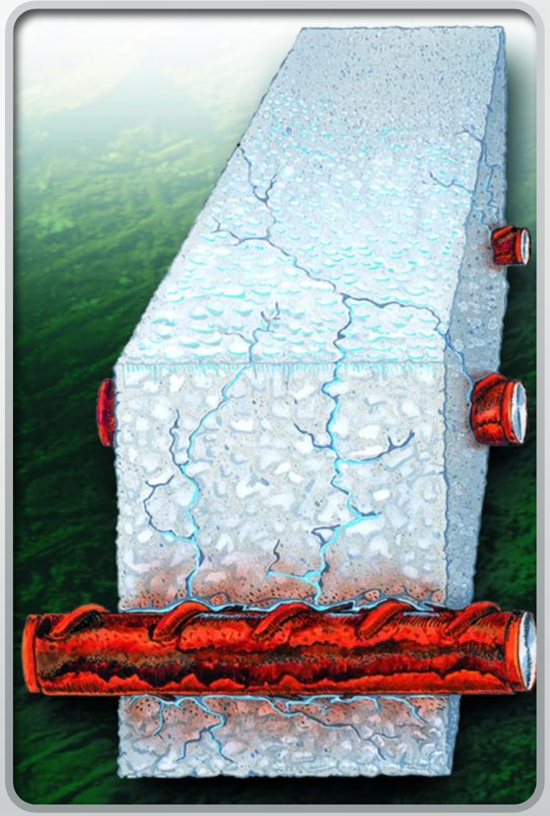
Overview

- Chemistry of Amine Based Corrosion Inhibitors (MCI)
- Assessment of Corrosion Protection
- Assessment of Migrating Ability
- New Construction Applications
- Repair Applications
- Specialty Applications
- Conclusions

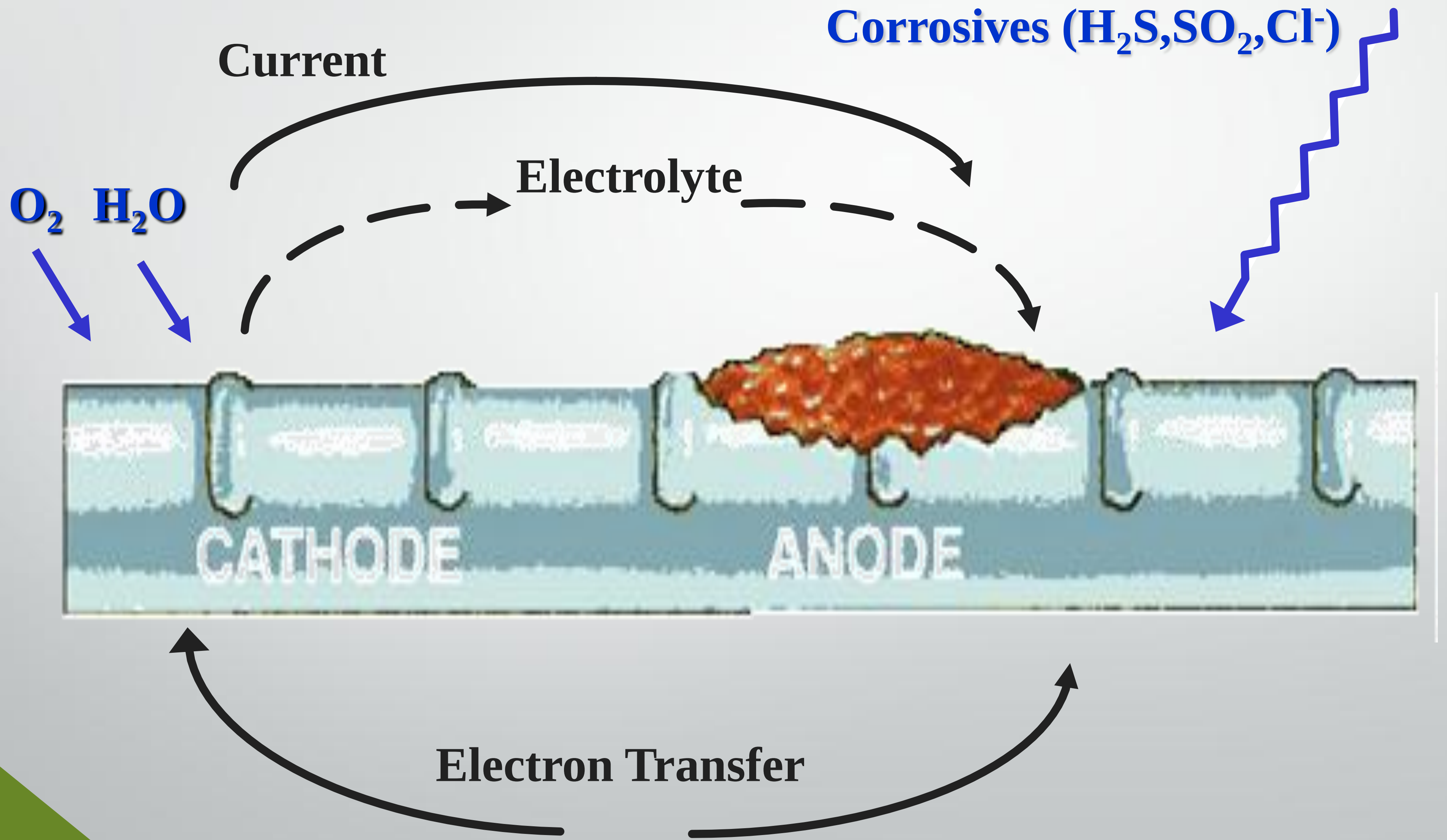
MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

How does corrosion occur?

- **Corrosion** is the destruction of metal by chemical, electrochemical, or electrolytic reaction within its environment (American Concrete Institute).



Understanding Corrosion



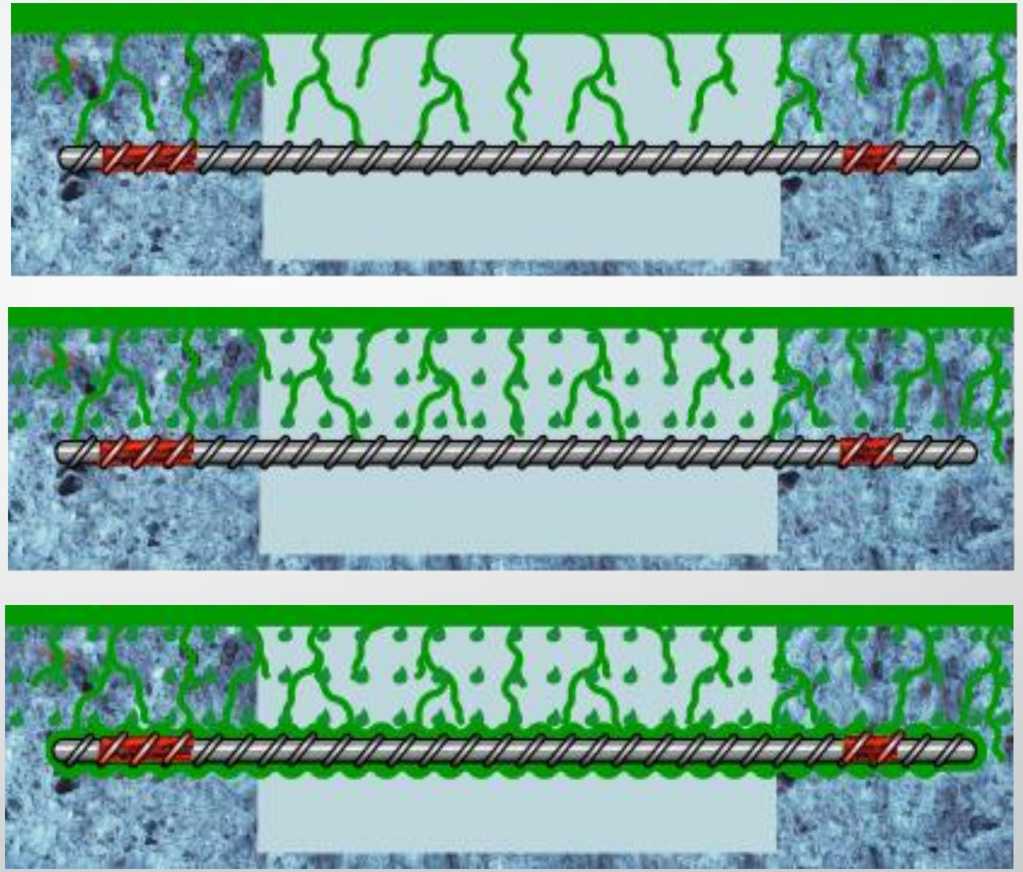
Amine Based Corrosion Inhibitors (MCI)

- Amine Based
- Affect both the anodic and cathodic reactions; shift the corrosion potential in the direction determined by the predominant reaction.
- Dosages may be greatly reduced
  - Admixtures
    - 0.6-1.0 l/m^3
    - 0.6 kg/m^3
  - Surface Treatments
    - 3.68 m^2/l
    - 3.0-4.0 m^2/l

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

How Do MCI Inhibitors Work?

- **Migrate via:**
  - Capillary Action
  - Vapor Diffusion
  - Ionic Attraction
- **On the Rebar Surface:**
  - Monomolecular layer
  - Establish a physical adsorption
  - Nitrogen allows for a tenacious bond



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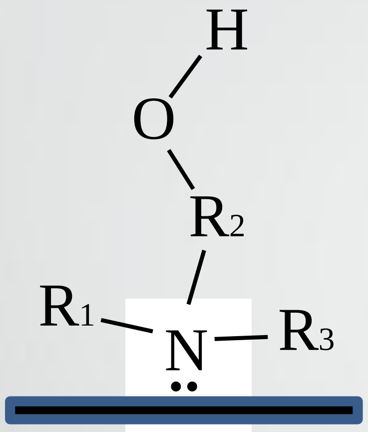
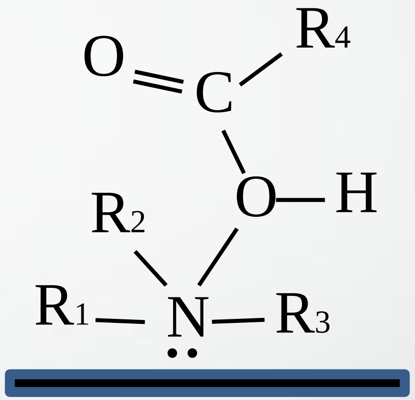
FROM GREY TO GREEN

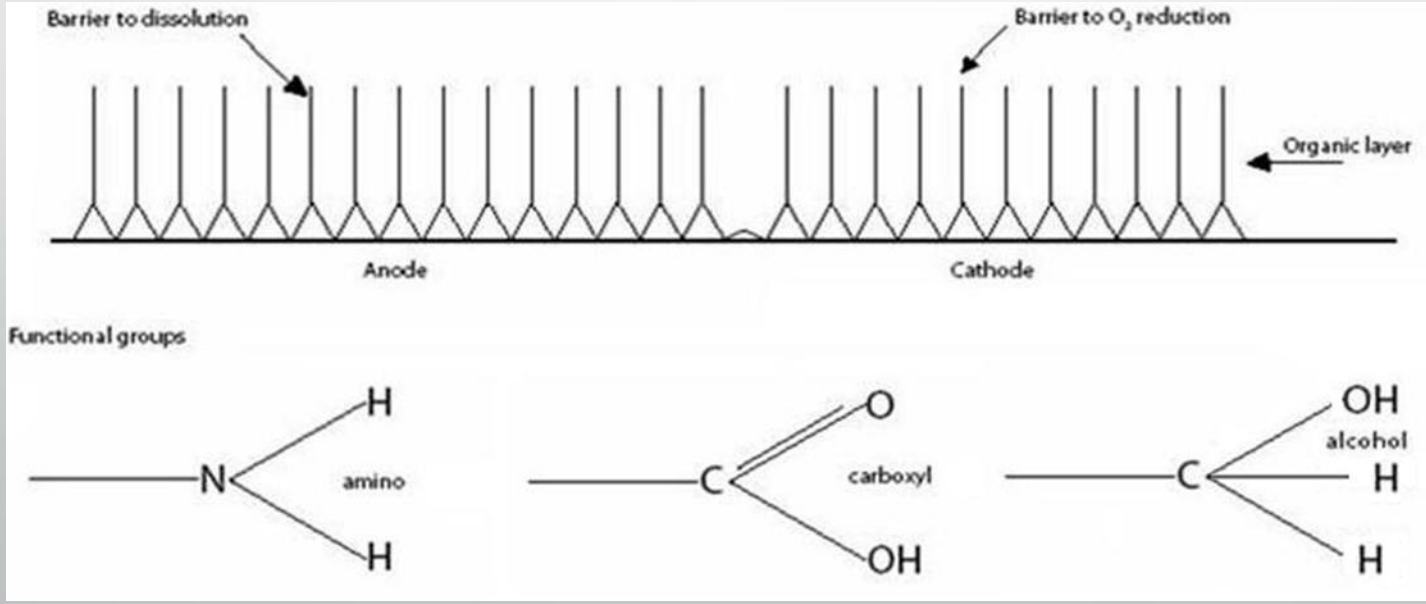
MCI Chemistry

Amine Alcohol



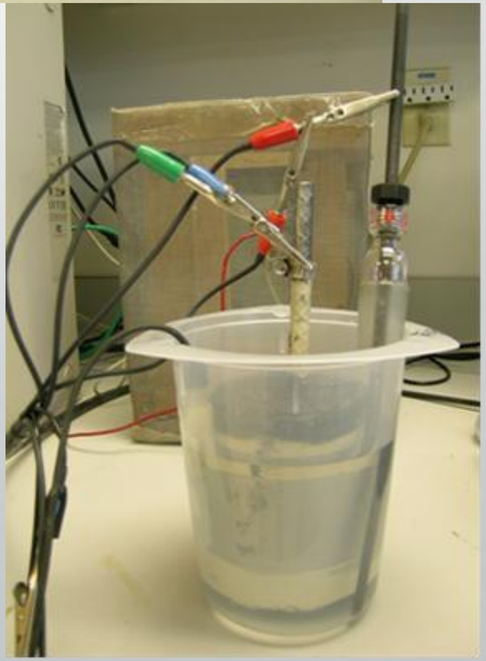
Amine Carboxylate





Assessment of Corrosion Protection

- ASTM C1582
  - ASTM G109
  - ASTM G180
- Modified ASTM G109
- EIS



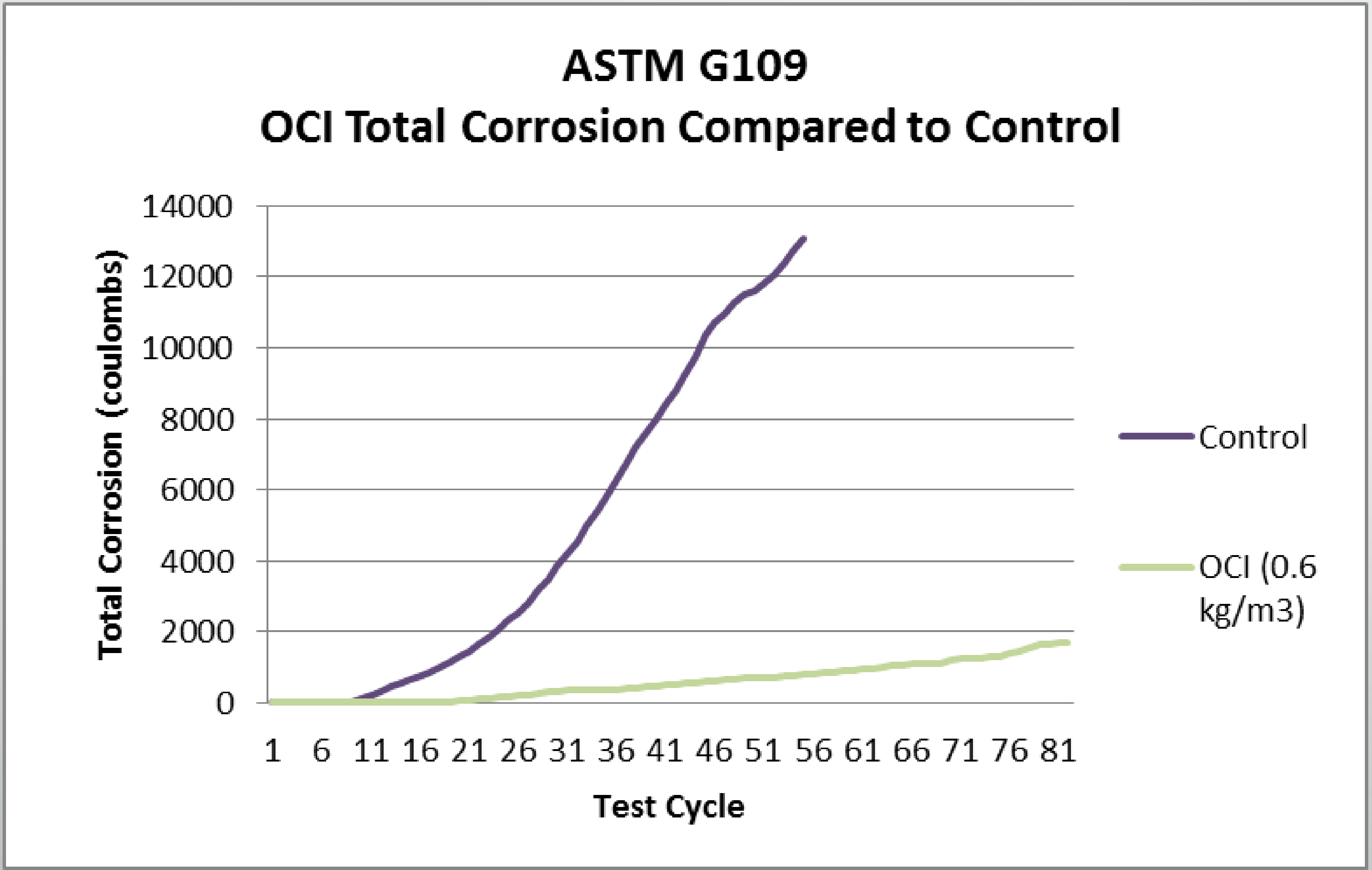
MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

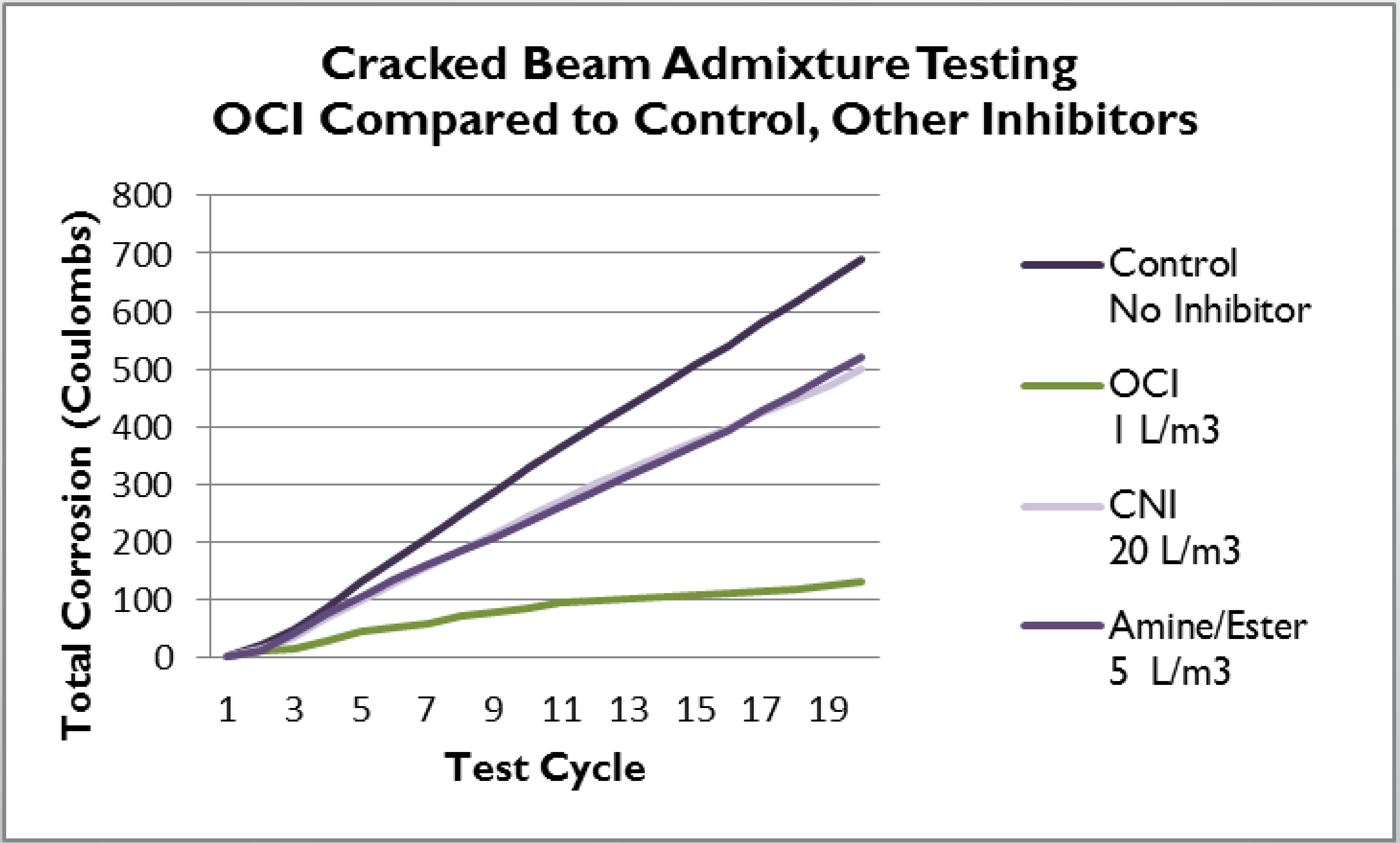
Results for Normal Set (NS) MCI

	Control	MCI - NS	Relative to Control		ASTM C1582 Requirements	Results
Average Integrated Current, C	155	29	n/a		$\leq$ 50C when control is 150C	Meets Requirement
Ave. Area Corroded, in^2	8.93	2.36	0.29%		$\leq$ 1/3 of control	Meets Requirement
Critical Chloride Content*, ppm	2861	2898	1.01%		$\geq$ Critical Control	Meets Requirement

* Critical chloride content (based on control average at 50 Coulombs plus one standard deviation)

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN


ASTM G109
OCI Total Corrosion Compared to Control
Total Corrosion (coulombs)
14000
12000
10000
8000
6000
4000
2000
0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81
Test Cycle
Control
OCI (0.6 kg/m3)



MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Vachon Bridge, Montreal, Canada

- Bridge north of Montreal, carries Hwy 13 over the Mille-Îles River
- National Research Council of Canada formed a consortium to review performance of corrosion inhibitors in bridge deck repair
- 10 year study, update given at 5 years
- Final results – CNI (20 L/m^3) first; Amine alcohol based MCI (0.6 L/m^3) runner up

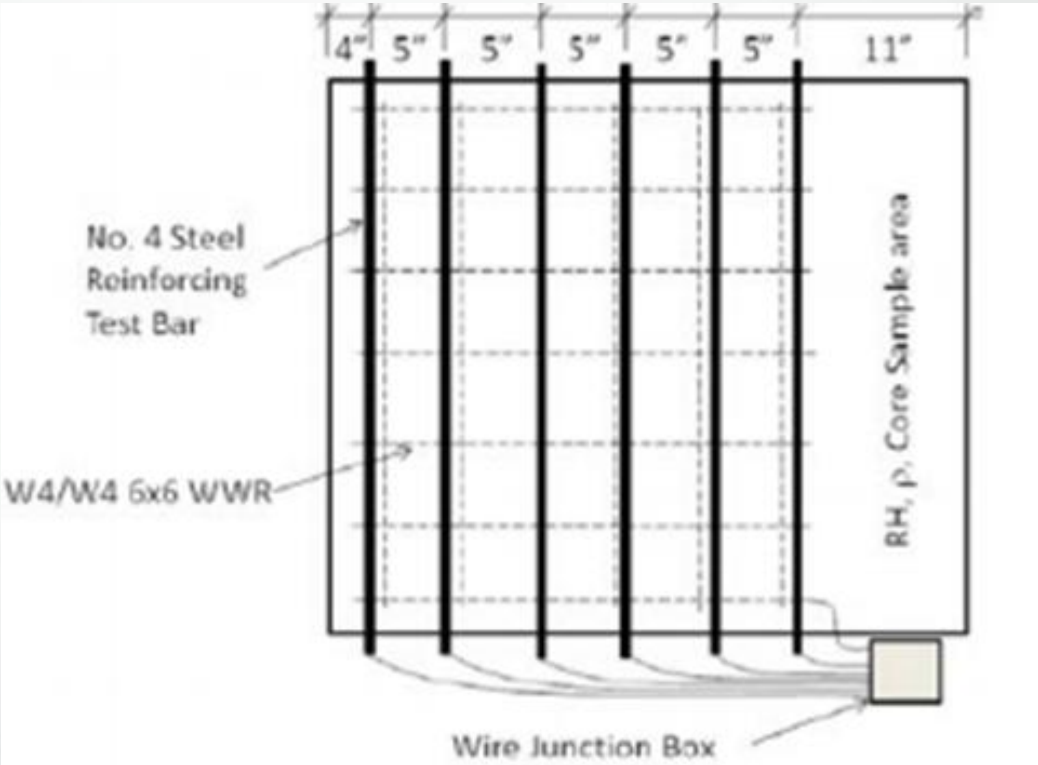
MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Field Testing - Canada

Table 2: Performance Ranking of the Corrosion Inhibiting Systems

Field Corrosion Tests \ SPANS	21*	12	A	B	C	D	E	F	G	H	Units
Half-cell potential of reinforcement (median value, June 2001)	-415 (4)	-453 (8)	-374 (1)	-420 (5)	-405 (3)	-420 (5)	-453 (8)	-487 (10)	-380 (2)	-428 (7)	mV
Corrosion rate of reinforcement, no cracks (average value, June 2001)	0.200 (5)	0.005 (1)	0.125 (2)	0.230 (8)	0.145 (3)	0.260 (10)	0.185 (4)	0.200 (5)	0.240 (9)	0.220 (7)	$\mu A/cm^2$
Corrosion rate of reinforcement, cracks (average value, June 2001)	0.260 (5)	0.195 (2)	0.200 (3)	0.375 (8)	0.270 (7)	0.410 (9)	0.230 (4)	0.180 (1)	0.500 (10)	0.263 (6)	$\mu A/cm^2$
Potential of rebar ladders, top bar (average value, June 2001)	-570 (4)	-630 (8)	-670 (10)	-620 (6)	-623 (7)	-515 (3)	-640 (9)	-600 (5)	-510 (2)	-360 (1)	mV
Potential of rebar ladders, 2nd bar (average value, June 2001)	-490 (5)	-460 (3)	-540 (8)	-520 (6)	-570 (9)	-607 (10)	-520 (6)	-480 (4)	-400 (2)	-333 (1)	mV
Corrosion rate of rebar ladders, top bar (average value, June 2001)	0.375 (5)	0.290 (3)	0.620 (7)	0.970 (9)	0.390 (6)	0.200 (2)	0.870 (8)	0.360 (4)	2.100 (10)	0.135 (1)	$\mu A/cm^2$
Corrosion rate of rebar ladders, 2nd bar (average value, June 2001)	0.250 (8)	0.200 (6)	0.400 (10)	0.120 (3)	0.100 (1)	0.240 (7)	0.163 (5)	0.110 (2)	0.270 (9)	0.130 (4)	$\mu A/cm^2$
Chloride content at 25-50 mm (average value, June 2001)	0.32 (10)	0.19 (4)	0.20 (6)	0.22 (7)	0.15 (2)	0.195 (5)	0.12 (1)	0.23 (8)	0.26 (9)	0.15 (3)	%
Chloride content at 50-75 mm (average value, June 2001)		0.03 (5)	0.04 (8)	0.03 (6)	0.03 (3)	0.037 (7)	0.02 (2)	0.02 (1)	0.05 (9)	0.03 (3)	%
OVERALL RANKING:	**5.8**	**4.4**	**6.1**	**6.4**	**4.6**	**6.4**	**5.2**	**4.4**	**6.9**	**3.7**	

Assessment of Corrosion Protection



M-82 Protocol Test Slab

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Average Chloride Values (ppm)

	Control		Treatment A		Treatment B		Treatment C	
	Repair	End	Repair	End	Repair	End	Repair	End
Average	2604	3520	2378	2620	2706	2600	2744	2540
SD	181	264	268	223	399	190	147	171
Sp	242							
95% CL	230							
90% CL	190							

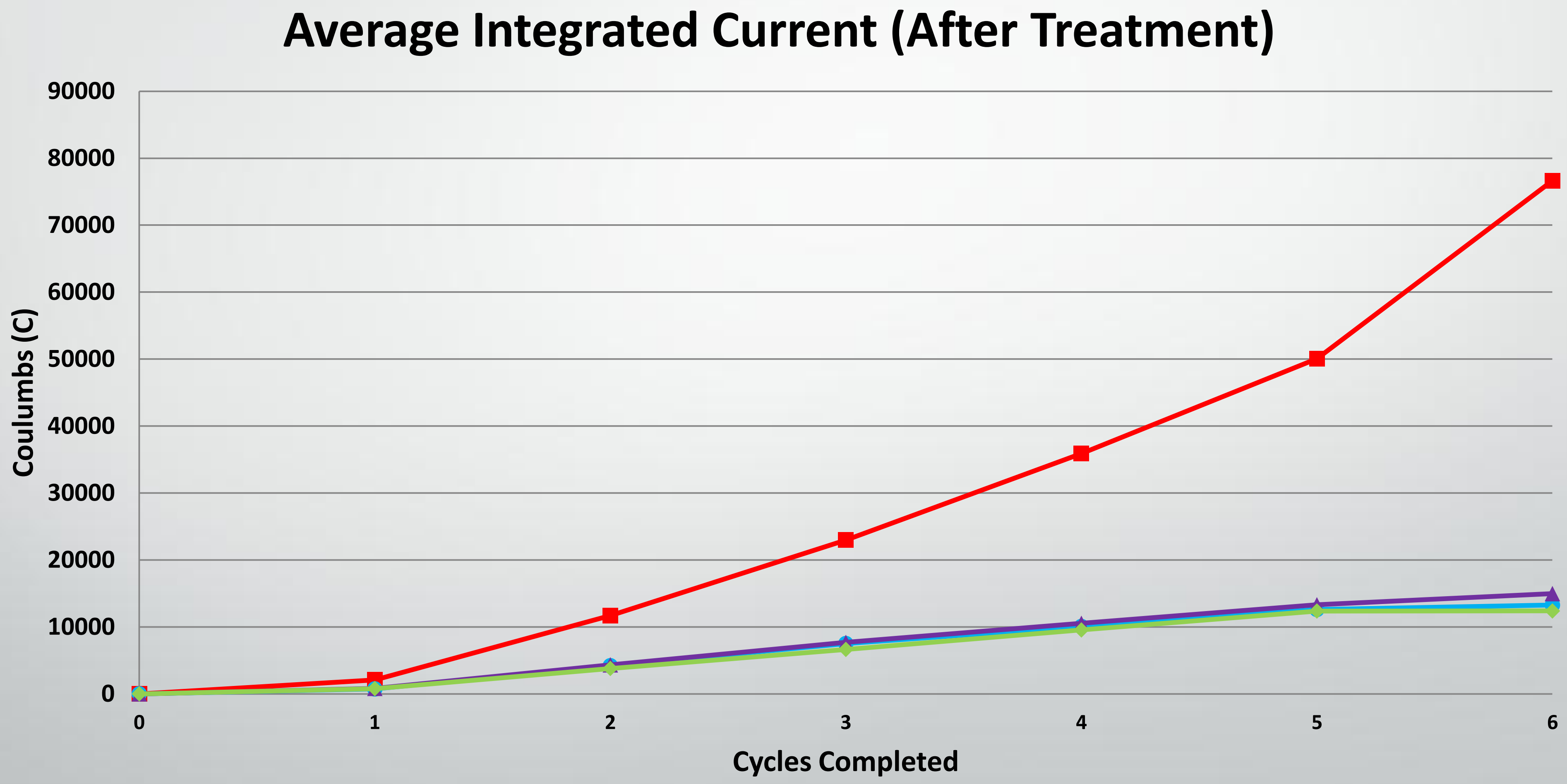
MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Crack Length & Area by Treatment

	Length (mm)		Area (mm2)	
	Repair	End	Repair	End
Control	2315	311	284	78.55
Treatment A	915	820	106.06	101.24
Treatment B	689	341	75.10	44.496
Treatment C	465	527	51.92	61.63
Sp	539		74	
95% CL	511		71	

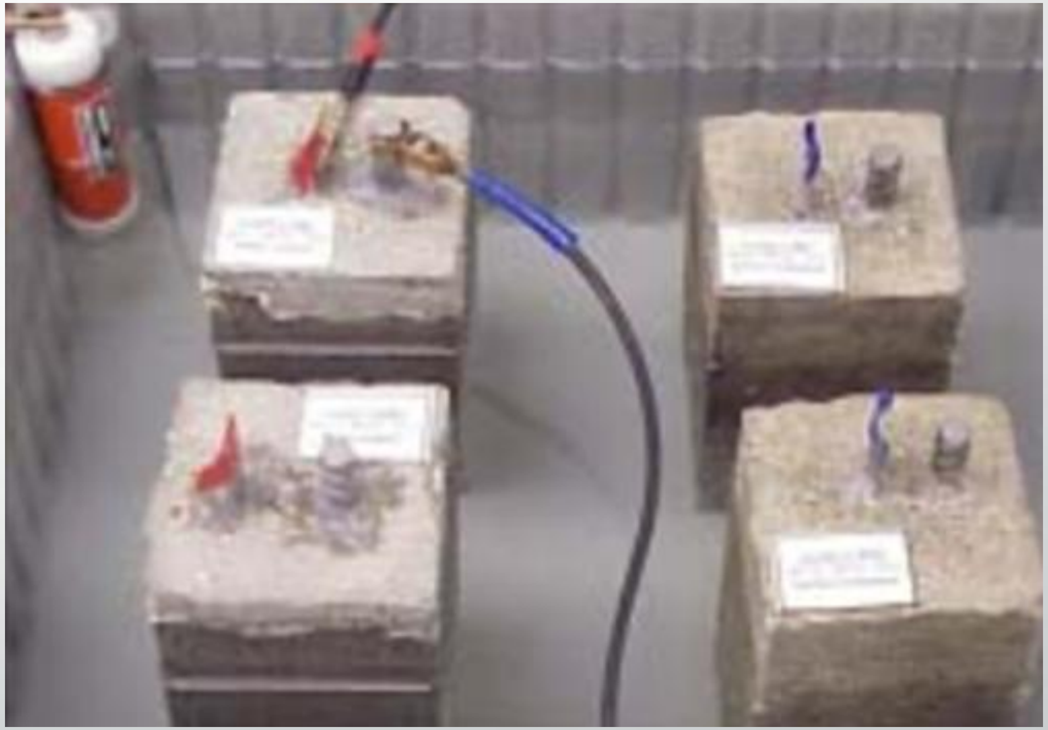
MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Results of MCI Treatments



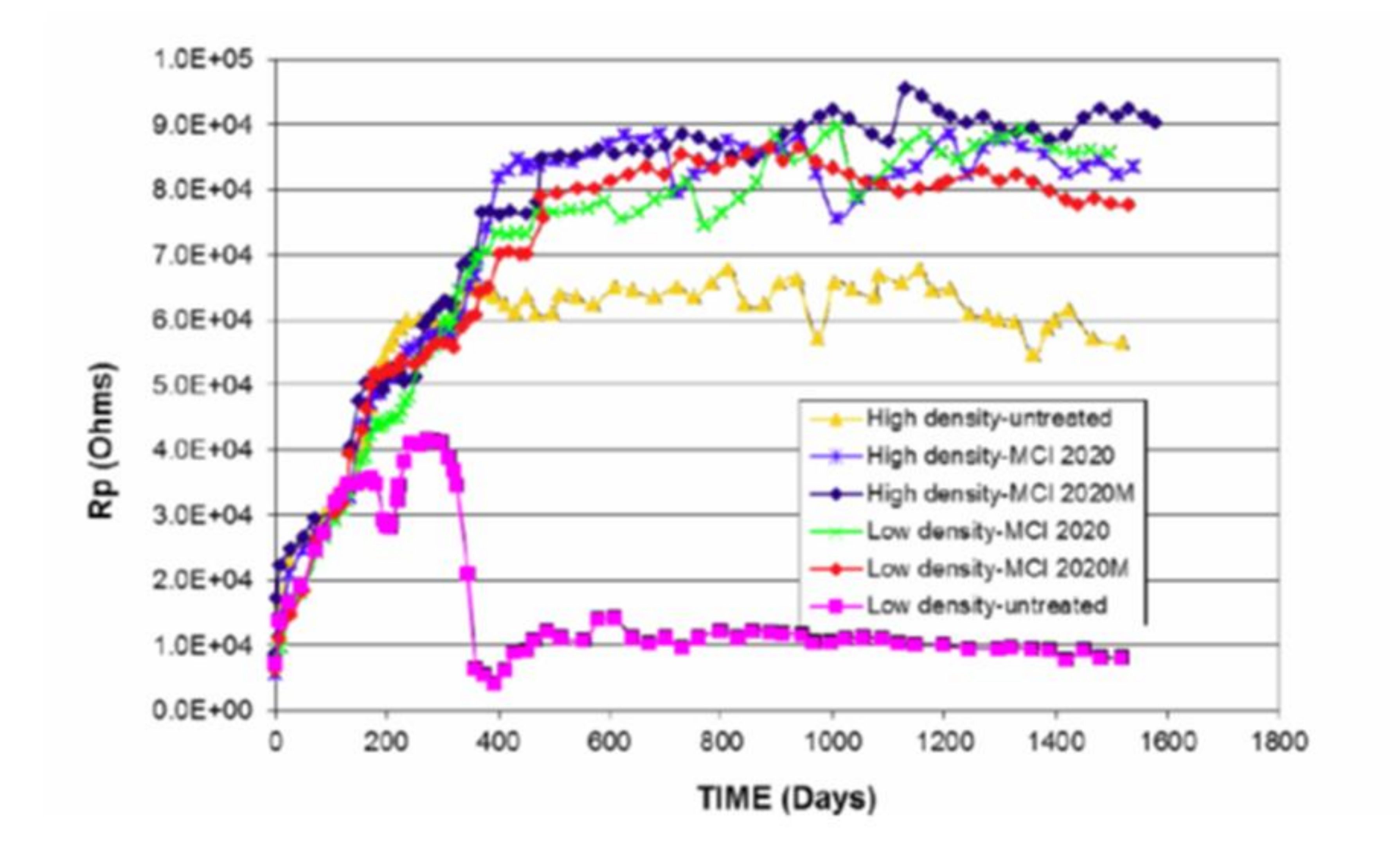
Modified G109 – Topical MCI

- 1500 day test
- 200 cycles wet/dry; 3.5% NaCl solution
- Low & High density concrete
- XPS/SEM confirmed migration of MCI in ≤150 days
- MCI samples showed no signs of corrosion while control samples did



MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Polarization Resistance (Rp) Low & High Density Concrete - MCI vs. Untreated



MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

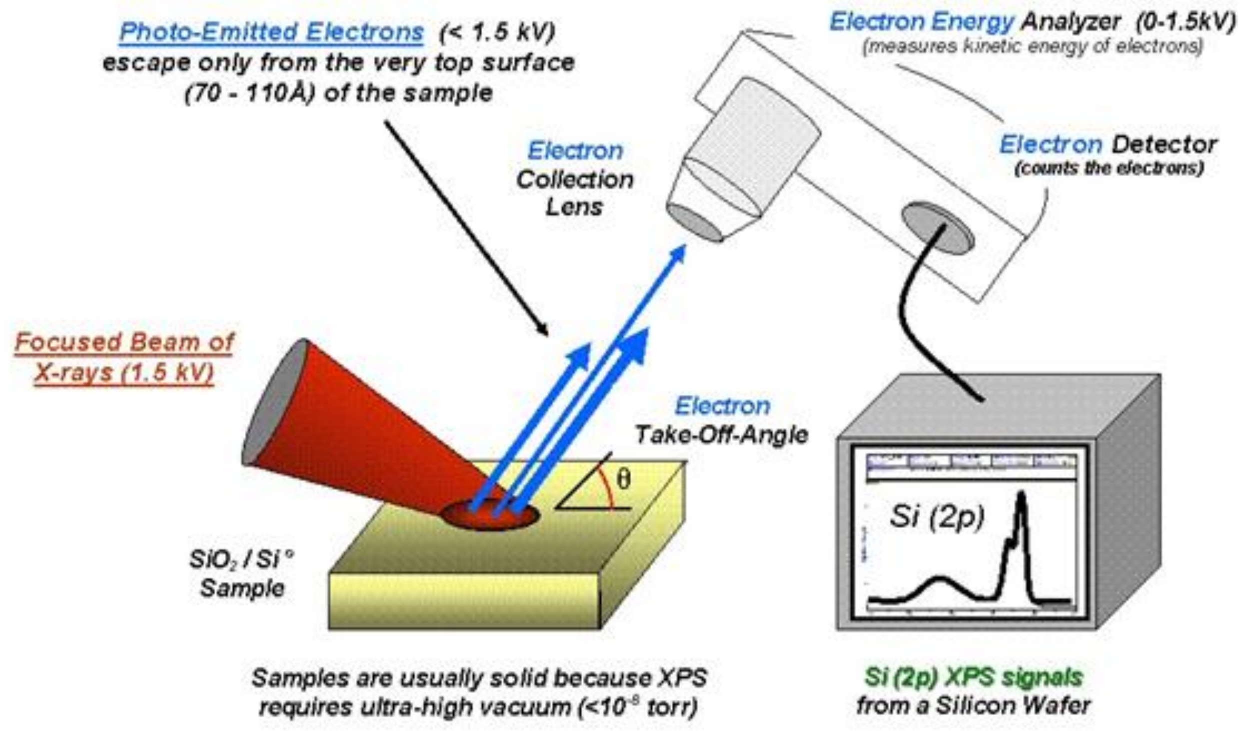
XPS Analysis, MCI & Untreated

Peak	Atomic Conc. (%)	Mass Conc. (%)	Atomic Conc. (%)	Mass Conc. (%)
	Untreated	Untreated	MCI	MCI
Fe 2p	0.87	3.32	0.08	0.3
O 1s	30.19	33.06	31.4	35.91
C 1s	62.48	51.37	59.43	48.12
Si 2p	4.72	9.08	1.26	4.14
Cl 2p	0.84	2.04	1.11	2.81
N 1s	0.74	0.71	5.64	5.71

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Assessment of Migrating Ability

- XPS/SEM Testing
- UV Mass Spec
- DART



New Construction Applications

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Advantages of MCI Admixtures

- Added to mix water at RM plant or dosed onsite and mixed prior to placing
- MUCH lower dosage rate than other types of inhibitors
- Protection directly to embedded metals
- Works even in cracked areas
- Tested to meet ASTM C1582 (C494, G109, G180)
- Does not affect finish properties when used with silica fume, fly ash, slag, etc.
- Can be used in conjunction with cathodic protection
- Certified to meet ANSI/NSF Standard 61 (Potable Water)

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Randolph Ave. Bridge

- 1986 Bridge Deck Repair
- Mill to 1.2 cm Depth, Patch and Overlay with LSDC
- Amine Inhibitor in westbound lane at 0.6 liters/m^3

Randolph Avenue Bridge

Gecor 6 Measurements

Half-Cell Potential Readings

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Randolph Ave – LSDC Mix Design

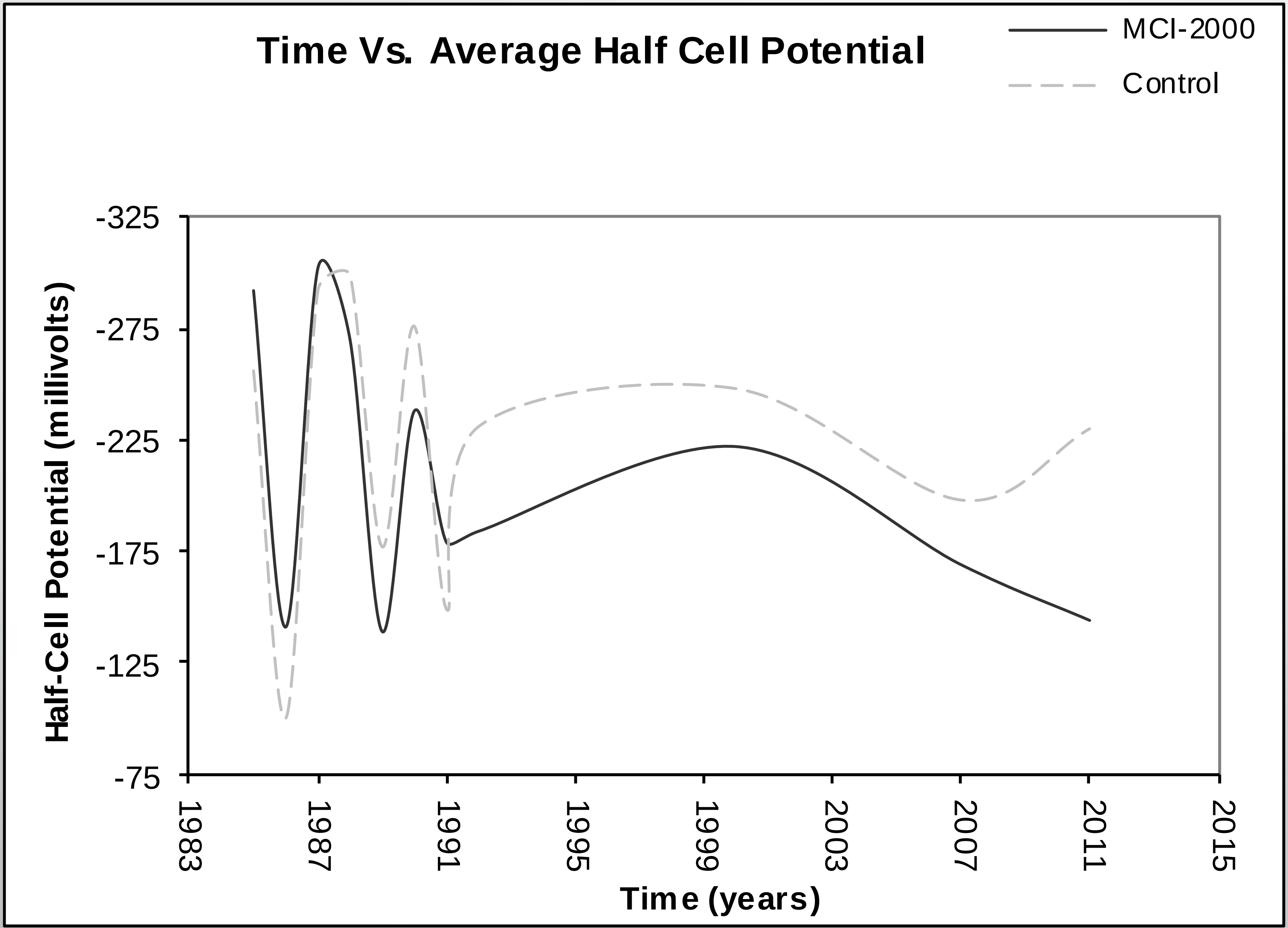
Component	Control (kg/m3) – Eastbound Lanes	Treated (kg/m3) – Westbound Lanes
Type I Cement	496	496
Water	160	160
W/C Ratio	0.32	0.32
Coarse Aggregate	821.69	821.69
Fine Aggregate	815.16	815.16
Water-Reducing Admixture	0.148	0.148
Air-Entraining Agent	0.043	0.043
Amine Based Corrosion Inhibitor (MCI)	--	0.564

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

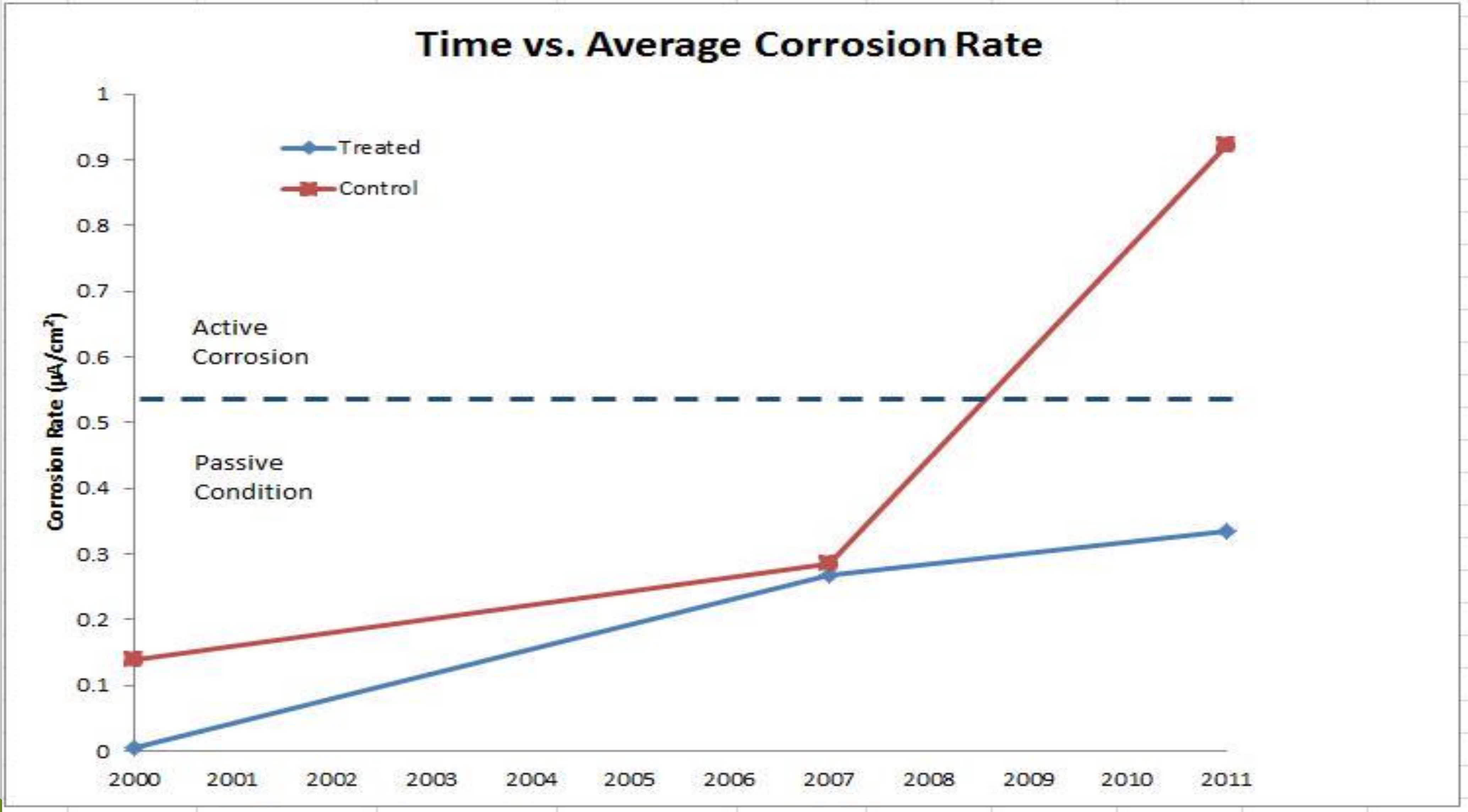
Average Chloride Levels

Year	Treated (kg/cubic meter)			Control (kg/cubic meter)		
	0-2.54 cm	2.54-5.08 cm	5.08-7.62 cm	0-2.54 cm	2.54-5.08 cm	5.08-7.62 cm
1991	2.08	0	0.415	4.57	1.48	1.13
1992	3.86	0.65	1.13	5.64	2.08	1.48
2000	6.94	0.95	0.77	10.2	3.67	1.42
2007	6.94	0.59	1.54	11.87	4.39	1.36
2011	7.30	2.91	1.07	8.72	3.92	2.08

Randolph Half-Cell Potential



Corrosion Rate Readings



Princess Tower, Dubai, UAE

- 101 Story, 413.4 m tall
- 107 Floors (6 basement, ground floor, 100 above)
- 763 Residential Units (1, 2, 3 Bedroom), 8 Retail Shops, 957 Parking Spaces
- Chloride levels in ground water in this area up to 90,000 mg/L
- 100+ year design life

Cost Analysis, Princess Tower

ITEM	COST (USD)
Construction Cost	188,000,000.-
Additional Cost of MCI (Substructure)	136,000.- (0.07%)
LIFE-365 Service Life (Without MCI)	48 Years
LIFE-365 Service Life (With MCI)	103 Years

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Princess Tower ROI Estimates (USD)

Year	1	10	48	100
Revenue	$28,066,757	$33,542,373	$71,186,938	$199,346,790
Building Management	$2,079,022	$2,712,653	$8,340,820	$38,792,200
Licensing & Insurance	$3,754,768	$4,106,535	$5,993,600	$10,055,396
Others	$3,754,768	$4,106,535	$5,993,600	$10,055,396
Total Cost	$9,588,559	$10,925,722	$20,328,019	$58,902,991
Net Profit	$18,478,198	$22,616,651	$50,858,920	$140,443,799
Return on Investment	9.8%	12.0%	27.1%	74.8%
Present Value @ 3% discount rate	$18,478,198	$16,828,912	$12,307,798	$7,307,690
ROI	$18,478,198	$174,387,898	$724,175,783	$1,224,731,446

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

CASE STUDY: Gulf State Hotel – Gulf Shores, AL

<u>Life 365 Analysis</u>
Base concrete 11.6 years
Epoxy Coated Rebar - 25.6 years
MCI - 40.7 years

<u>LEED Credit and Water Safety</u>
MCI qualified with over 67% bio-content
MCI was mfg. within 500 miles (Sarasota, Florida)
NSF61 Certified – Safe to be used with potable water

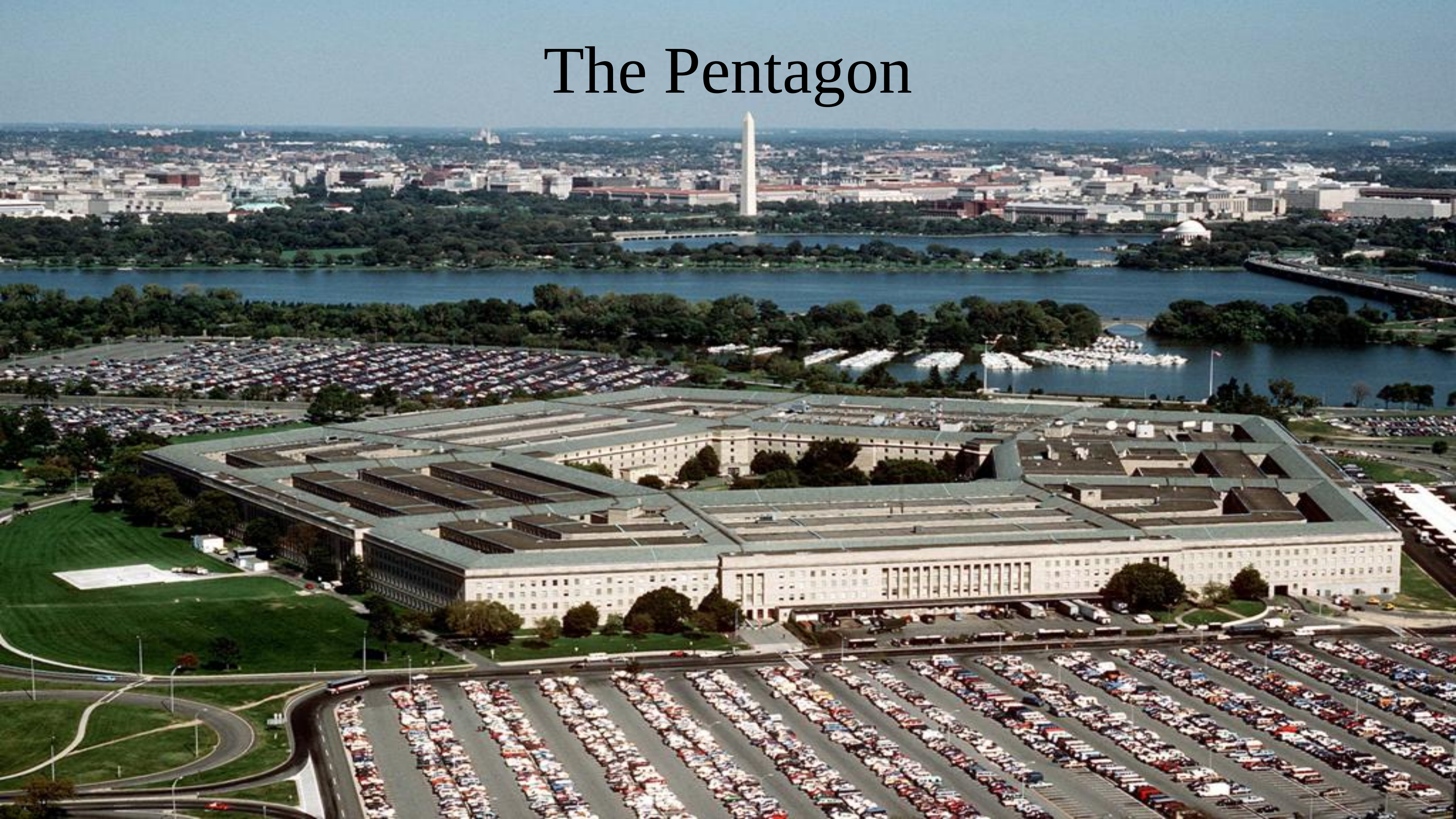
<u>Project Costs & Efficiency</u>
Significant cost savings (over six figures)
Decelerates set time by 1.5 hours at 70 degrees
Total Cubic Yards = 7,500
937.5 gal MCI vs. 30,000 gal of Calcium Nitrite

Wind Turbines – Penescal Wind Farms, TX

Repair Applications

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

The Pentagon



The Pentagon

- Corrosion due to carbonation and rebar close to the surface.
- Started 4/2003, completion 2012
  - Silicate and Silane Coatings applied over MCI for additional protection and longevity of repair.
- GalvaPulse Readings every 6 months

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

GalvaPulse

Corrosion Current, µA/cm2	Corrosion Rate, µm/year	Corrosion Level	Time to Visible Deterioration
< 0.5	< 5.8	Passive	N/A
0.5 to 5	5.8 to 58	Low	> 10 years
5 to 15	58 to 174	Moderate	3 to 10 years
> 15	>174	High	< 2 years
Corrosion rates by Thomas Frolund, 2002 (with GalvaPulse instrument)			

Chart from GalvaPulse Manual

GalvaPulse Readings

June 27, 2005, 2pm to 3:30pm Temperature ~ 77F (26C) Dew Point ~ 74F (23C) Barometric Pressure~ 30.2inHg (1023 hPa)		Sept. 27, 2005, 1pm to 2pm Temperature ~ 75F (24C) Dew Point ~ 50F(10C) Barometric Pressure~ 30inHg (1015 hPa)	
Corrosion Current, µA/cm^2	Corrosion Rate, µm/year	Corrosion Current, µA/cm^2	Corrosion Rate, µm/year
10.9000	126.44	0.0957	1.11
2.8133	32.63	0.0808	0.94
0.1552	1.80	0.0927	1.08
0.9165	10.63	0.1130	1.31
0.6977	8.09	---	---
3.10	35.92	0.10	1.11
<u>June Average:</u>	32.41	<u>September Average:</u>	1.11

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

C.A.T. – Consorci D'Aigües, Tarragona, Spain

- Drinking water authority
- 30 yr. old network of pipes
- Carbonation and corrosion problems
- 7,000 m² repair, 13,000 m² treated with MCI

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Francis Scott Key Bridge, USA

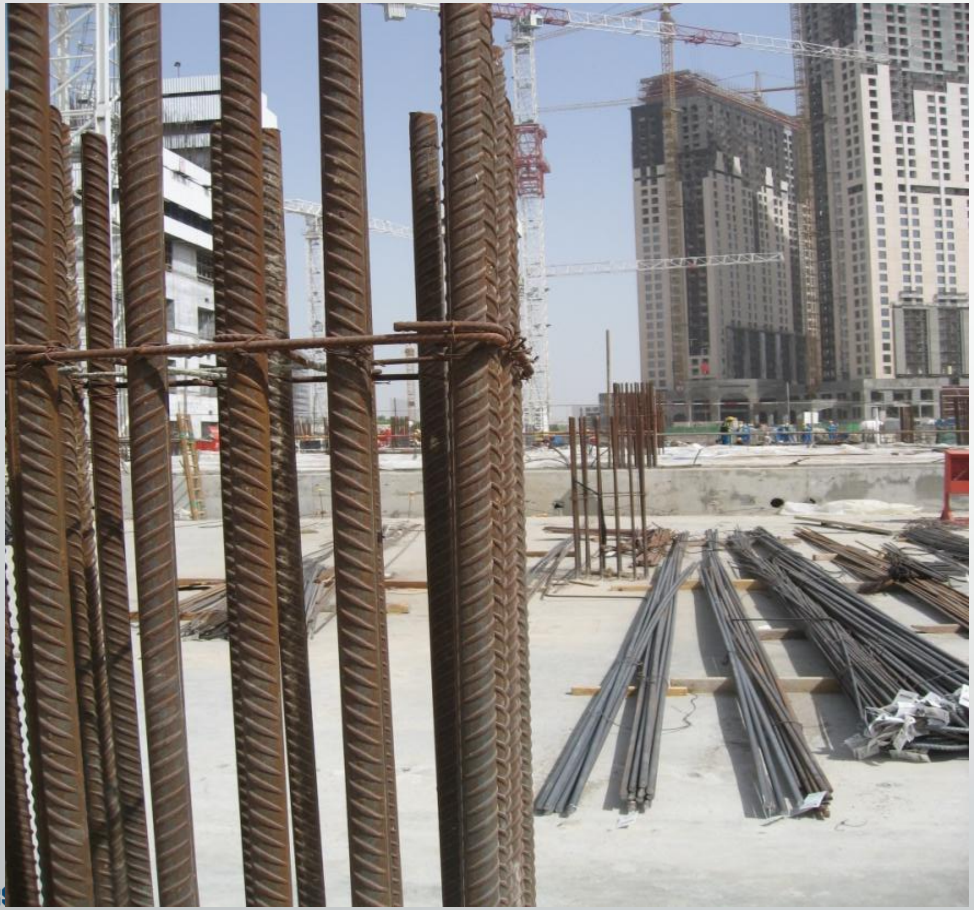
- 46,452 m² treated with 100% organofunctional silane + MCI
- Completed Spring 2008

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Specialty Applications

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Preservation of Exposed Reinforcing Steel



Temporary Protection of Post Tensioning

Cochrane Bridge
Mobile, Alabama


Corrosion on Strands
Cochrane Bridge
02/05/03
15:57:56

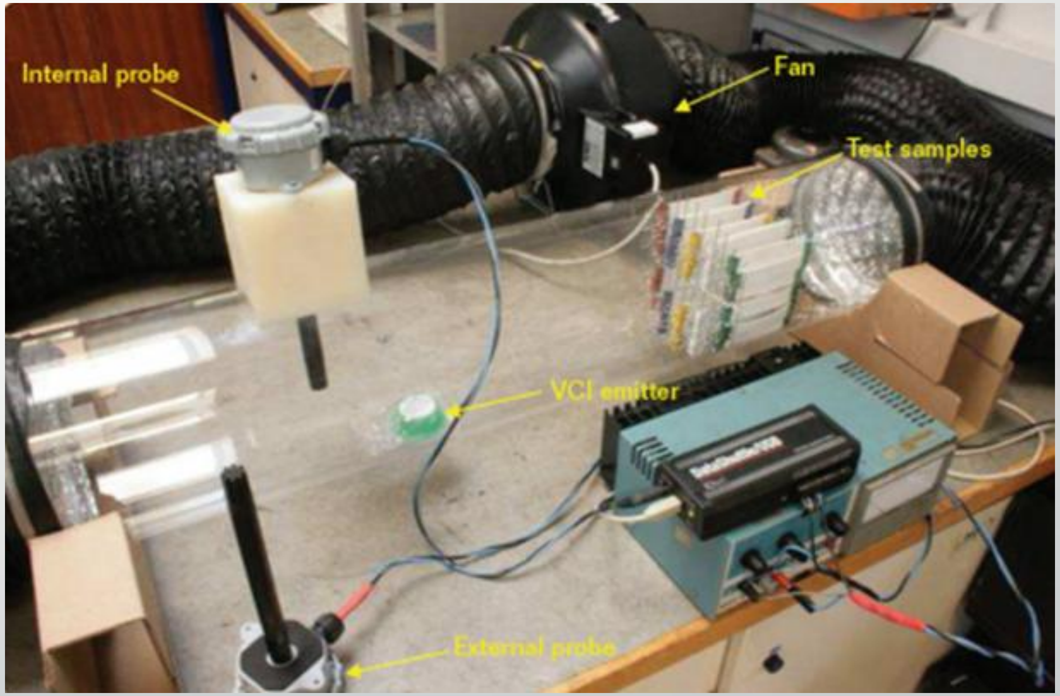
Severn Bridge, UK

- 988 m span bridge, carries M48 over Severn River
- UK Highway Agency
- Dehumidification System
  - Reduce moisture
  - Prevent corrosion
  - MCI used for protection during initial period of moisture reduction and as back up in event dehumidification system down

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Severn Bridge, UK

- Testing to confirm
  - MCI did not affect system components
  - MCI would reach all areas needing protection
  - Presence of MCI in the field
- Consultant developed monitoring criteria and systems for future management to comply with BD79/13 Standard
- Acoustic emissions (strand breakage) decreased from 0.4% to less than 0.04%



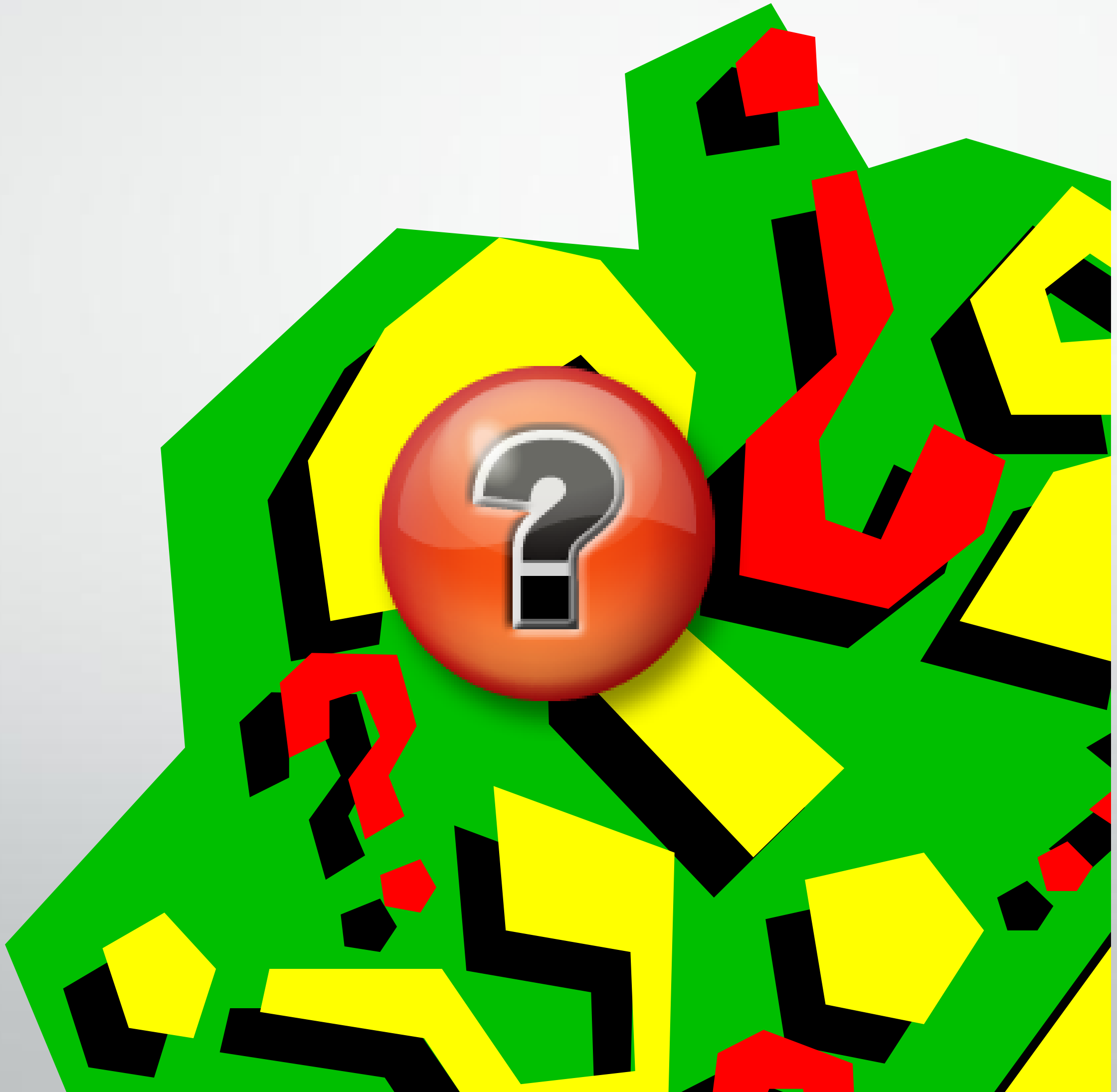
MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Conclusions

- MCI have been used in industry more than 30 years
- Effectiveness of MCI demonstrated in both lab and field testing
- MCI can effectively increase expected service life
- Use of MCI not limited to new construction or repair, but also useful in specialty applications

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

Thank You! Obrigado!

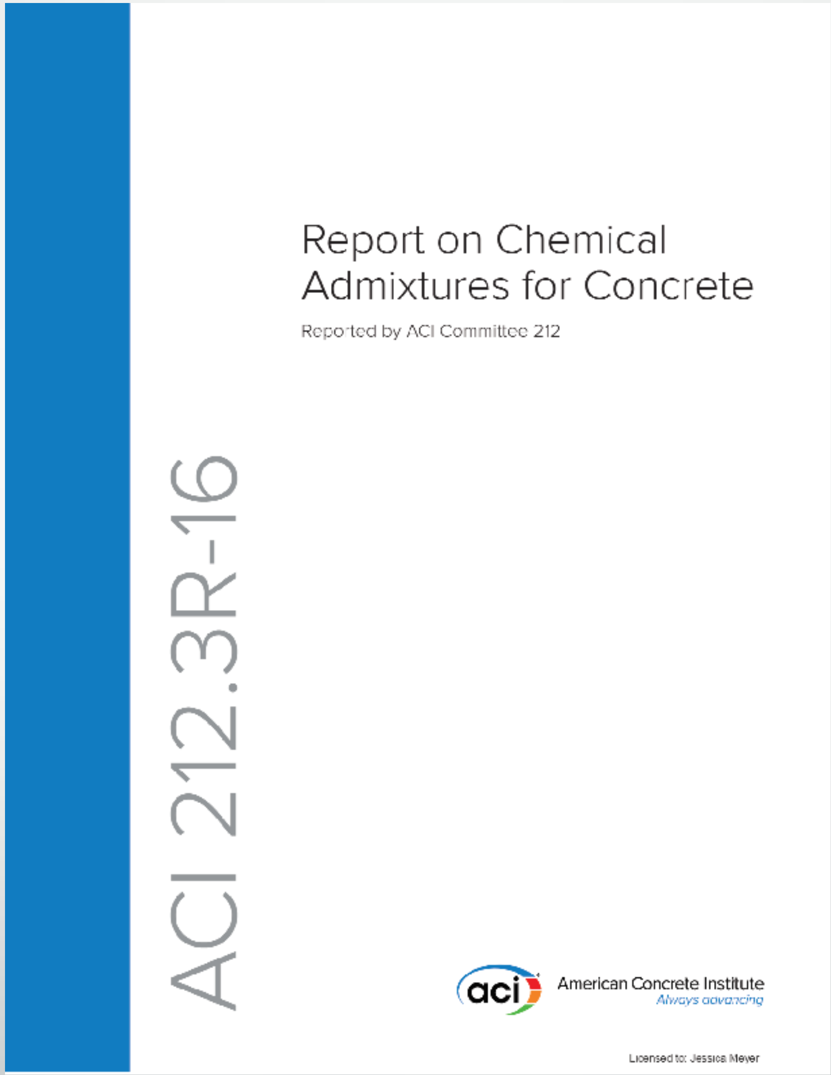


MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN

ACI 212.3R-16
Report on Chemical Admixtures for Concrete

Chapter 13 – Corrosion Inhibiting Admixtures

MIGRATING CORROSION INHIBITORS
FROM GREY TO GREEN



ACI 212.3R-16

Report on Chemical Admixtures for Concrete

Reported by ACI Committee 212

American Concrete Institute
Always advancing

ICRI Corrosion Committee 510

Guideline for Use of Penetrating Surface Applied Corrosion Inhibitors for Corrosion Mitigation of Reinforced Concrete Structures

Guideline No. 510.2-2016