



Northeastern States Materials Engineers' Association  
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# DSS Corrosion Inhibitor Evaluations (Hycrete)

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## Outline

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- ◆ Corrosion Testing (UMass, UConn)
- ◆ Materials Testing (UConn, UMass)
- ◆ Field Applications
- ◆ NETC Project 03-2



## References

### ◆ UMass (NETC 97-2)

- ◆ Civjan S. A., LaFave J. M., Lima J., and Pfiefer D. “Effectiveness of Corrosion Inhibiting Admixture Combinations in Structural Concrete” *Cement and Concrete Composites*, Elsevier – In Publication
- ◆ Civjan, S. A., LaFave, J. M., Lovett, D., Sund, D. J., and Trybulski, J. “Performance Evaluation and Economic Analysis of Combinations of Durability Enhancing Admixtures (Mineral and Chemical) in Structural Concrete for the Northeast U.S.A.” Final Report (NETC 97-2).  
<http://docs.trb.org/00960060.pdf>

### ◆ UConn (CT DOT Project 96-2)

- ◆ Allyn, M. and Frantz, G. C. “Strength and Durability of Concrete Containing Salts of Alkenyl-Succinic Acid.” *ACI Materials Journal* 2001; V. 98 (1); 52-58.
- ◆ Allyn, M. and Frantz, G.C. “Corrosion Tests with Concrete Containing Salts of an Alkenyl-Succinic Acid.” *ACI Materials Journal* 2001, V. 98 (3): 224-232.



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# Corrosion Testing



UConn

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- ◆ Corrosion Testing – UConn (Allyn and Franz 2001a)
- ◆ 48/100 Weeks
- ◆ w/cm of 0.38 to 0.45
- ◆ 1 or 2 Percent Hycrete DSS Addition by Cement Weight
- ◆ Linear Polarization Testing

- ◆ Sponsor: Connecticut DOT Project 96-2



UConn

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- ◆ Lollipop (2”and 3”) and Slab Specimens
  - ◆ 15% NaCl Ponding
  - ◆ 4 Days Wet, 3 Days Dry
  - ◆ Up to 2 Years
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- ◆ Sponsor: Connecticut DOT



# From UConn Project 96-2 Phase II Report

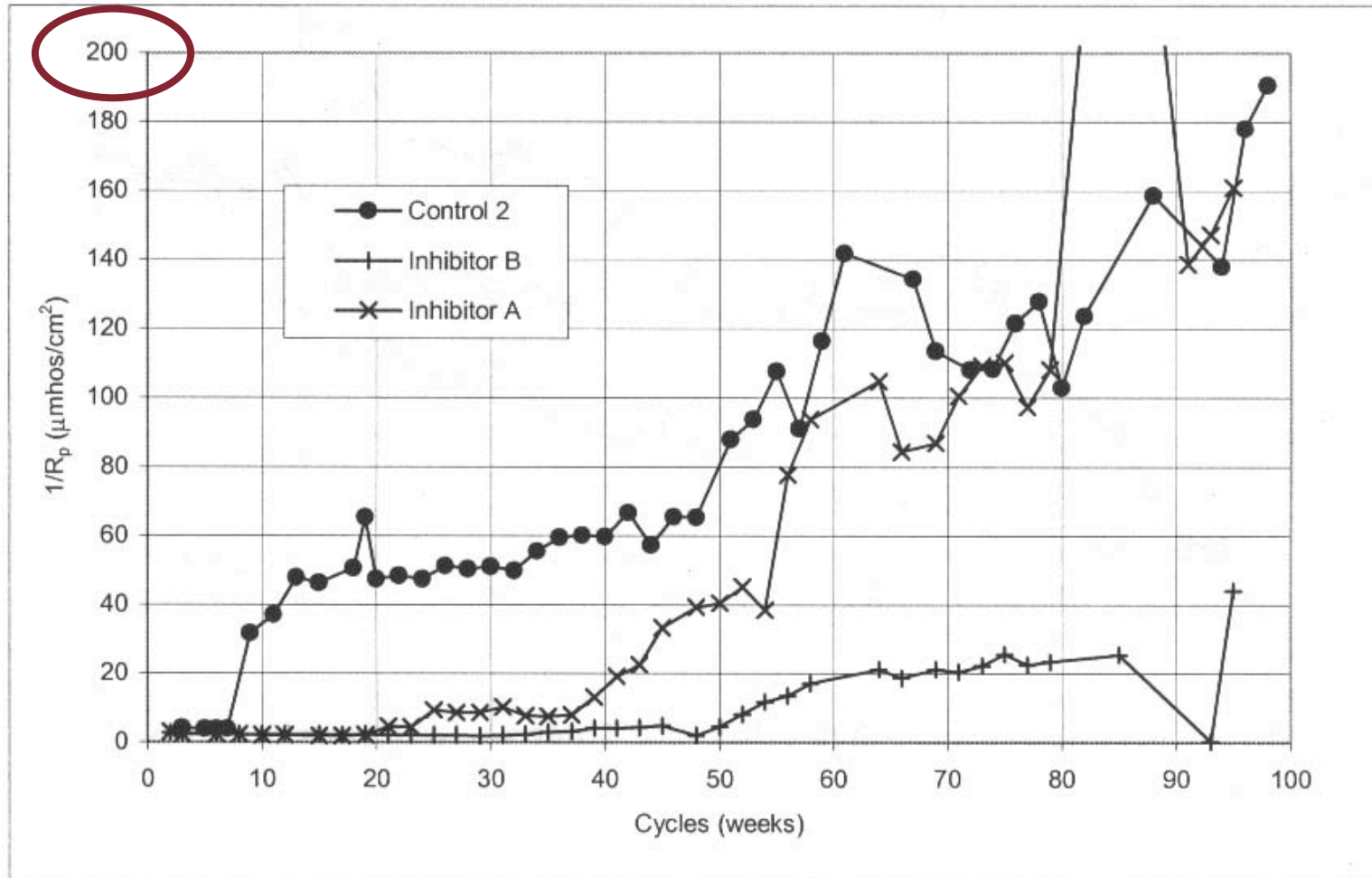


Figure 5.17 Corrosion rates, 3-inch cylinders: Control, Inhibitors A and B.



# From UConn Project 96-2 Phase II Report

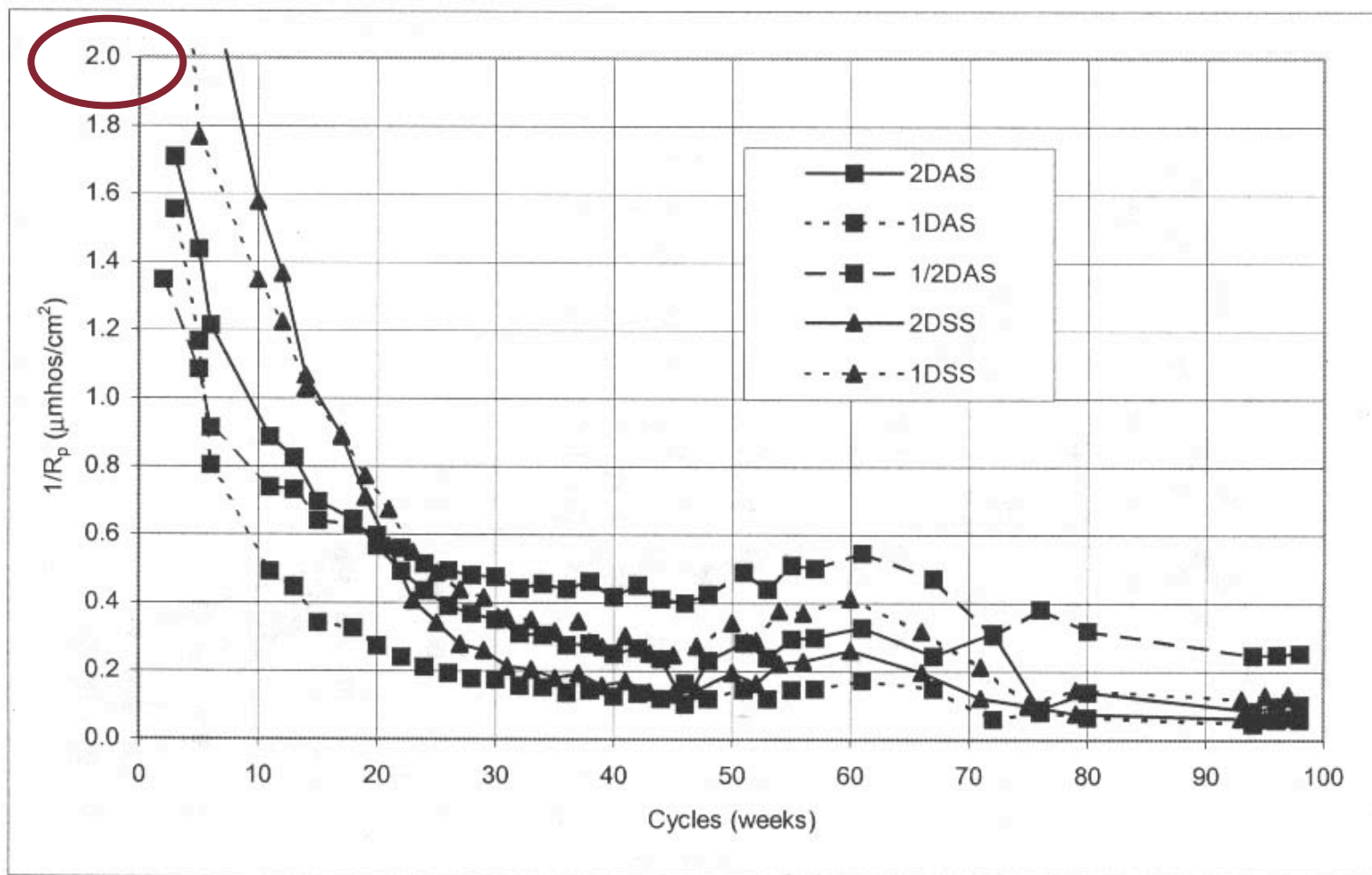
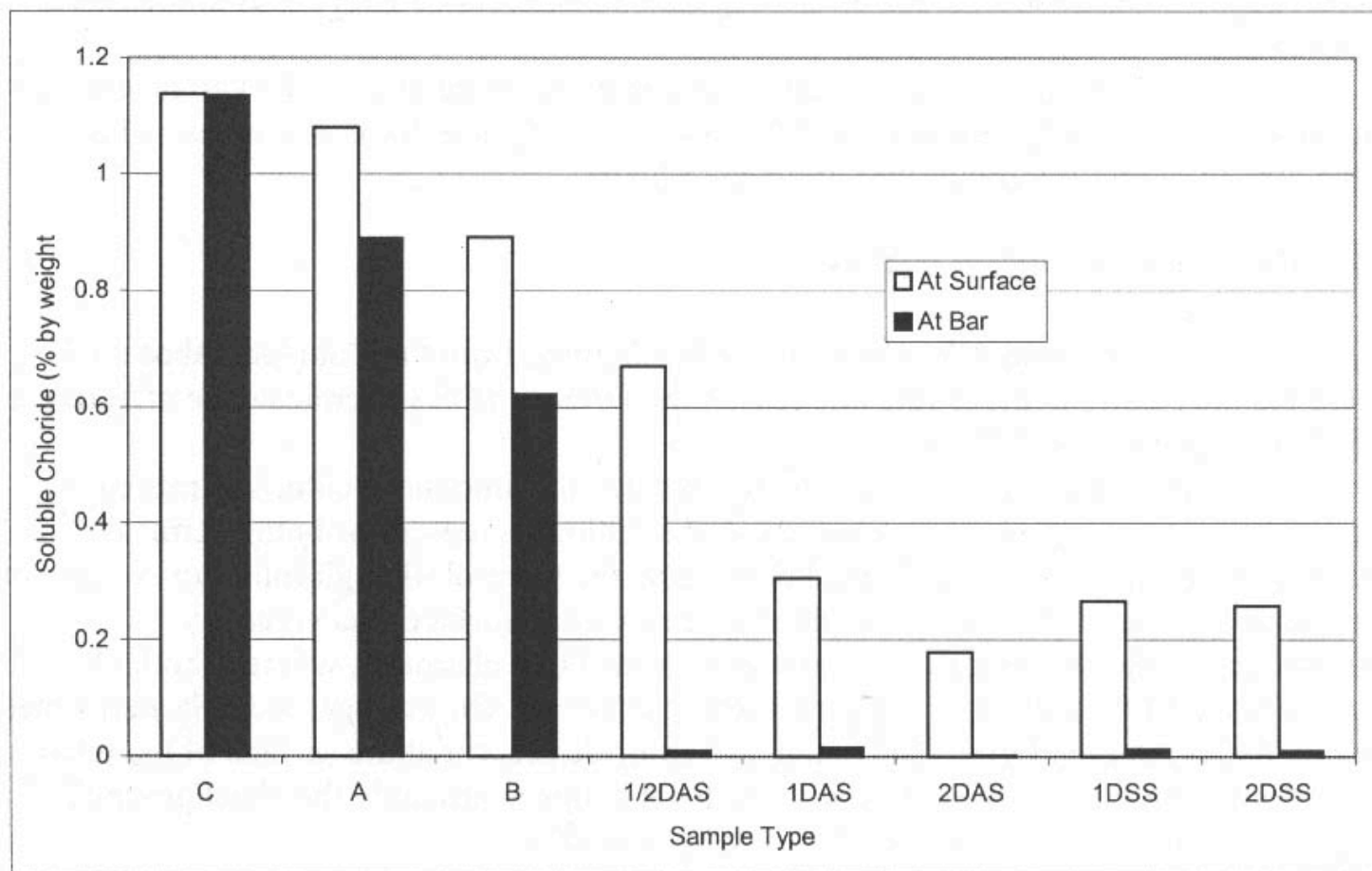


Figure 5.18 Corrosion rates, 3-inch cylinders: DAS and DSS.





## From UConn Project 96-2 Phase II Report



**Figure 5.6 Soluble chlorides (% by weight) present in the concrete at both the surface and rebar.**



- ◆ “Complete lack of corrosion in specimens containing the new chemicals”
  - ◆ Specimen dropped/cracked
  - ◆ Saw Cut Specimens
- 
- ◆ Sponsor: Connecticut DOT



UMass

◆ Goal: Evaluate Performance of Admixture Combinations

◆ Slab Specimens – 24 week ponding cycles

◆ Visual Inspection

◆ Half-Cell

◆ Macrocell

◆ Destructive Evaluation

◆ Chloride Testing (Minimal)

◆ Sponsor: New England Transportation Consortium



## Mix Design

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- ◆ 14 Mix Designs
  - ◆ 12 w/cm=0.40, 2 w/cm=0.47
- 
- ◆ Hycrete DSS: 2 Mixes  
Additions 1/2% Cement Content
- 
- ◆ Single: CN, SF, FA, GBFS, Hycrete DSS
  - ◆ Double CN+(SF, FA, GBFS or Hycrete DSS)
  - ◆ Triple CN+SF+(FA or GBFS)

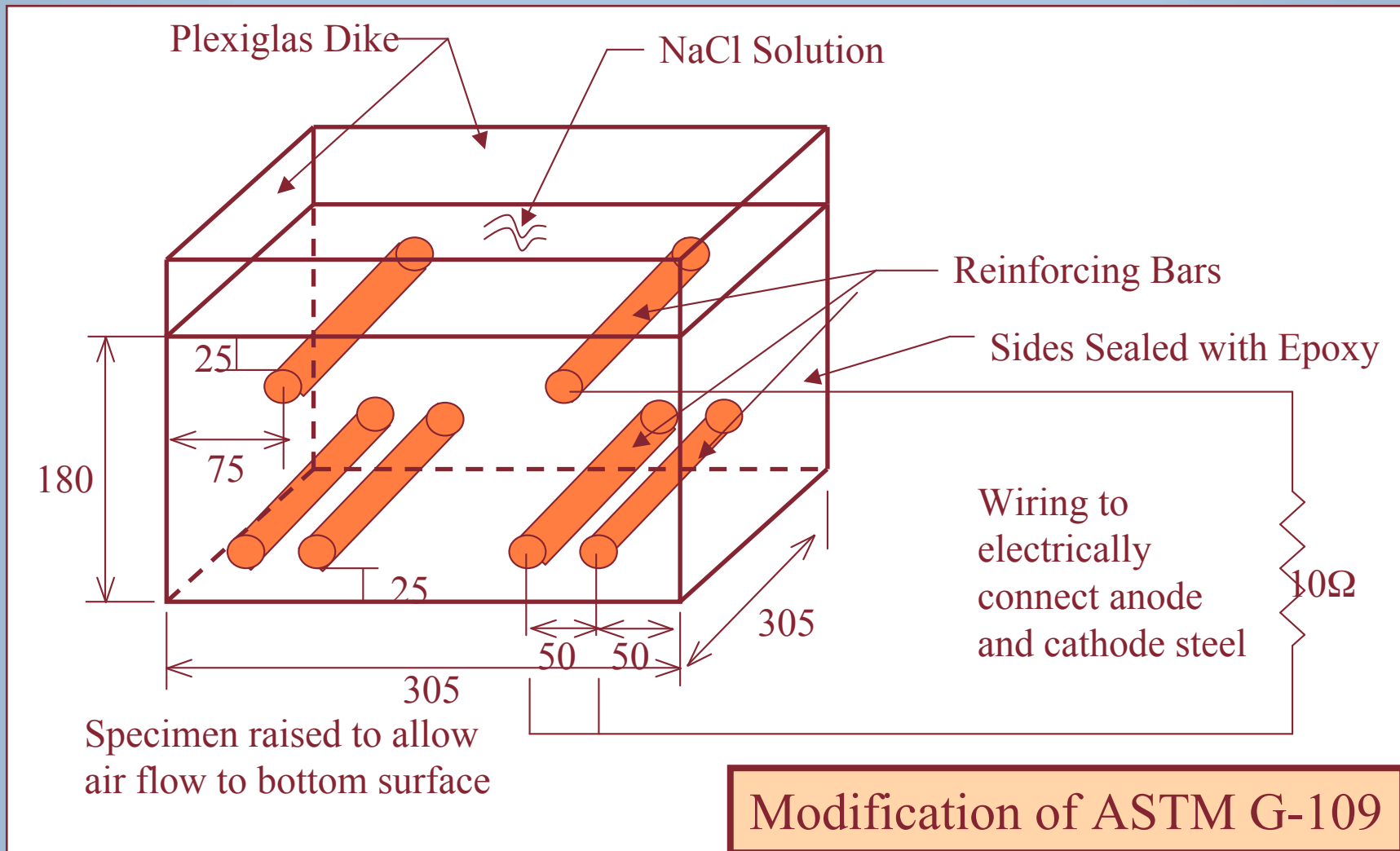


## Mix Design

- ◆ Dosages
  - ◆ CN: 14.8 l/m<sup>3</sup> (3 gal/yd<sup>3</sup>)
  - ◆ SF: 6% Cement Replacement
  - ◆ FA: 15% Cement Replacement
  - ◆ GBFS: 25% Cement Replacement
  - ◆ Hycrete DSS: Additions 1/2% Cement Content
  
  - ◆ Replacements/Additions = Weight Basis



# Specimen Details





## Specimen Details

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- ◆ Replicates of 3
  - ◆ A and B: Non-Cracked
  - ◆ C: Pre-Cracked



## Test Protocol

- ◆ 24 Week Cycles

- ◆ 1<sup>st</sup> 12 Weeks - Cycled
  - ◆ 4 Days Ponded/3 Days Dry
  - ◆ Ponded: Min. 21°C (70° F)  
15% NaCl Solution
  - ◆ Dry: Min. 38°C (100° F)
- ◆ 2<sup>nd</sup> 12 Weeks – Ponded

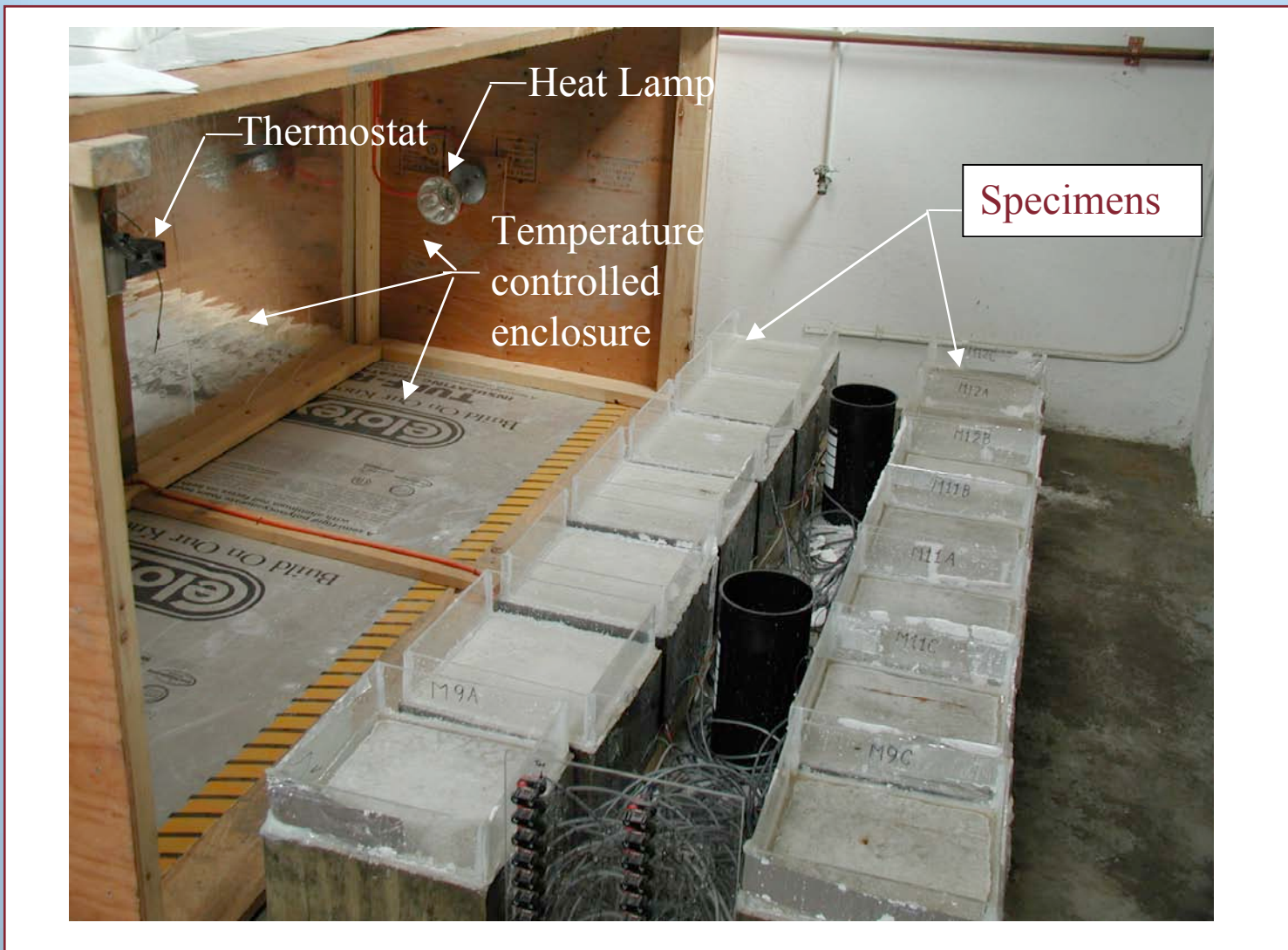
- ◆ 108 Weeks Total

Some Specimens Continued to 204 Weeks





# Test Protocol - Enclosures





## Macrocell Readings – Iron Loss

Metal loss in grams/amp-hour

=atomic weight/[ $(\text{Faraday's Constant}) * (\text{electron charge change})$ ]

$$= \frac{(55.8 \text{ grams} / \text{mol})(3600 \text{ s} / \text{hr})}{96489(\text{amp} * \text{s}) / \text{mol}(2 \text{ electrons})} = 1.04 \text{ grams/amp} \quad \text{- hr} \quad (1)$$



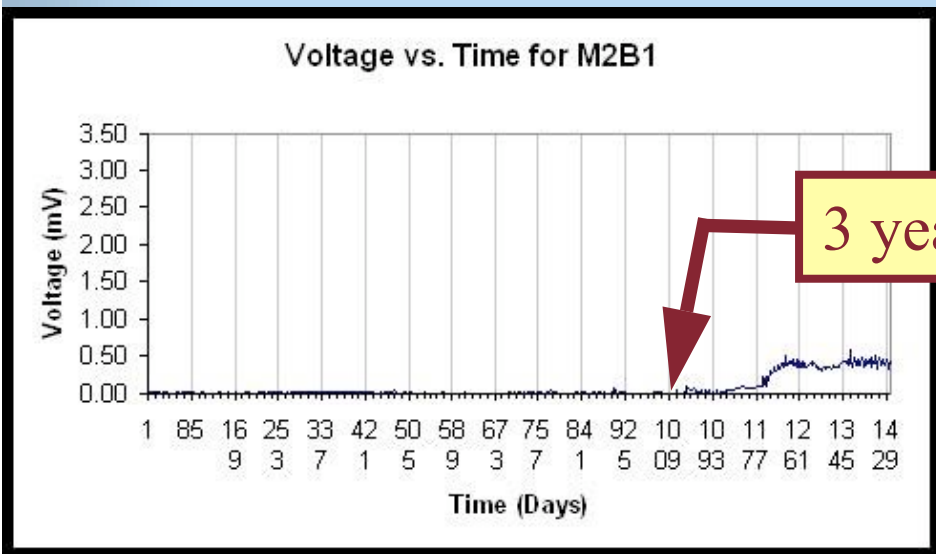








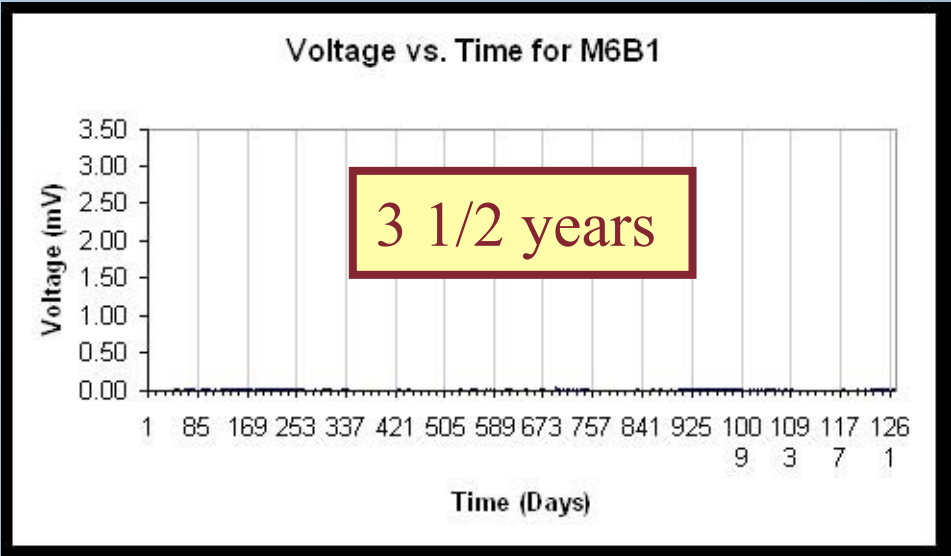
# MacroCell Readings



3 years

Hycrete DSS

Calcium Nitrite

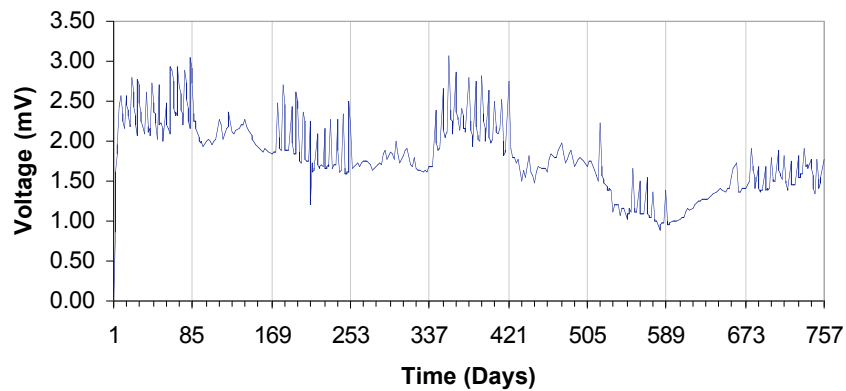


3 1/2 years

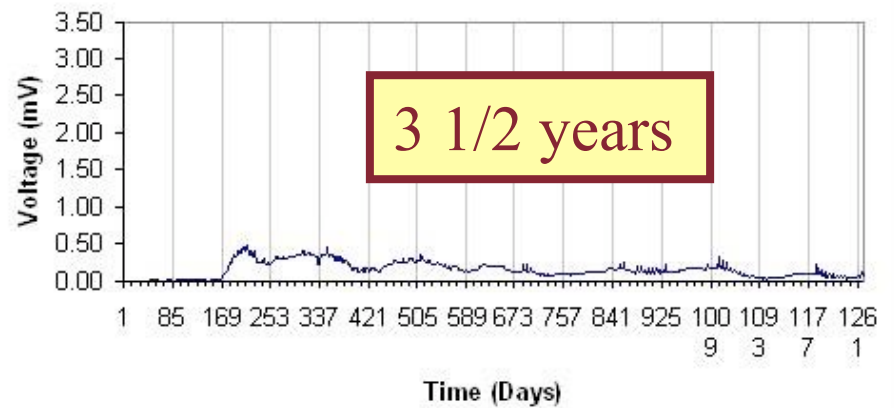


# MacroCell- Pre-Cracked

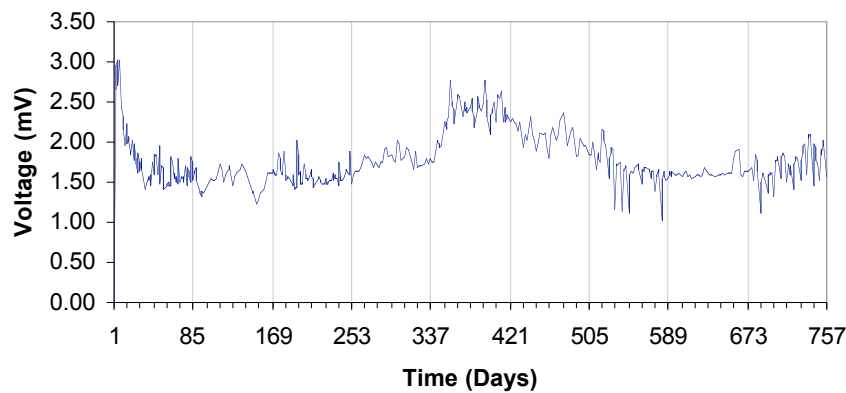
Voltage vs. Time for M1C1



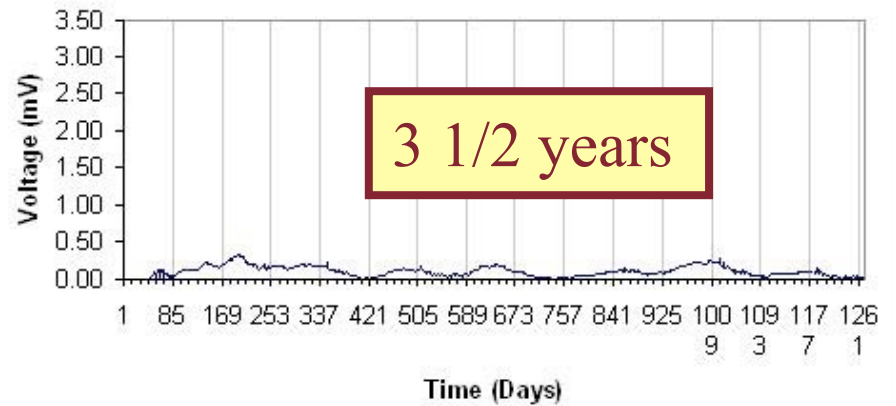
Voltage vs. Time for M6C1



Voltage vs. Time for M2C1



Voltage vs. Time for M10C2

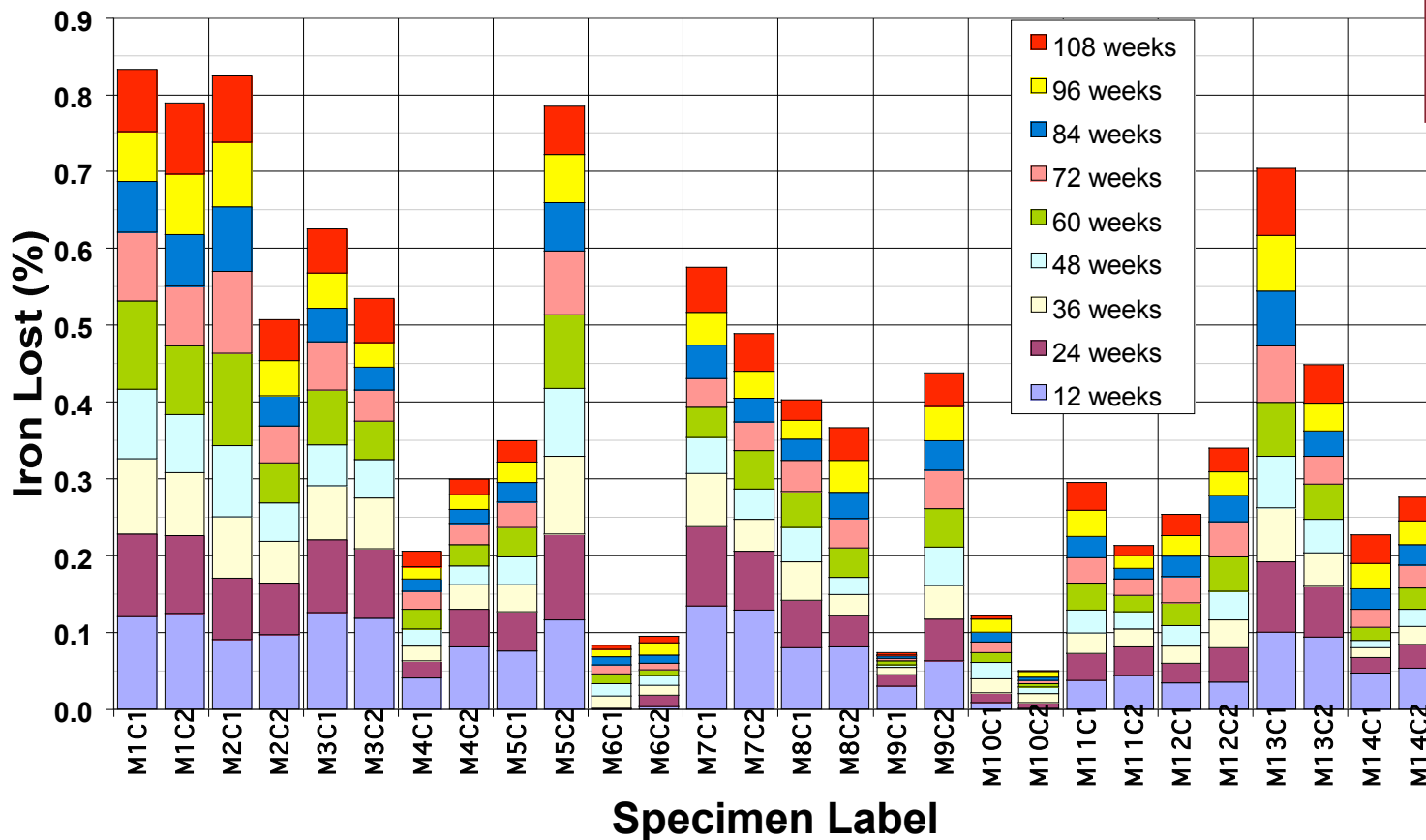






# Iron Loss – Pre-Cracked

## Iron Lost (Pre-Cracked Specimens)



M6 and M10  
<0.2 through  
204 weeks



# Specimen Rankings

Mix	Average Cumulative Iron Loss (%) Through 108 Weeks	Magnifier Over M10AB	Notes
M10AB	4.93E-03	1X	No Cracking
M6AB	5.39E-03	1X	No Cracking
M2AB	5.45E-03	1X	No Cracking
M11AB	6.80E-03	1X	Cracking in one specimen only
M9AB	9.54E-03	2X	No Cracking
M12AB	2.22E-02	4X	Cracking in one specimen only
M8AB	2.33E-02	5X	No Cracking
M14AB	3.78E-02	8X	Cracking in one specimen only
M3RB only	6.52E-02	13X	Specimen with no initial cracking
M4AB	7.82E-02	16X	Cracking in one specimen only
M5AB	8.13E-02	16X	Cracking in one specimen only
M10C	8.54E-02	17X	No Additional Cracking
M6C	8.88E-02	18X	No Additional Cracking
M13AB	9.54E-02	19X	Cracking in one specimen only
M14C	2.51E-01	51X	
M4C	2.52E-01	51X	
M11C	2.54E-01	51X	
M9C	2.55E-01	52X	
M12C	2.96E-01	60X	
M1AB	3.22E-01	65X	<i>Control</i>
M8C	3.84E-01	78X	
M7AB	3.96E-01	80X	
M3AB	4.86E-01	98X	Premature Cracking in A
M7C	5.31E-01	108X	
M5C	5.67E-01	115X	
M13C	5.76E-01	117X	
M3C	5.80E-01	118X	
M2C	6.65E-01	135X	
M1C	8.11E-01	164X	<i>Control</i>



## Chloride Results (Water Soluble)

Specimen	Depth		
	0 to 13 mm	13 to 25 mm	25 to 38 mm
M1B	0.53	0.49	0.46
M2A	0.49	0.28	0.25
M3A	0.42	0.39	0.37

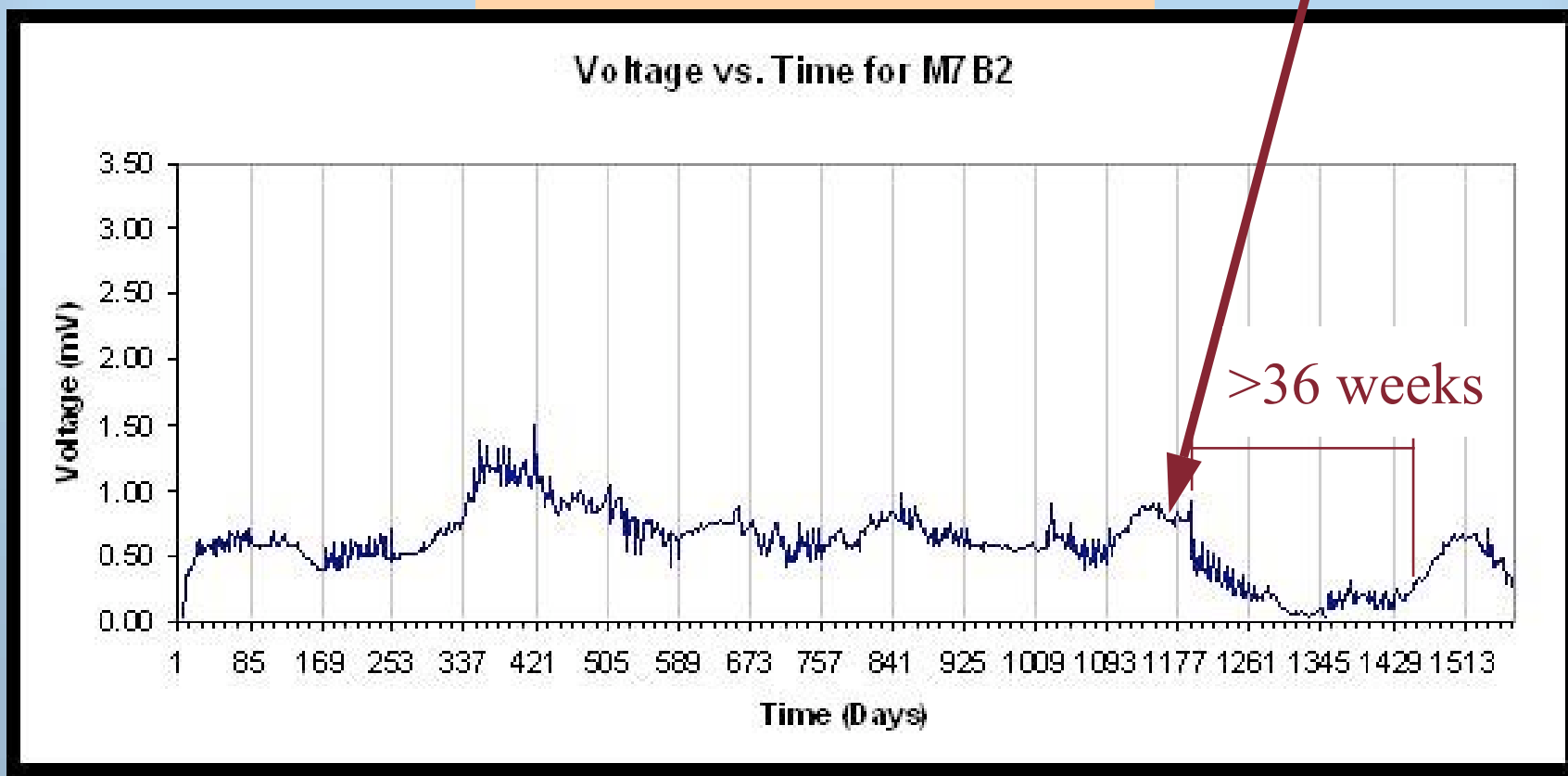
New Results Pending  
(Assistance?)

M11A	0.30	0.25	0.13
M12A	0.51	0.30	0.13
M13A	0.54	0.50	0.43
M14B	0.79	0.68	0.45

\*Notes: All data is from autopsied specimens, after 108 weeks of testing for all but M6A and M10A which were after 84 weeks of testing



◆ Spray Application





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# Materials Testing



UConn

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- ◆ Materials Testing
- ◆  $\bar{\epsilon}_c$ ,  $\bar{\epsilon}_t$ , 1 and 2 %

- ◆ Absorption
- ◆ Freeze Thaw
- ◆ Compressive Strength

- ◆ Sponsor: Connecticut DOT



# From UConn Project 96-2 Phase II Report

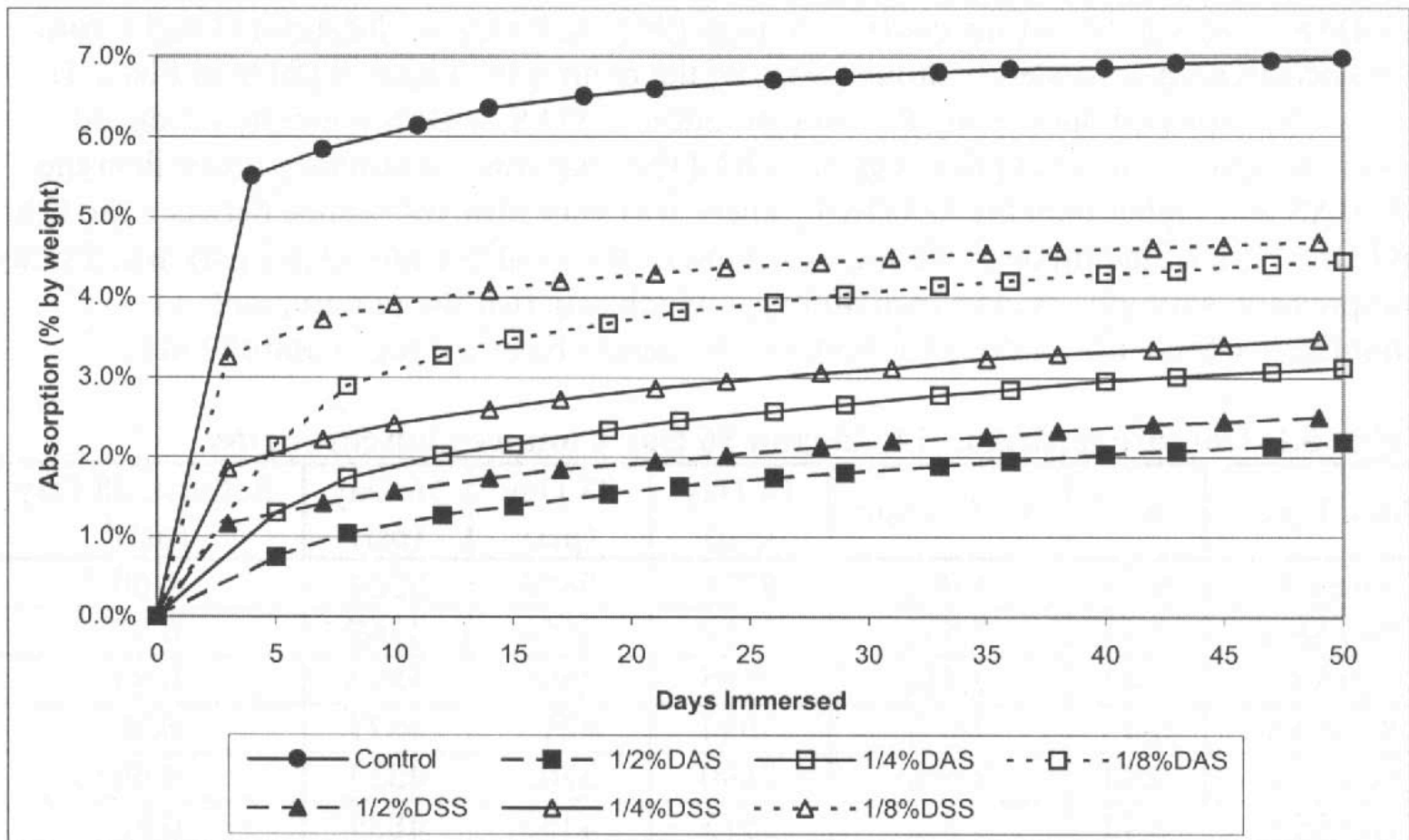


Figure 5.2 Absorption versus time: Control, DAS and DSS specimens, dried at 40°C, Phase II specimens.



◆ Absorption – Dried at 100°C

◆ Control	8.5
◆ _ %	5.1
◆ _ %	3.8
◆ 1 and 2 %	3.0

◆ Absorption - Dried at 40°C

◆ Relative Values Similar

ASTM C642-90





UConn

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- ◆ Freeze-Thaw
- ◆ -18 to 4 °C
- ◆ >300 cycles

◆ Reported Acceptable for HPC

ASTM C666-92

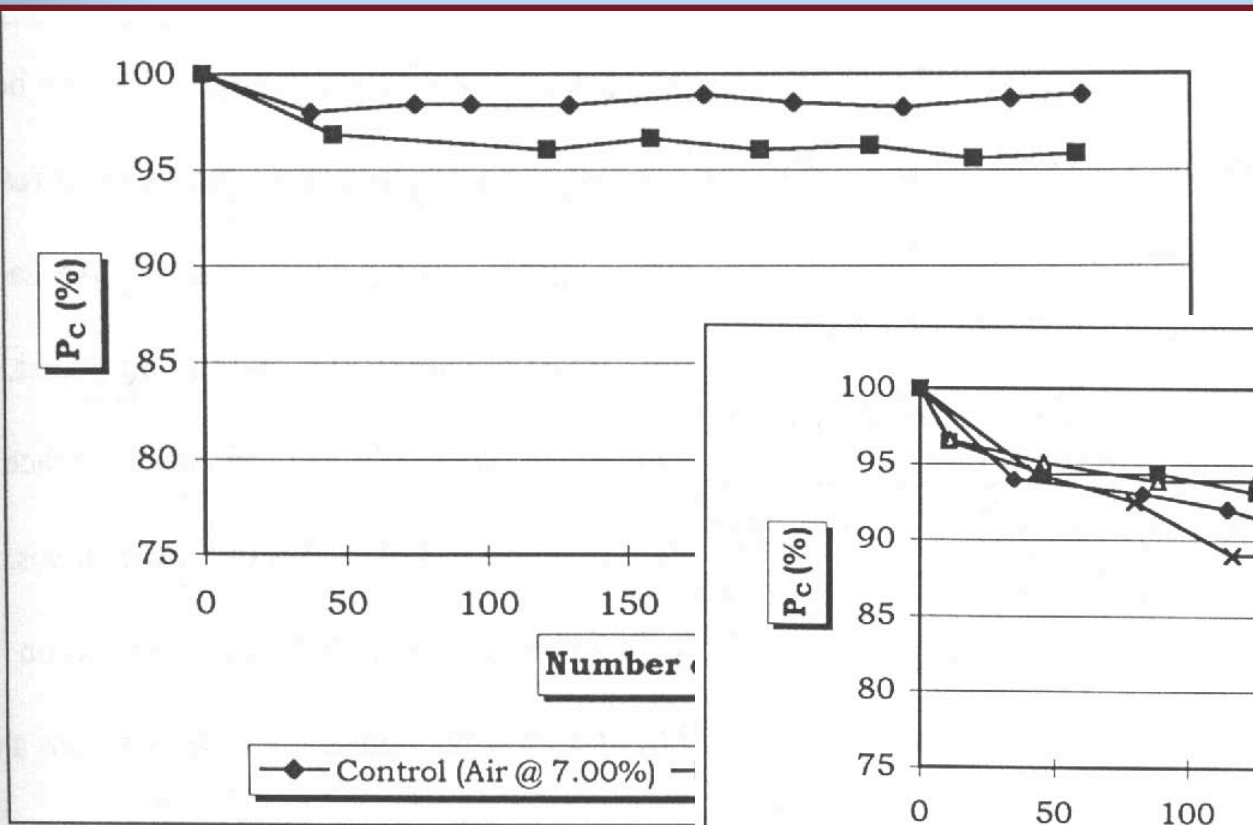


Figure A-6 Relative Dynamic Modulus of Elasticity, Control (Air @ 7.00%)

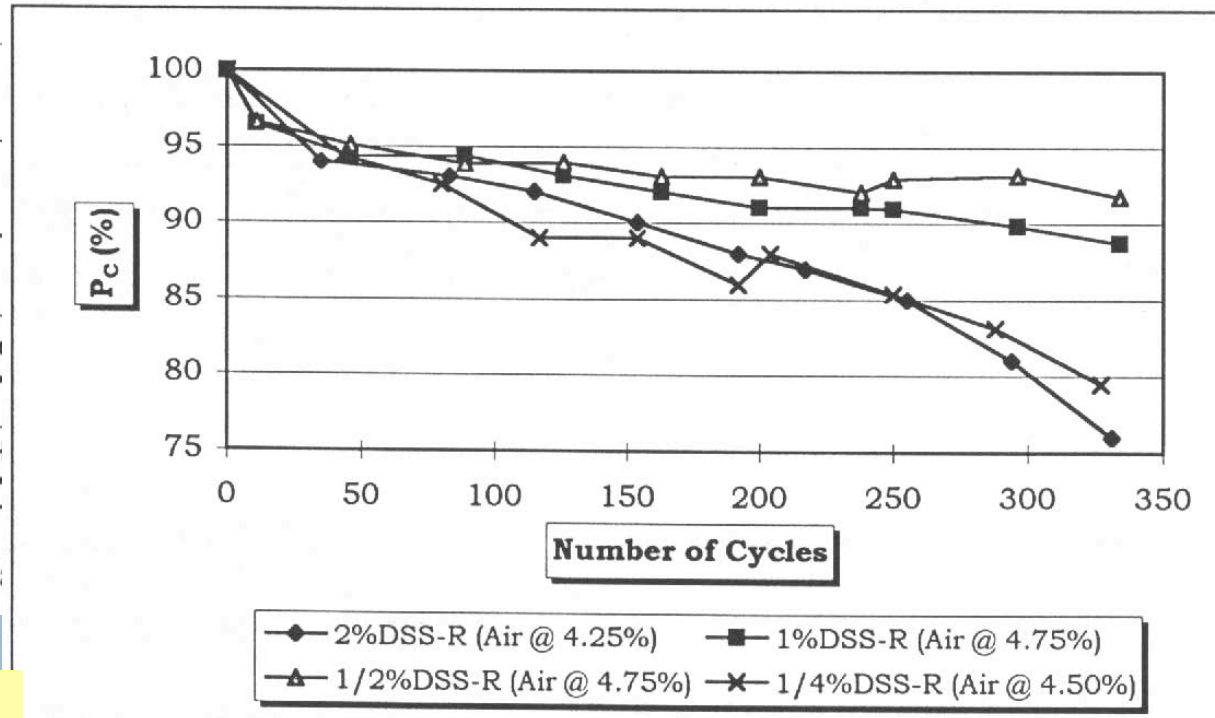


Figure A-11 Relative Dynamic Modulus of Elasticity, DSS-R Mixes.

From UConn Project 96-2  
Phase I Report



- ◆ Stable Air Entrainment
  - ◆ Better Without De-foaming Agent
  - ◆ Likely Best with Full De-Foaming and Air-entraining Admixture

- ◆ If allowed to dry before testing  
“resistance to freeze-thaw damage  
might increase very significantly”  
(Phase II pg. 124)



◆ Strength Loss

◆ 0.5, 1 %	10 to 20 % Reduction
◆ 1 and 2 %	up to 37% reduction

◆ Possible De-foaming Agent Issue

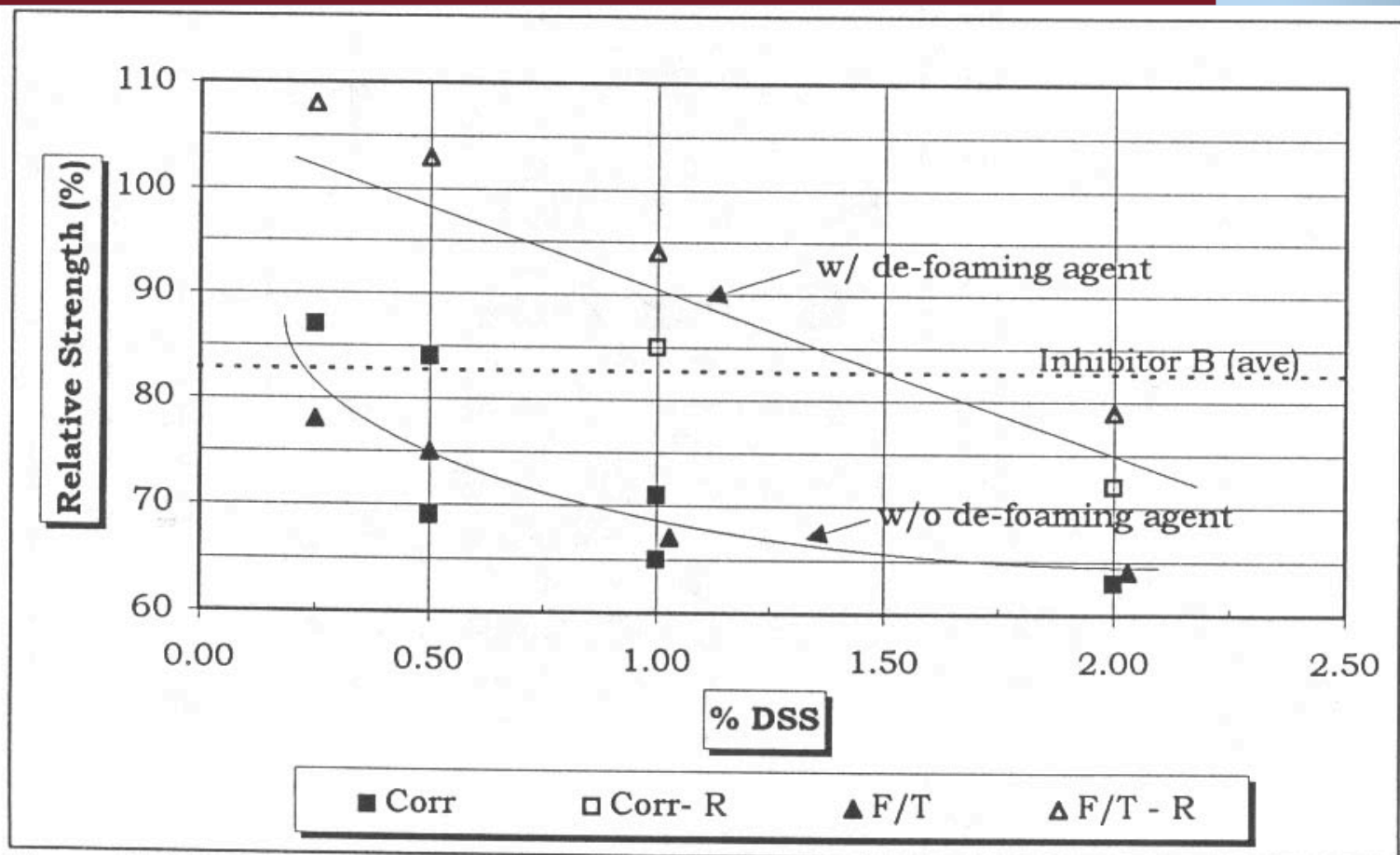


Figure C-4 Relative 28 Day Compression Strengths: all DSS Mixes (Control Mixes = 100%).

From UConn Project 96-2  
Phase I Report



UMass

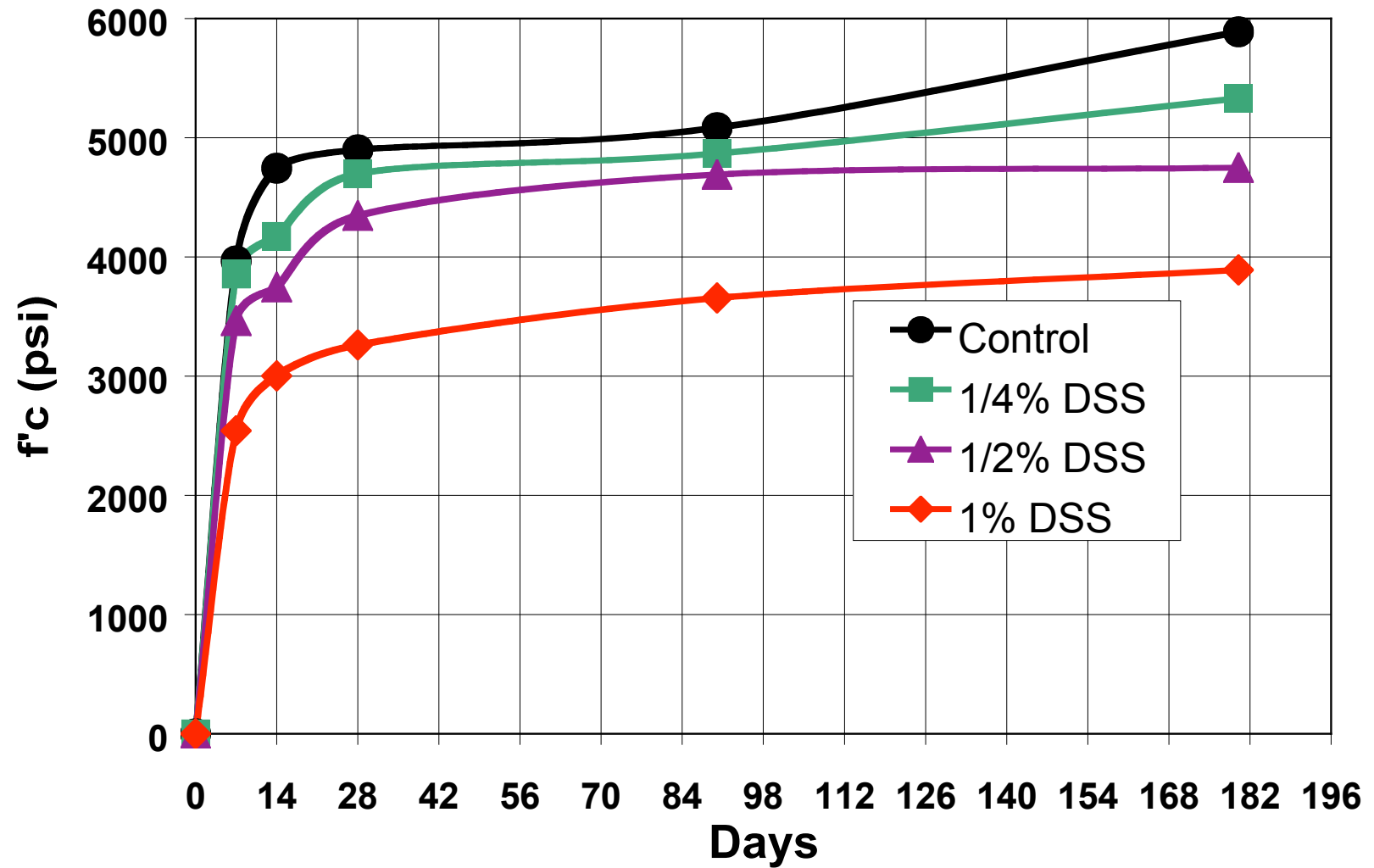
- ◆ Compressive Strength – NETC Test
- ◆ \_ % Hycrete DSS

◆ Triple Combinations:	Strength <b>Increased</b> 15%
◆ GBFS, CN/GBFS:	Strength <b>Increased</b> 15%

◆ CN+Hycrete DSS:	Strength <b>Reduced</b> 25%
◆ Hycrete DSS:	Strength <b>Reduced</b> 10%



# Compressive Strengths





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# Field Implementation





## Field Implementation



1 Year

50 Barriers

I-84

Guard Rails – Connecticut DOT

Photo Courtesy of CT DOT



- ◆ New York/New Jersey Port Authority - Sidewalks
- ◆ Ohio – Noise Barriers/black steel
- ◆ Florida
- ◆ Rhode Island
- ◆ Texas
  
- ◆ Ohio DOT Spec Approval



# Field Implementation

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## Bridge Decks

New Jersey Turnpike Authority

100 yd<sup>3</sup> Deck

Hycrete

High Performance



## Field Implementation



2-decks with black bars  
embedded @ 1”

560 yd<sup>3</sup>

Hycrete vs. Normal  
High Performance

Corrosion Readings @  
28 days and once/twice  
yearly for 10 years

### Kansas Bridge Project

Photo Courtesy of Broadview Technologies



- ◆ FHWA Funding
  - ◆ Kansas
    - » KU and KS DOT
    - » Lab and Field Studies
  - ◆ Virginia DOT



## NETC 03-2

“Field Studies of Concrete Containing Salts of  
an Alkenyl-Substituted Succinic Acid”



NETC 03-2

## University of Massachusetts, Amherst

Initiated 09/15/04

- ◆ Large Scale Mix Design
- ◆ Materials Testing
- ◆ Project Selection
  
- ◆ Field Implementation
- ◆ Long-Term Corrosion Monitoring



Questions?

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## References

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### ◆ UMass (NETC 97-2)

- ◆ Civjan S. A., LaFave J. M., Lima J., and Pfiefer D. “Effectiveness of Corrosion Inhibiting Admixture Combinations in Structural Concrete” *Cement and Concrete Composites*, Elsevier – In Publication
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