Accelerated Testing of Corrosion Resistant Reinforcing Bars

Seung-Kyoung Lee, Ph.D.

Center for Advanced Infrastructure & Transportation

Rutgers University, Piscataway, New Jersey

July 17 & 19, 2012 (FL & SC DOTs Rebar Seminars)

Presentation Outline

- Experimental
- Data Collection
- Test Results
- Preliminary Findings

Experimental

Lab Evaluation of Various Reinforcements

- Twelve types of #5 or #6 reinforcing materials were acquired from 11 sources and they were embedded in eight slabs.
- The rebars were placed in the top and bottom mats.
- Three levels of artificial defects (0.15, 0.5 and 1.0 %) were introduced on ECR, Zbar, and galvanized.

1	Black
2	ECR
3	Zbar
4	Galvanized
5	MMFX
6	Duracorr
7	CMC
8	NX Infrastructure
9	3Cr12
10	2201
11	Arminox (2304)
12	EnduraMet 32

As-Received Rebar Samples

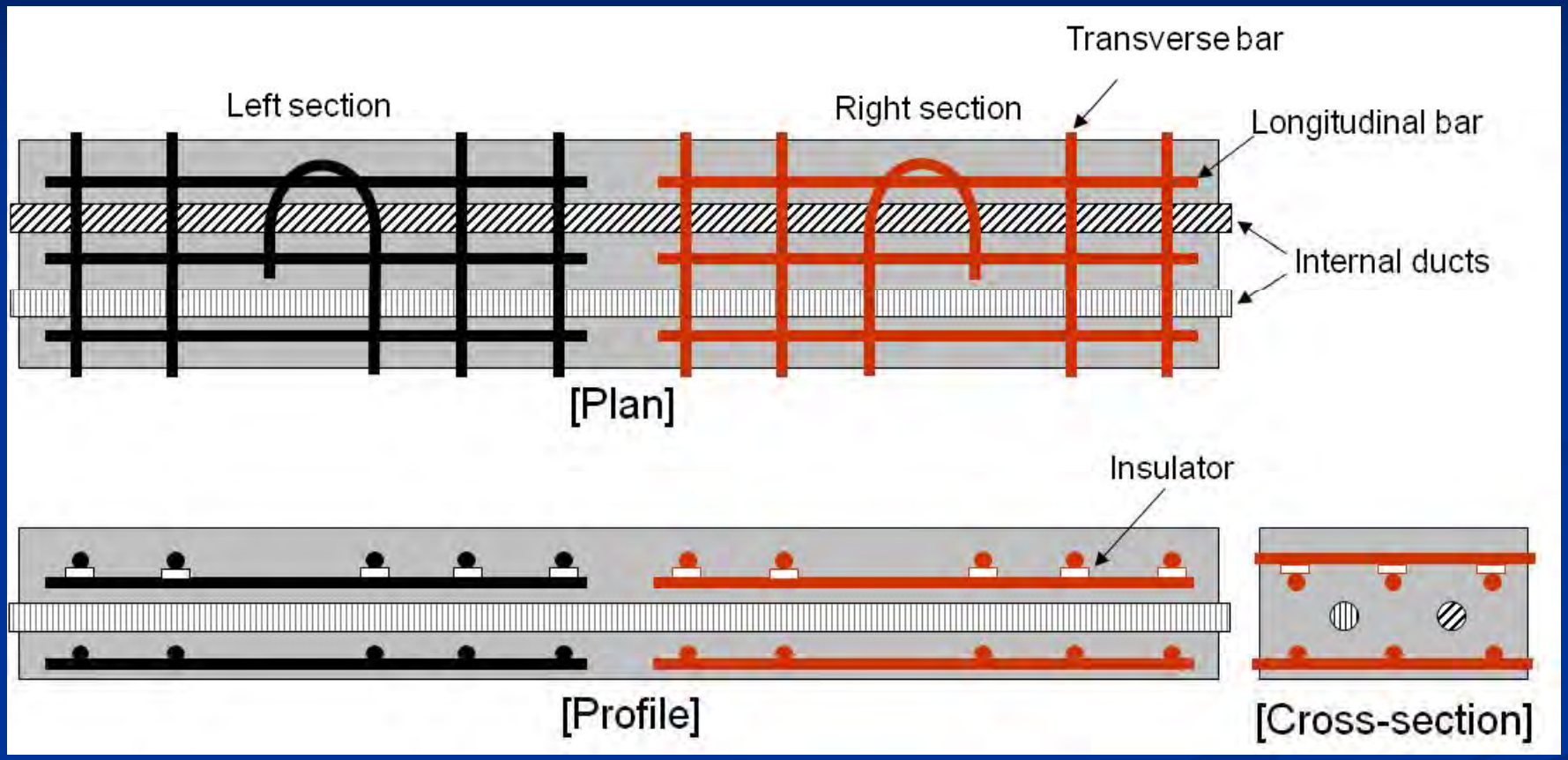
Defect Introduction

Damage Level / Mat (% of total surface area)	Number of defects based on 1/8 in. artificial defect size (ECRs, Zbars, and Galvanized)		
	Straight Bar		Bent Bar
	Transverse (18 in.)	Longitudinal (38 in.)	Transverse (30 in.)
0 - 0.05	0	3	
0.15	4	10	7
0.5	14	30	
1.0	29		

Defect Introduction

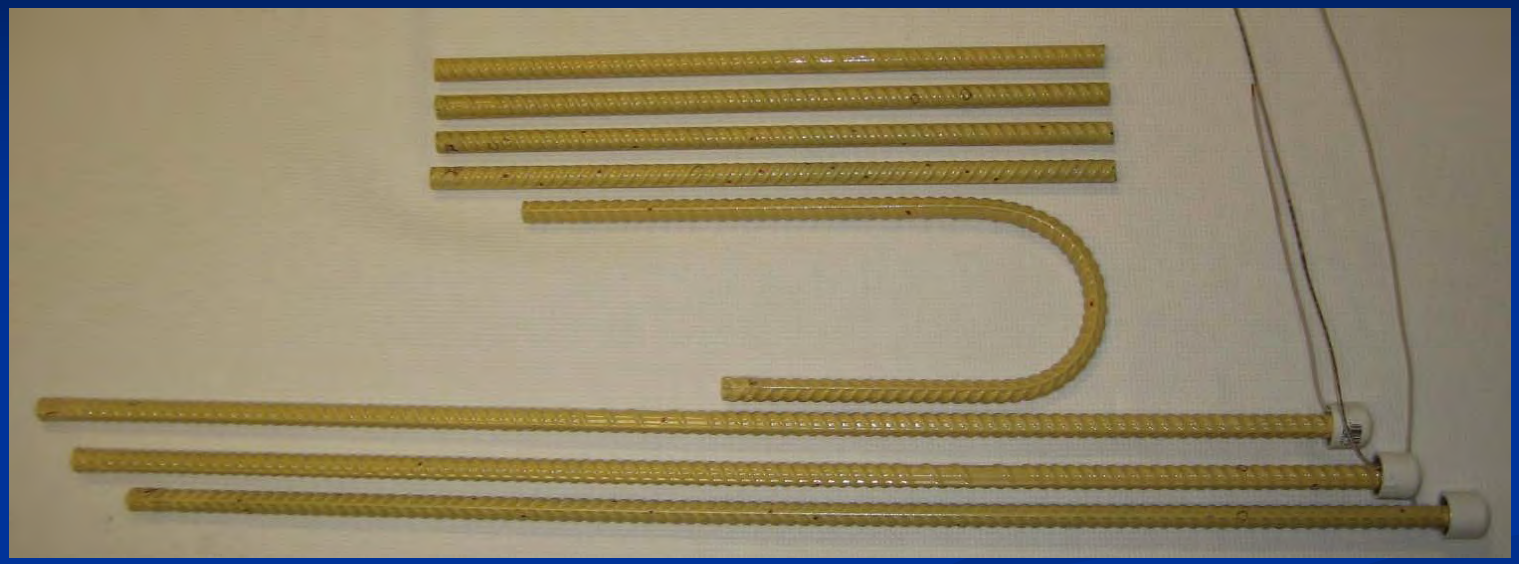
Encapsulation of Longitudinal Bars

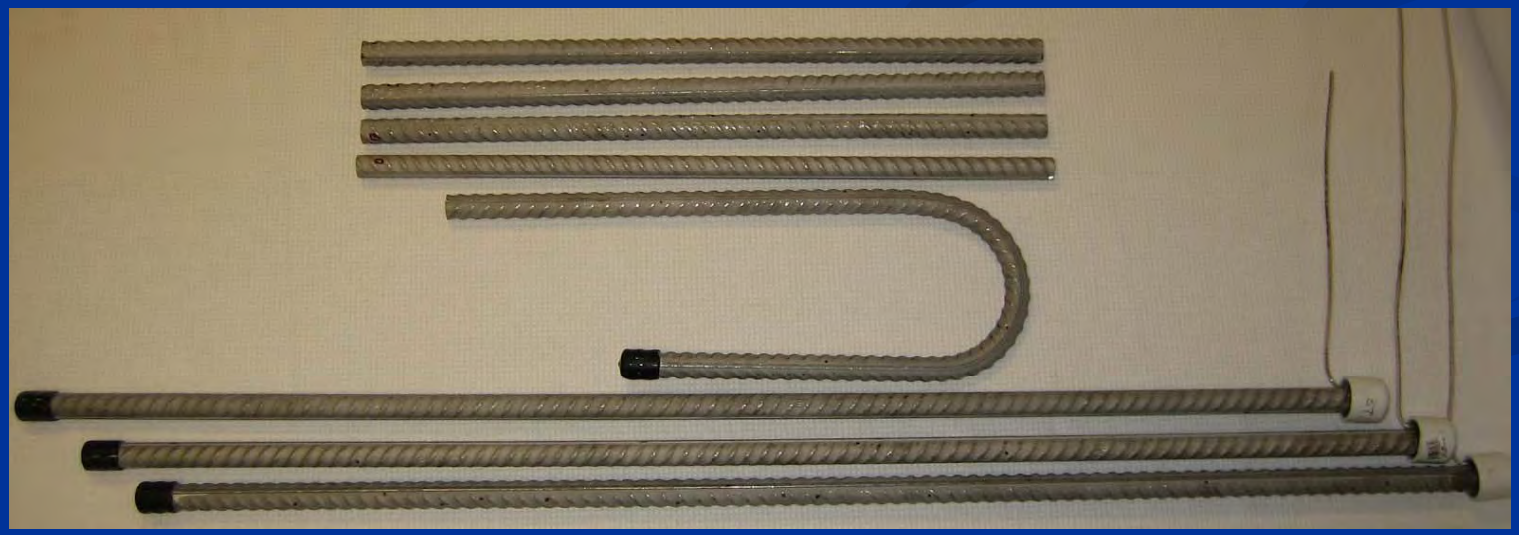
Slab Configuration



- Top mat clear cover = 2.0 in. (a black slab section had a 1.0 clear cover)
- Bottom mat clear cover = 0.5 in.

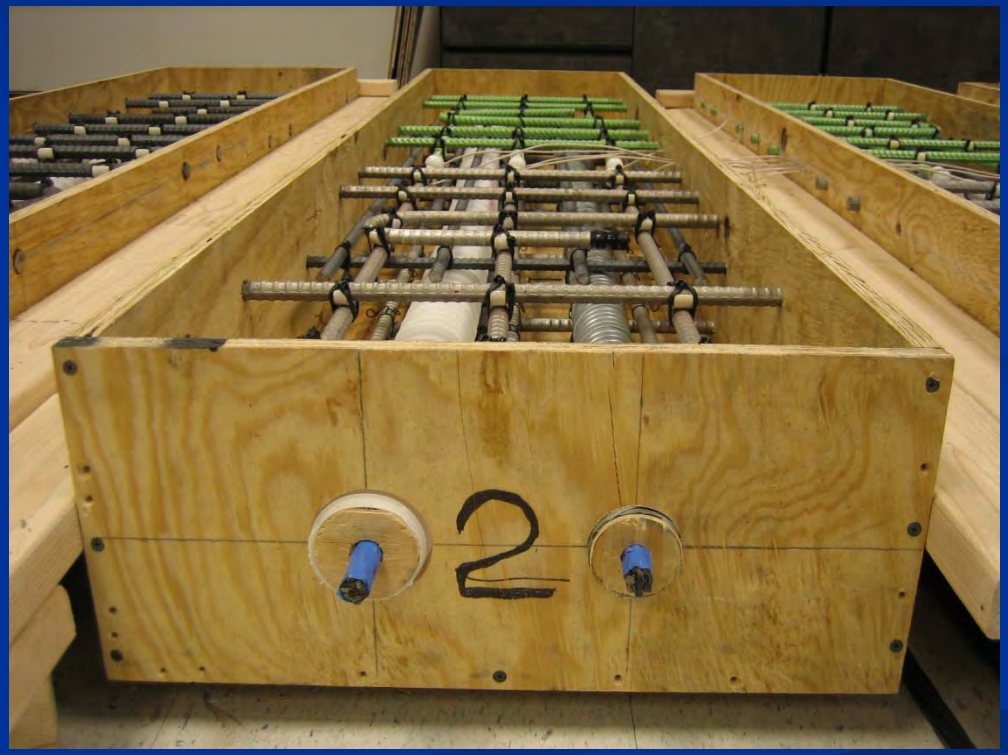
Bars Ready for Installation





Bar Arrangement in Bottom Mat

Top Mat Rebar Installation



Rebar Installation Details

Electrically Connected Rebars
in the Bottom Mat

Electrically Isolated Rebars
in the Top Mat

Molds Ready for Casting

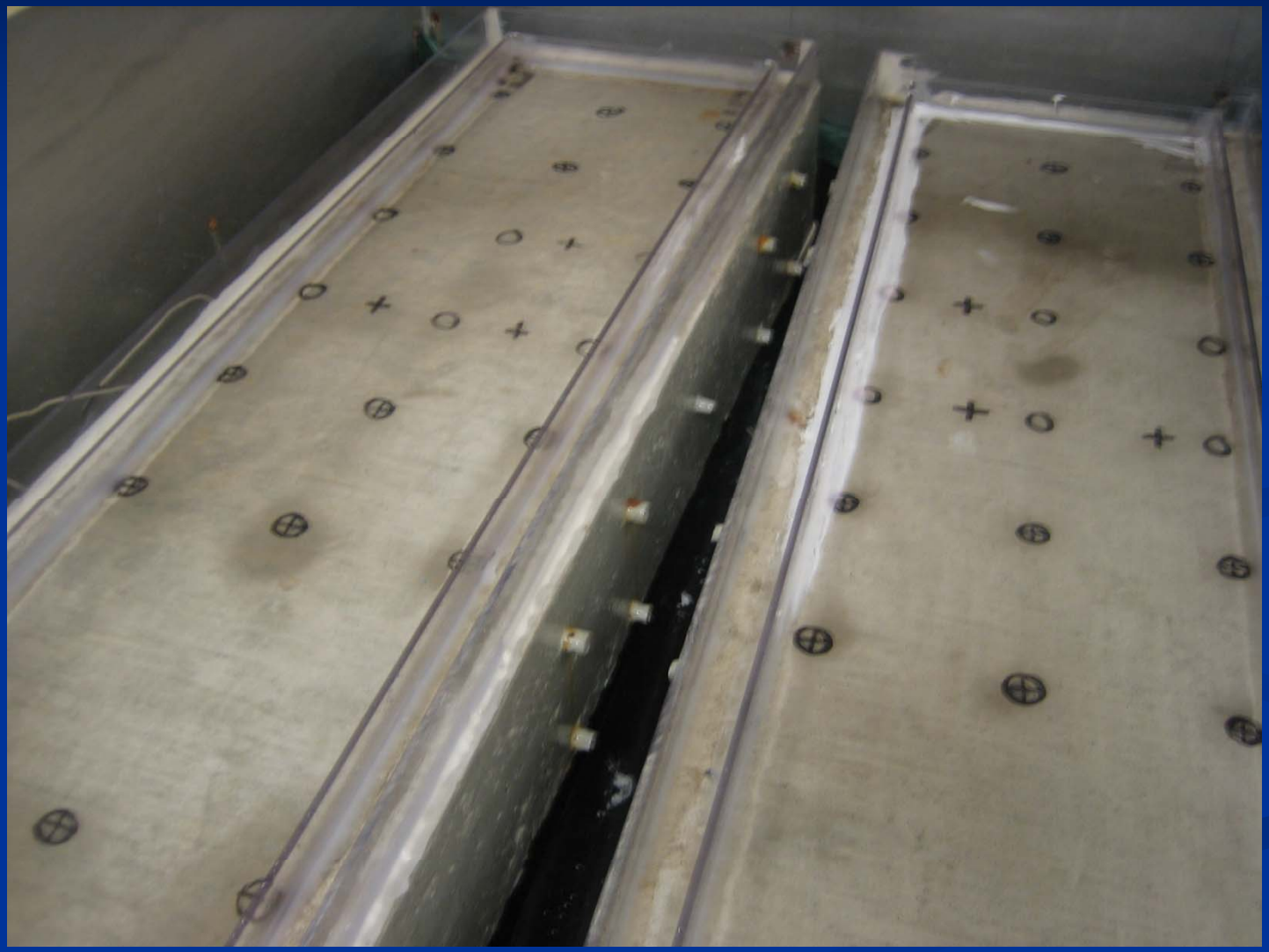
Casting (April 30, 2009)

Demolding

Curing

Slab Moving Day (May 27, 2009)

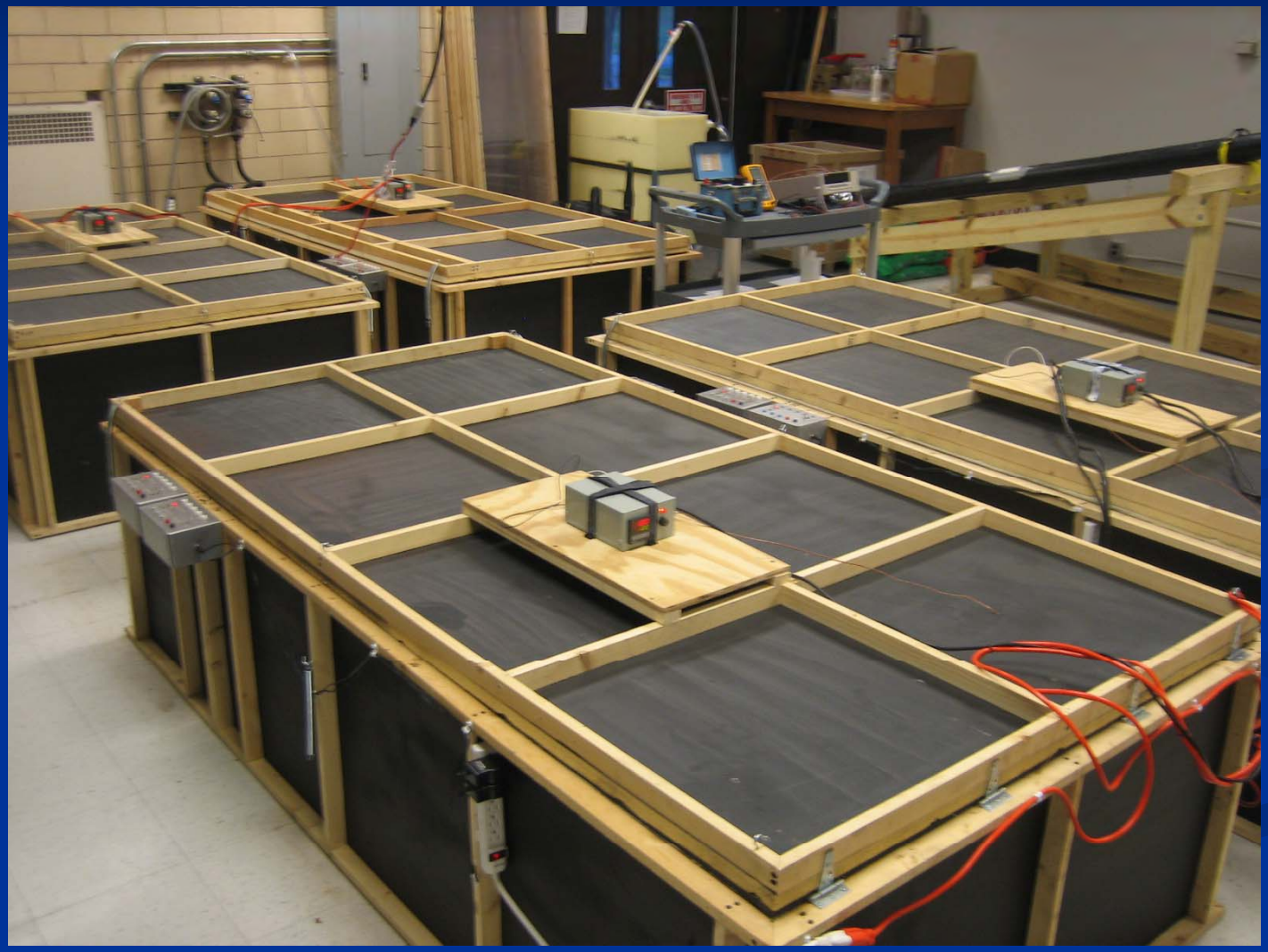
Slabs in a Heat Tent



Exposure Condition

- Modified Southern Exposure
  - Weekly wet-dry cycles
  - Wetting in 15 wt.% NaCl Solution at ambient temperature for three days (Monday–Wednesday)
  - Data Collection for one day (Thursday)
  - Drying at 100º F for three days (Friday-Sunday)
  - During 381-450 days, drying cycle only
- There was a 110-day interruption associated with ponding well leaking problems.

Drying Cycle



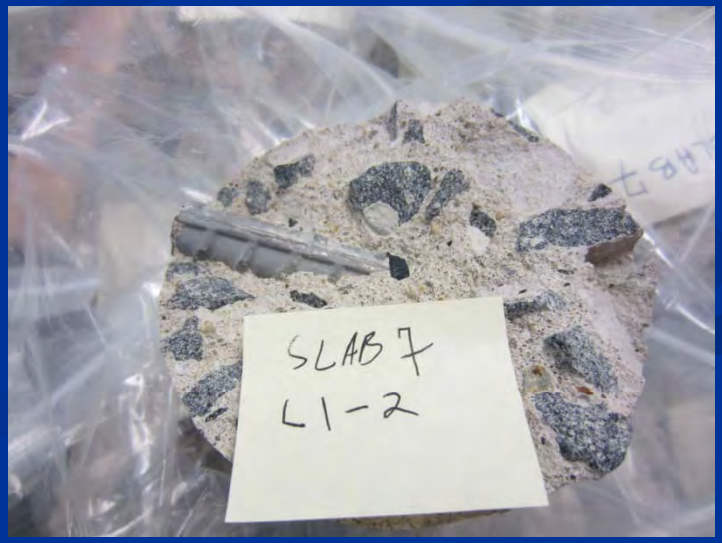
Wetting Cycle

Leaking Problem Encountered

Leaking Problem Encountered

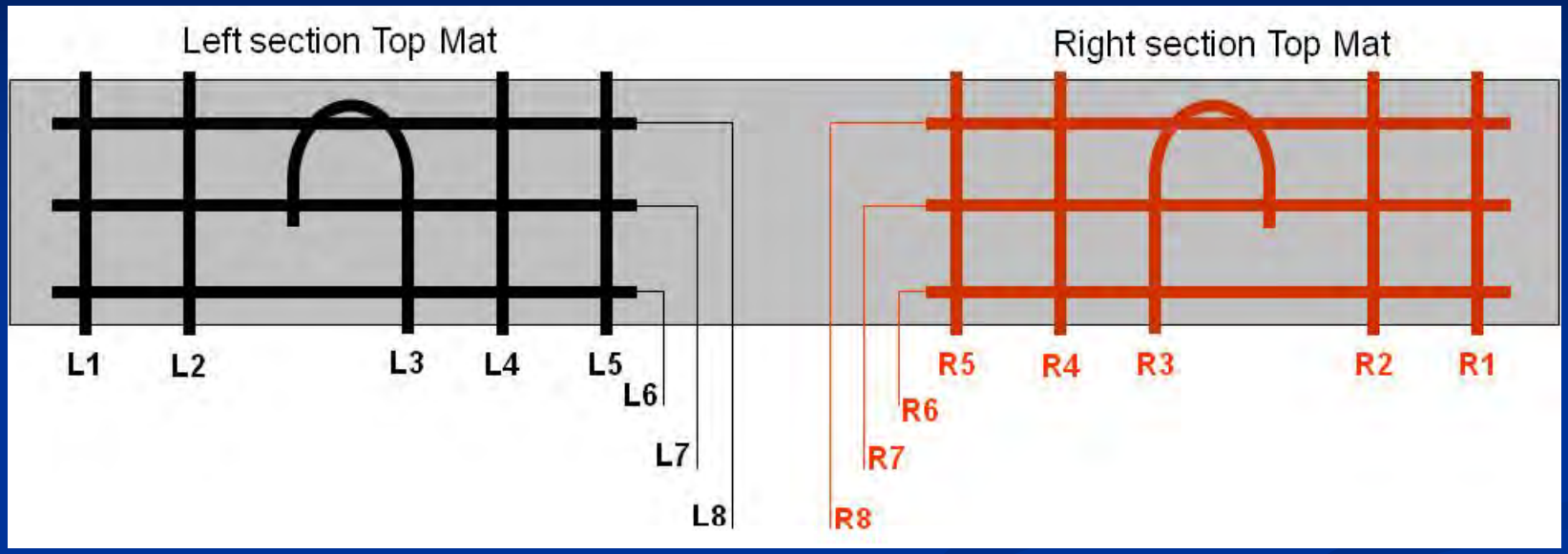
Coring

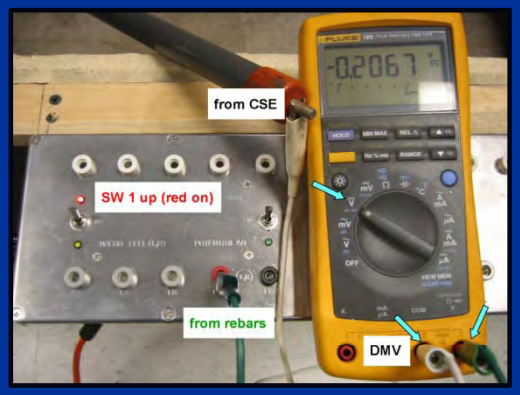
Extracted Cores for Autopsy



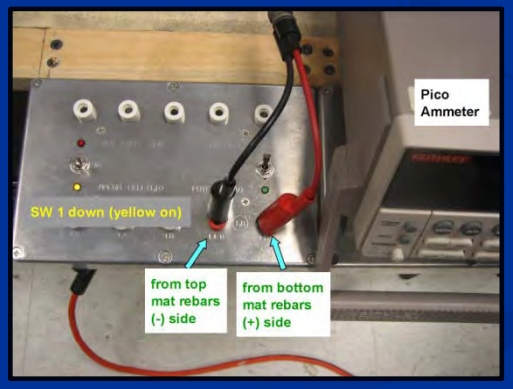
Data Collection

Data Collection

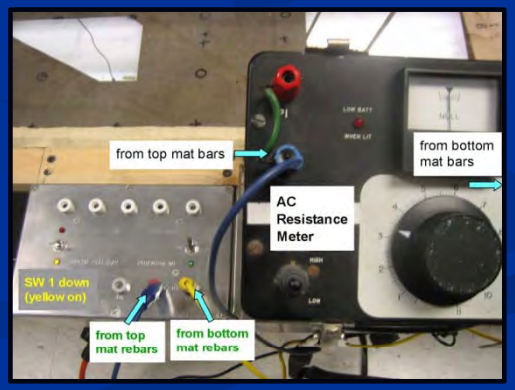




Potential

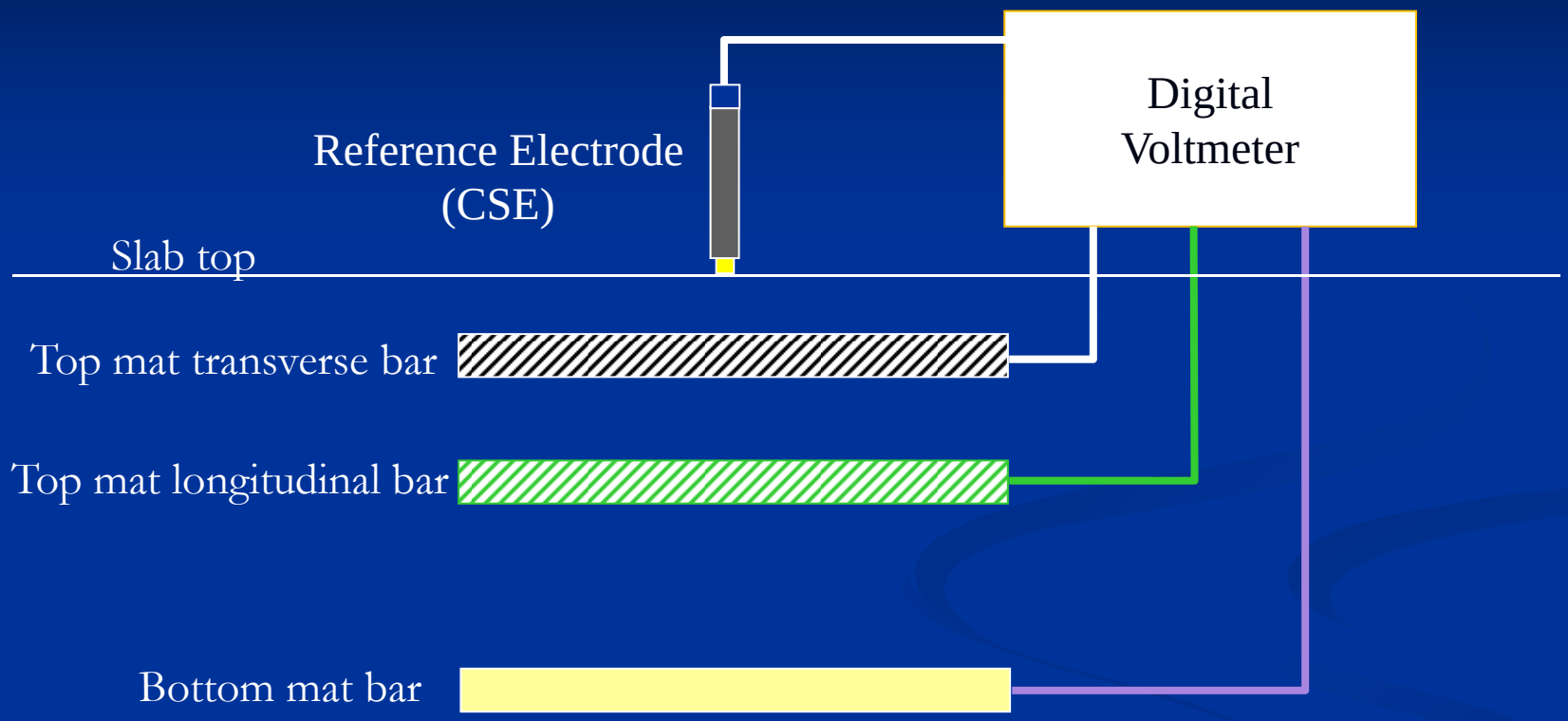


Macro-cell Current



AC Resistance

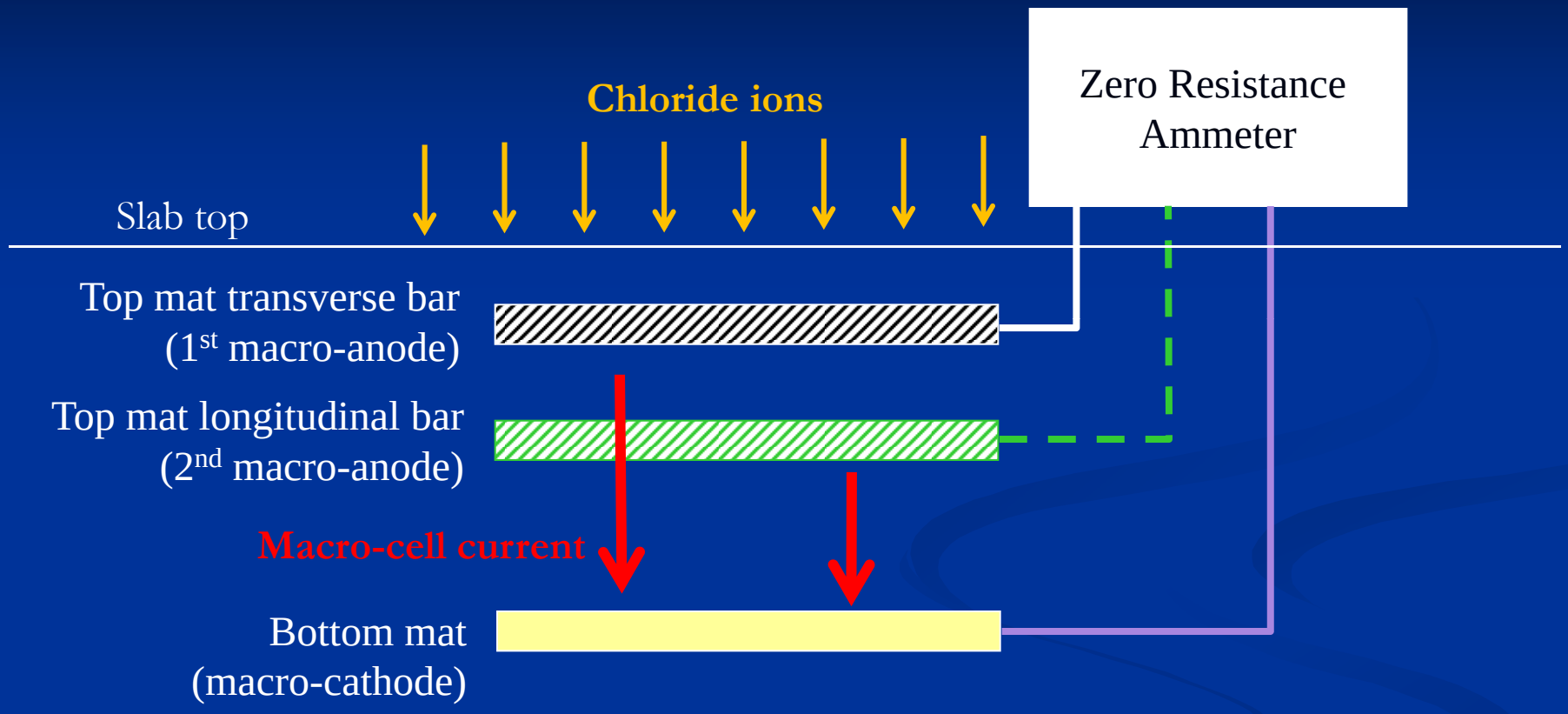
Corrosion Potential



It indicates a thermodynamic tendency whether corrosion can occur or not.

Macro-cell Current

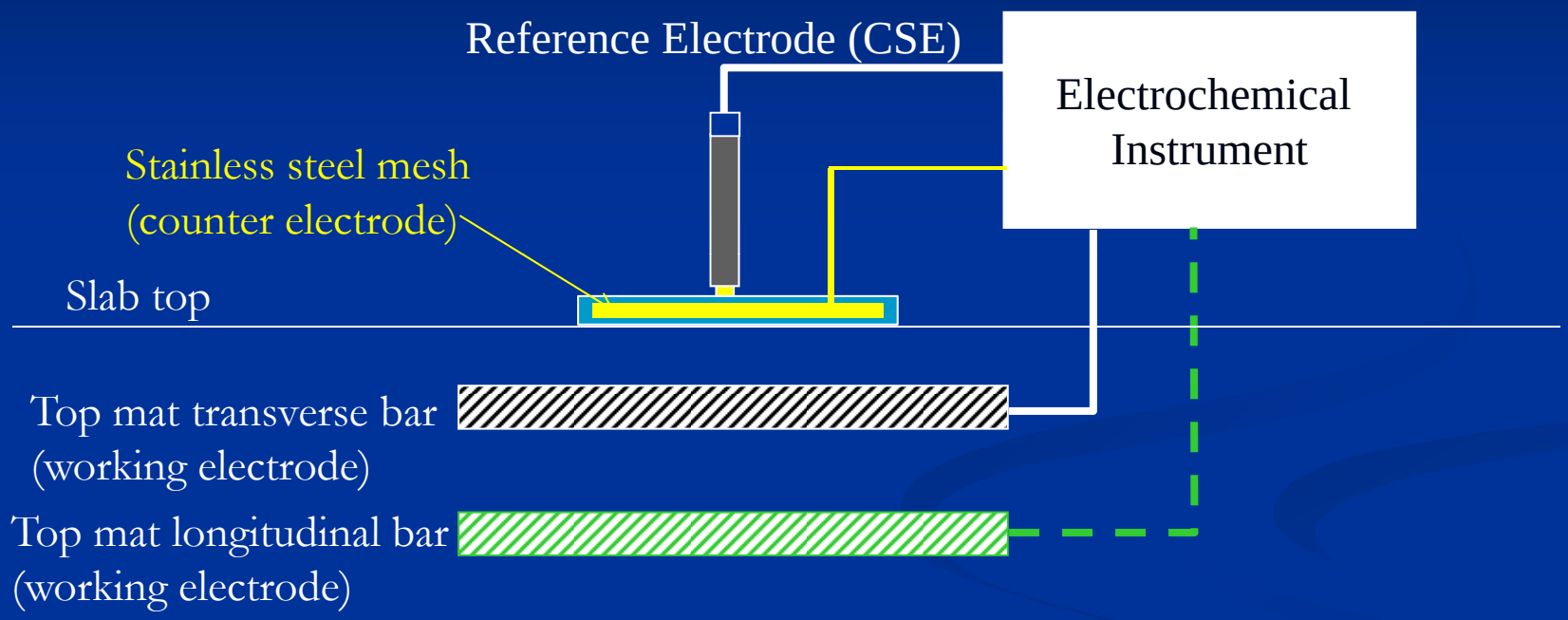
(A Galvanic Corrosion Current)



It indicates intensity of a galvanic corrosion under a given environment.

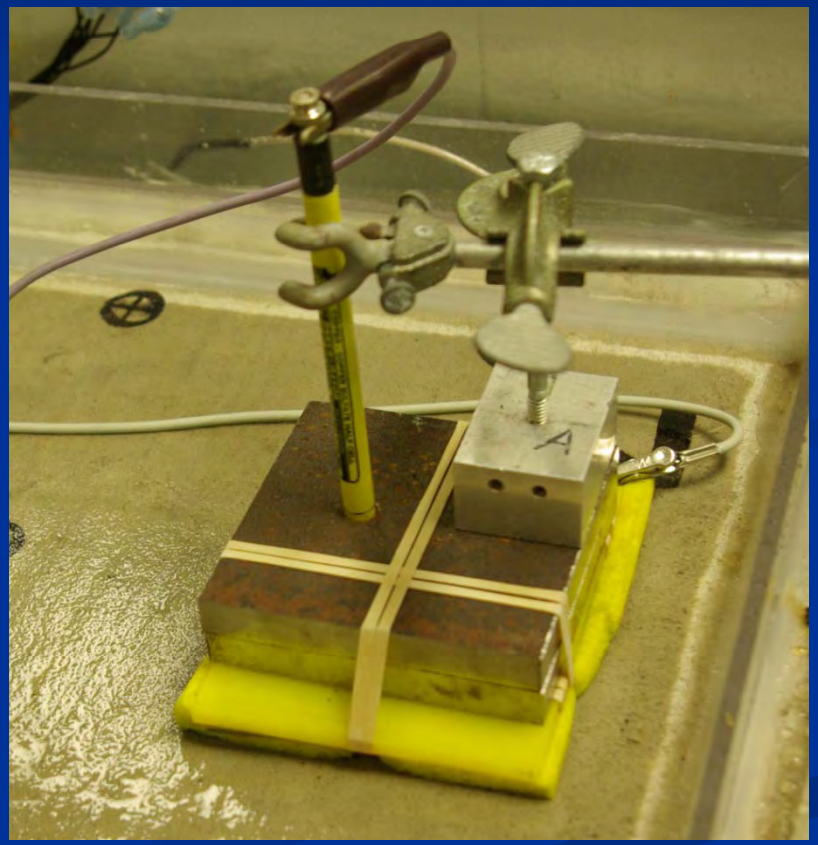
Linear Polarization Resistance

(Rp, instantaneous corrosion rate)

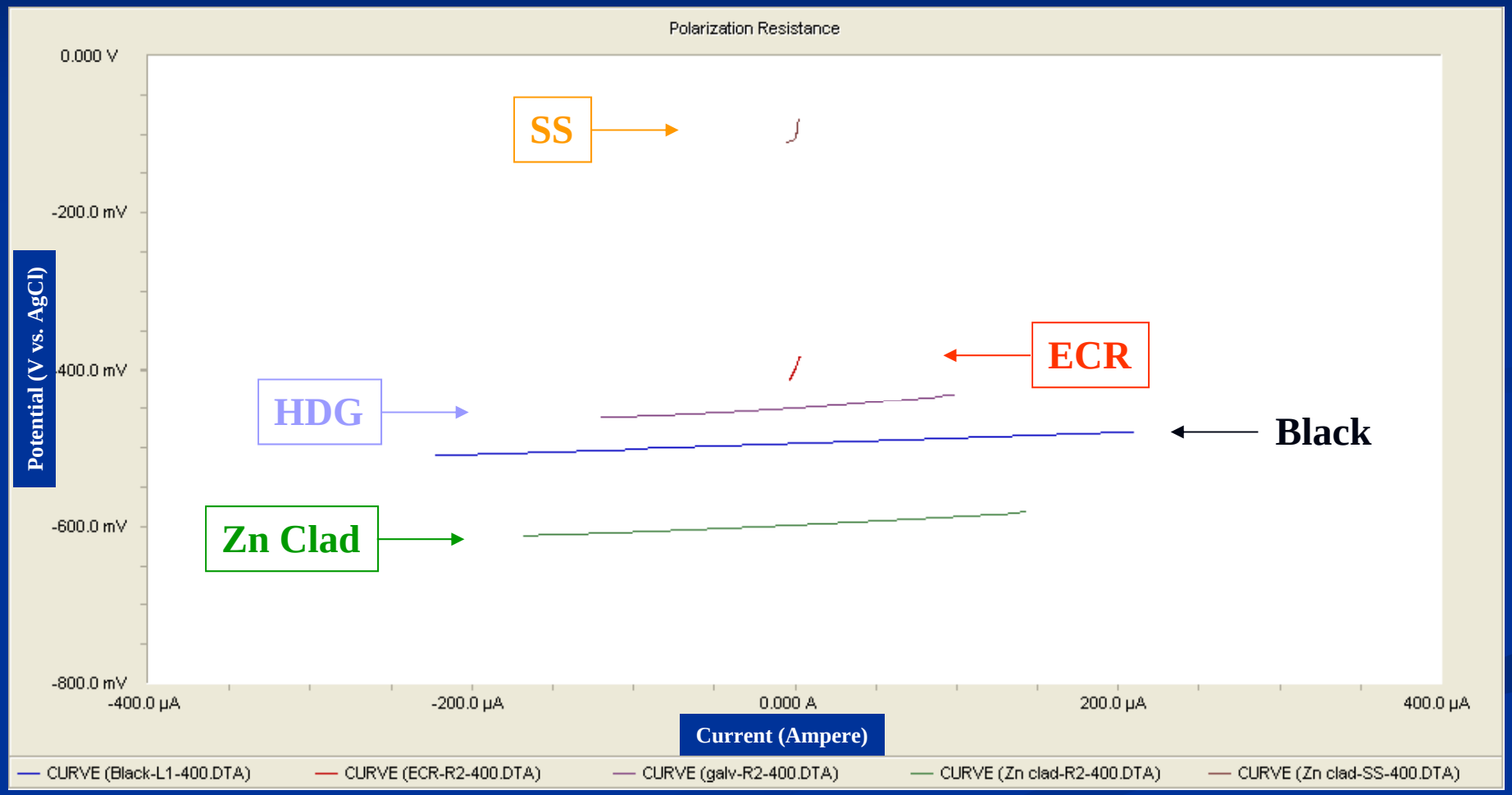


It represents quantitative electrochemical behavior how fast corrosion takes place at the moment of measurement.

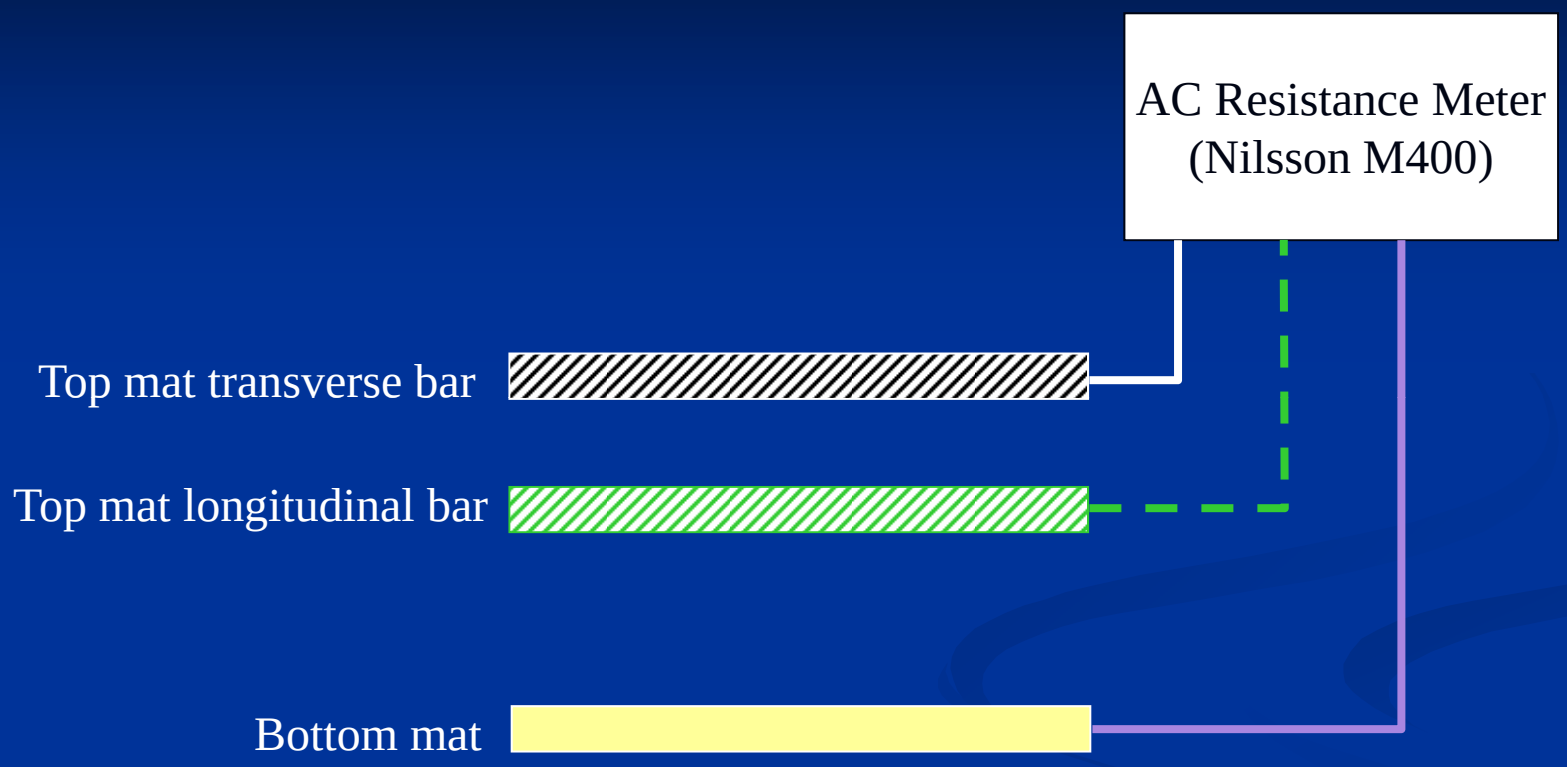
LPR Measurement



Example of LPR Data



AC Resistance



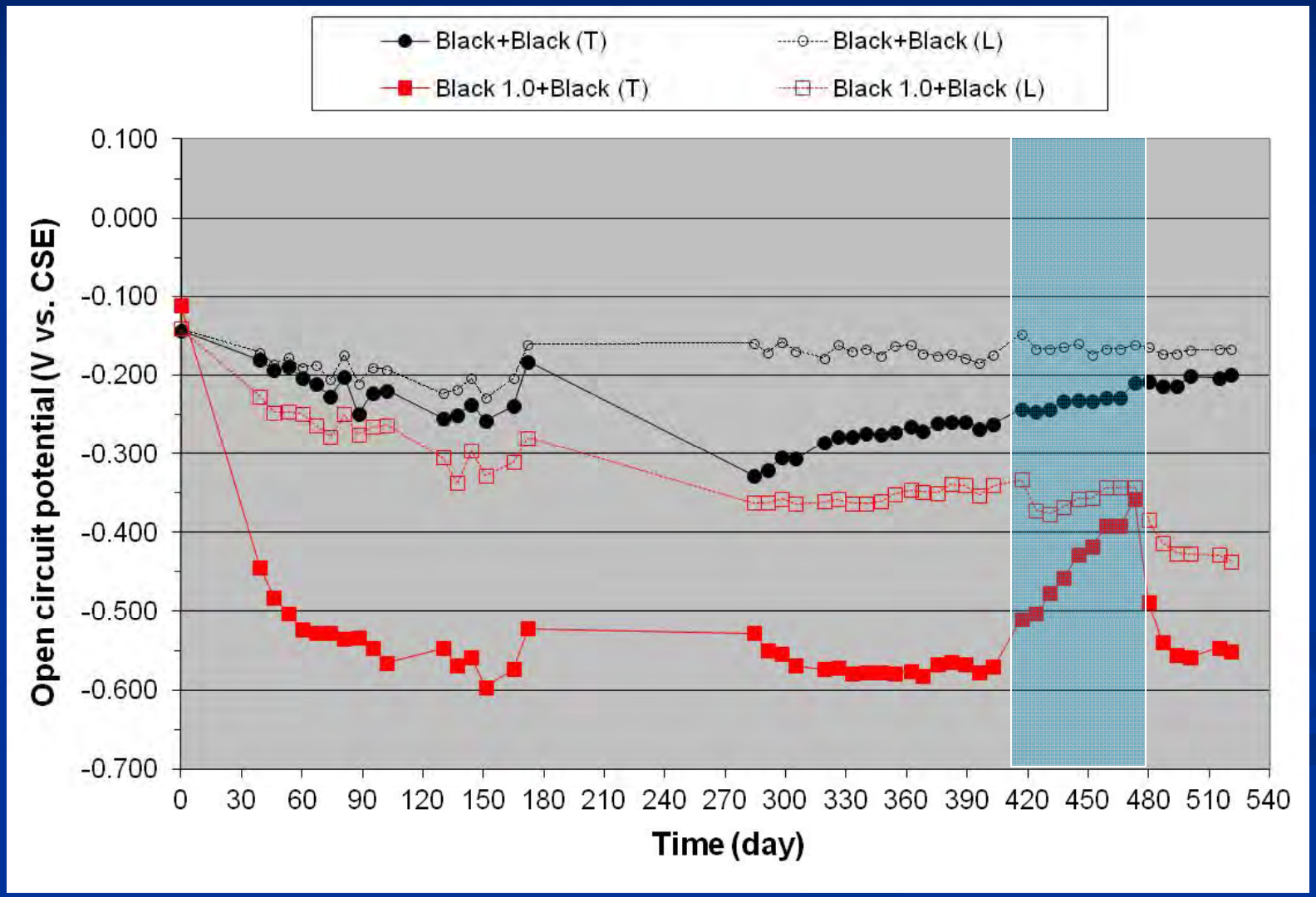
It indicates how easily corrosion current can flow from top mat bars to bottom mat.

Remaining Work

- Autopsy of the extracted bar samples
  - Thorough documentation of the bar conditions
- Chloride Analysis
  - Collection of the concrete powder samples
  - Determination of chloride diffusion coefficient per slab
  - Acid-soluble chloride at rebar/concrete interface

Test Results

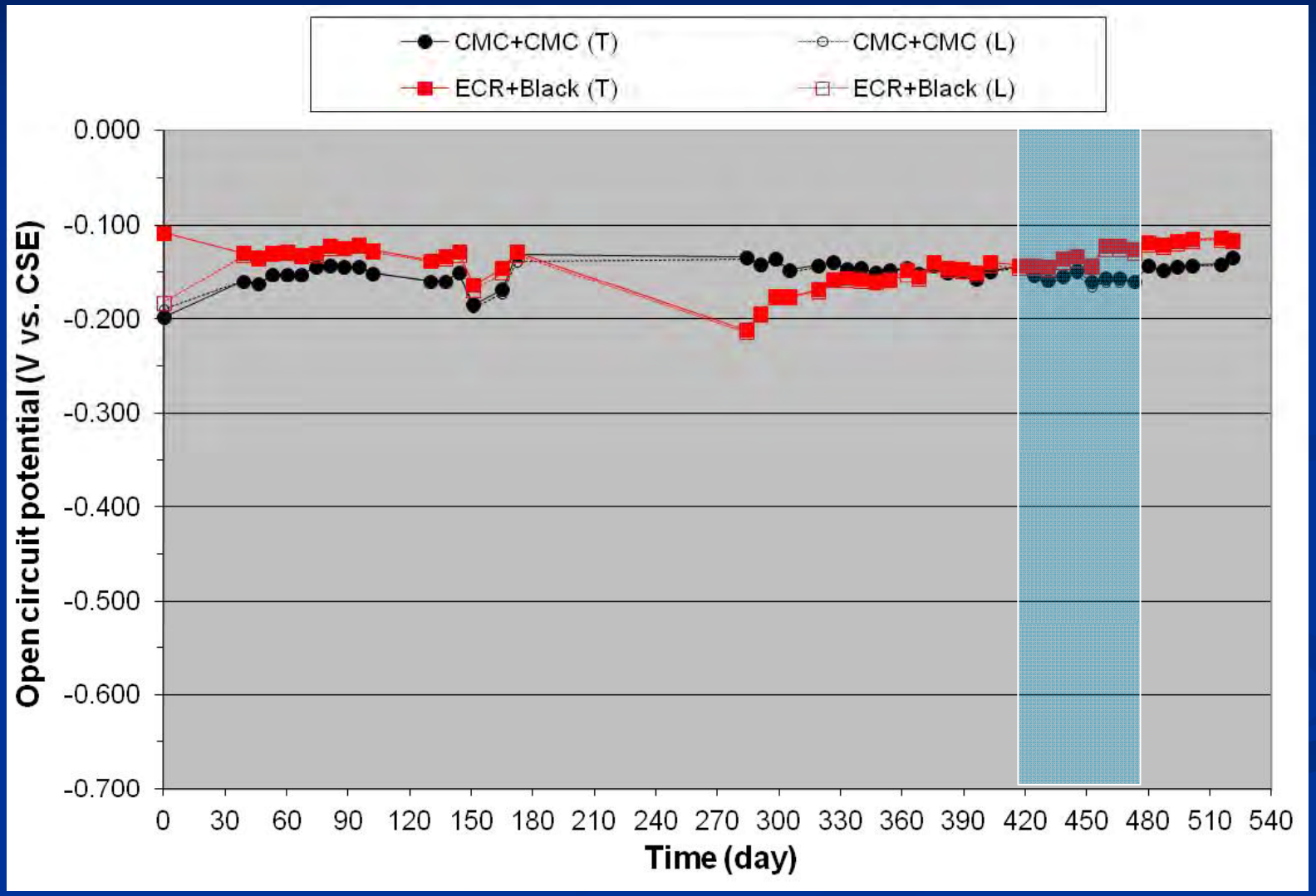
Corrosion Potential



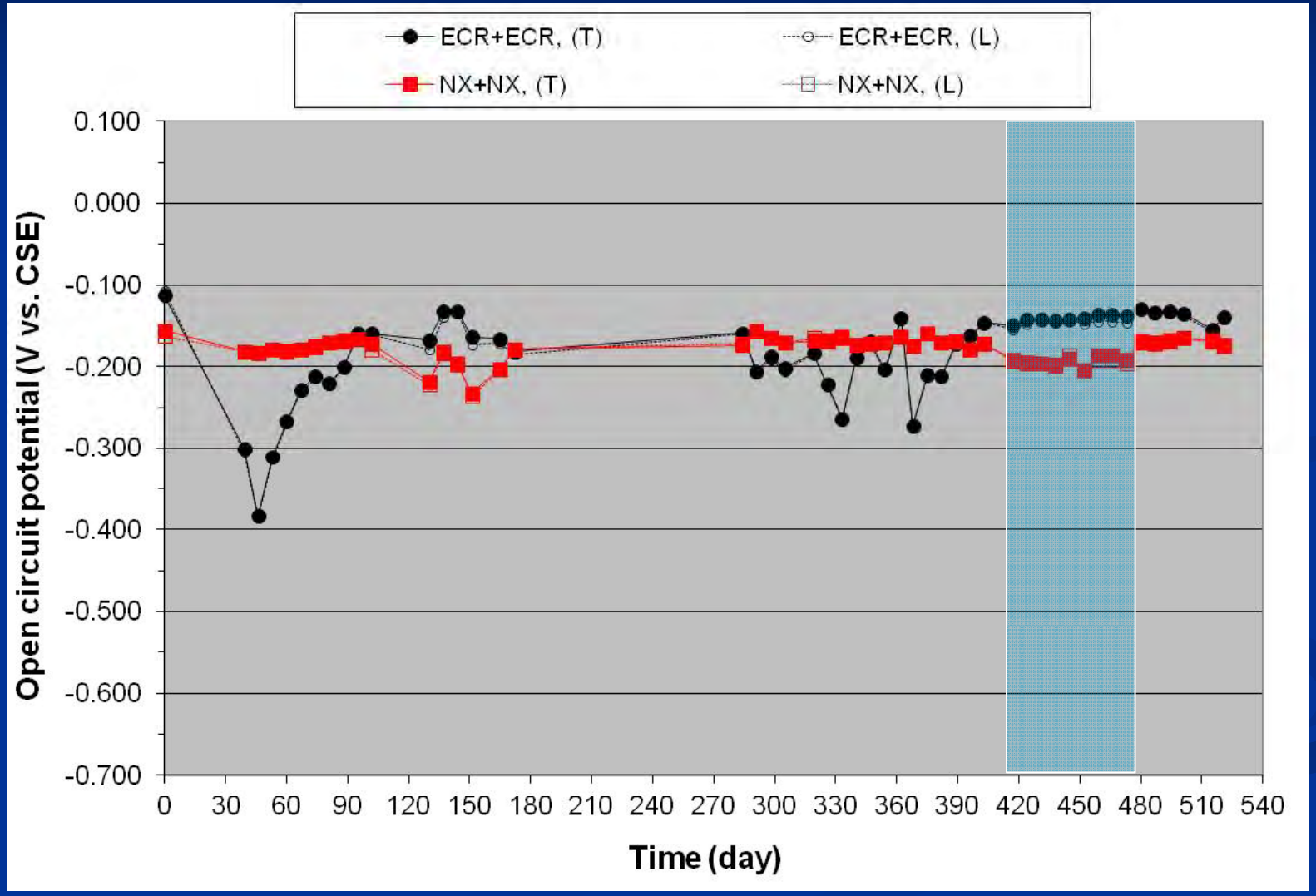
Corrosion Development

[Corrosion of a Black Bar Slab]

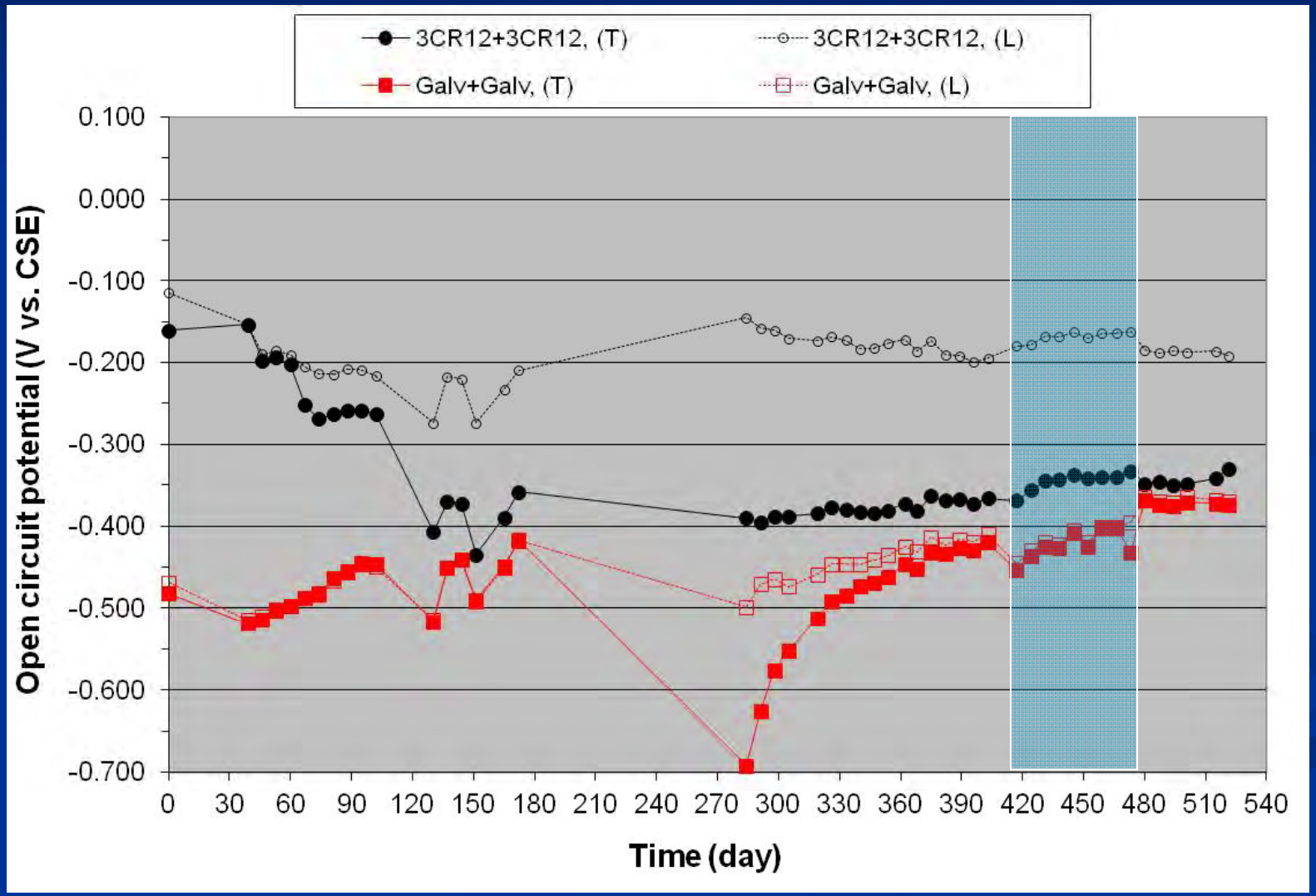
Corrosion Potential



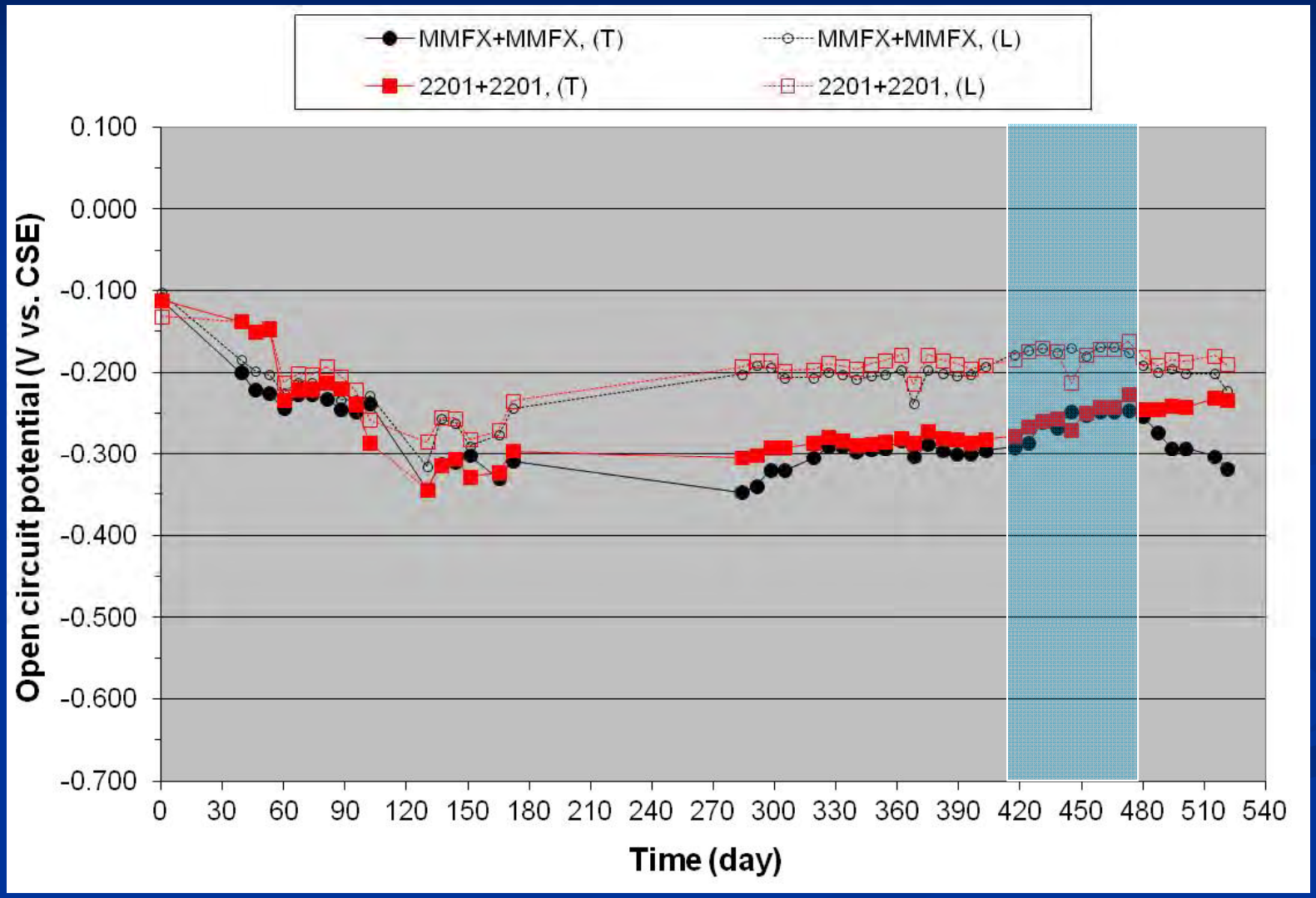
Corrosion Potential



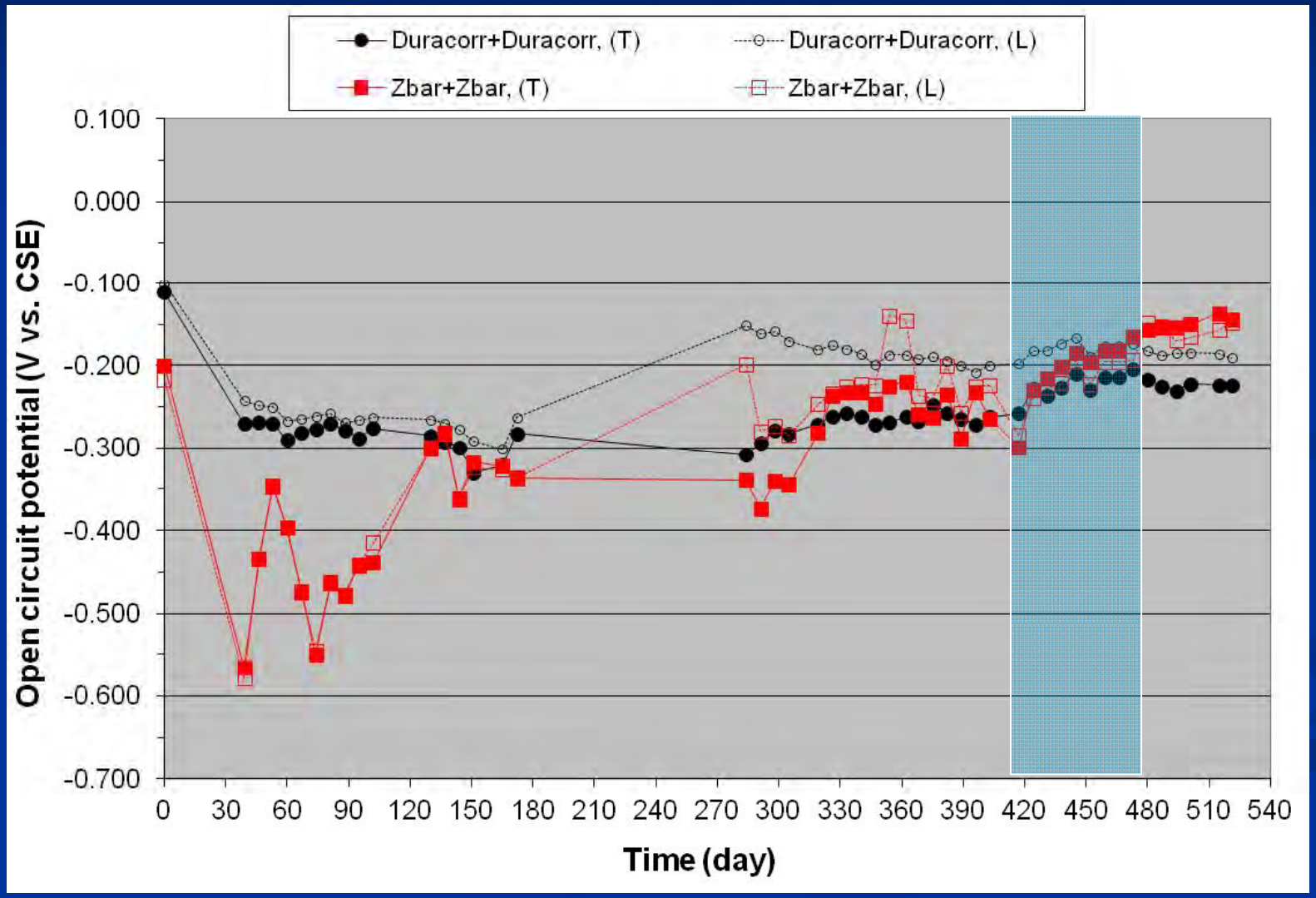
Corrosion Potential



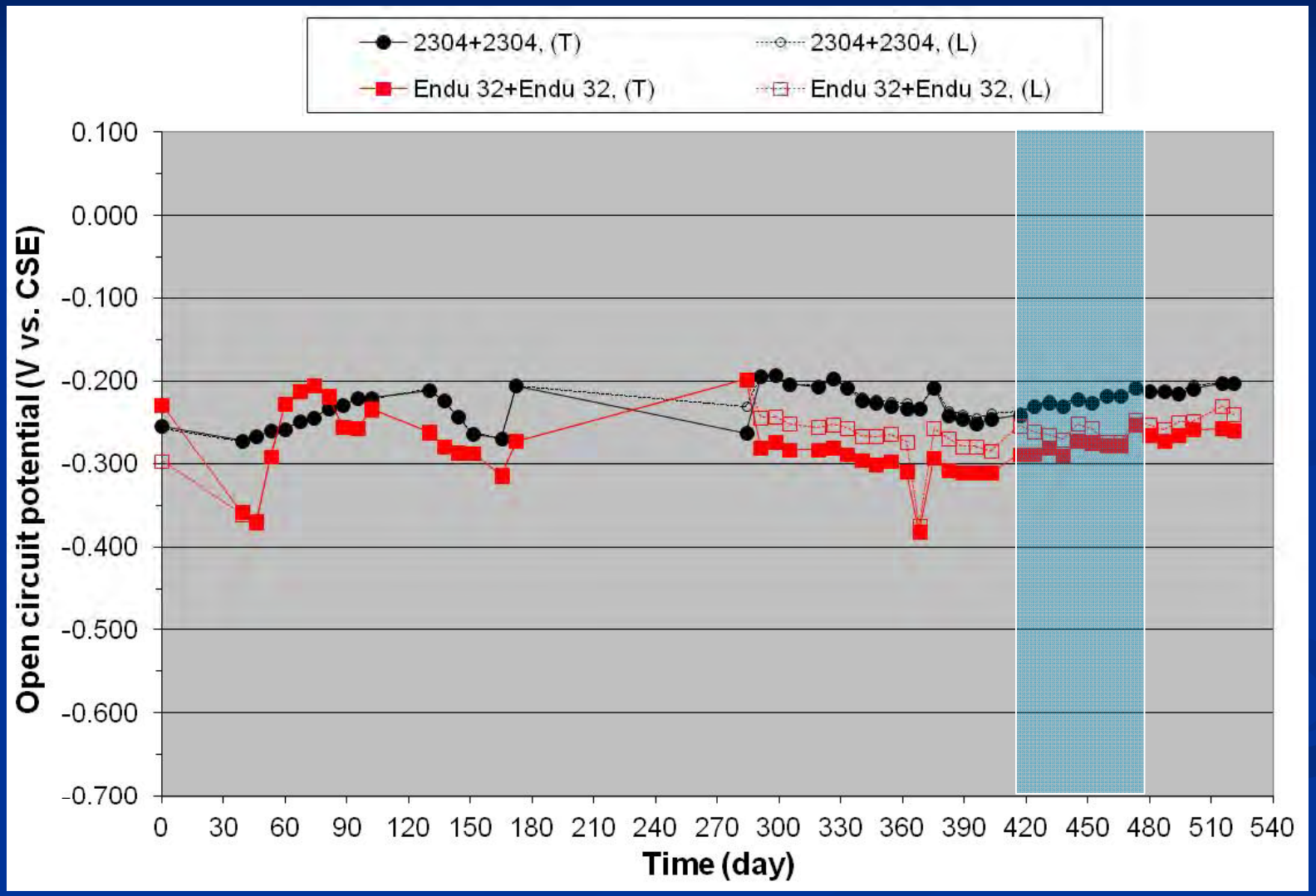
Corrosion Potential



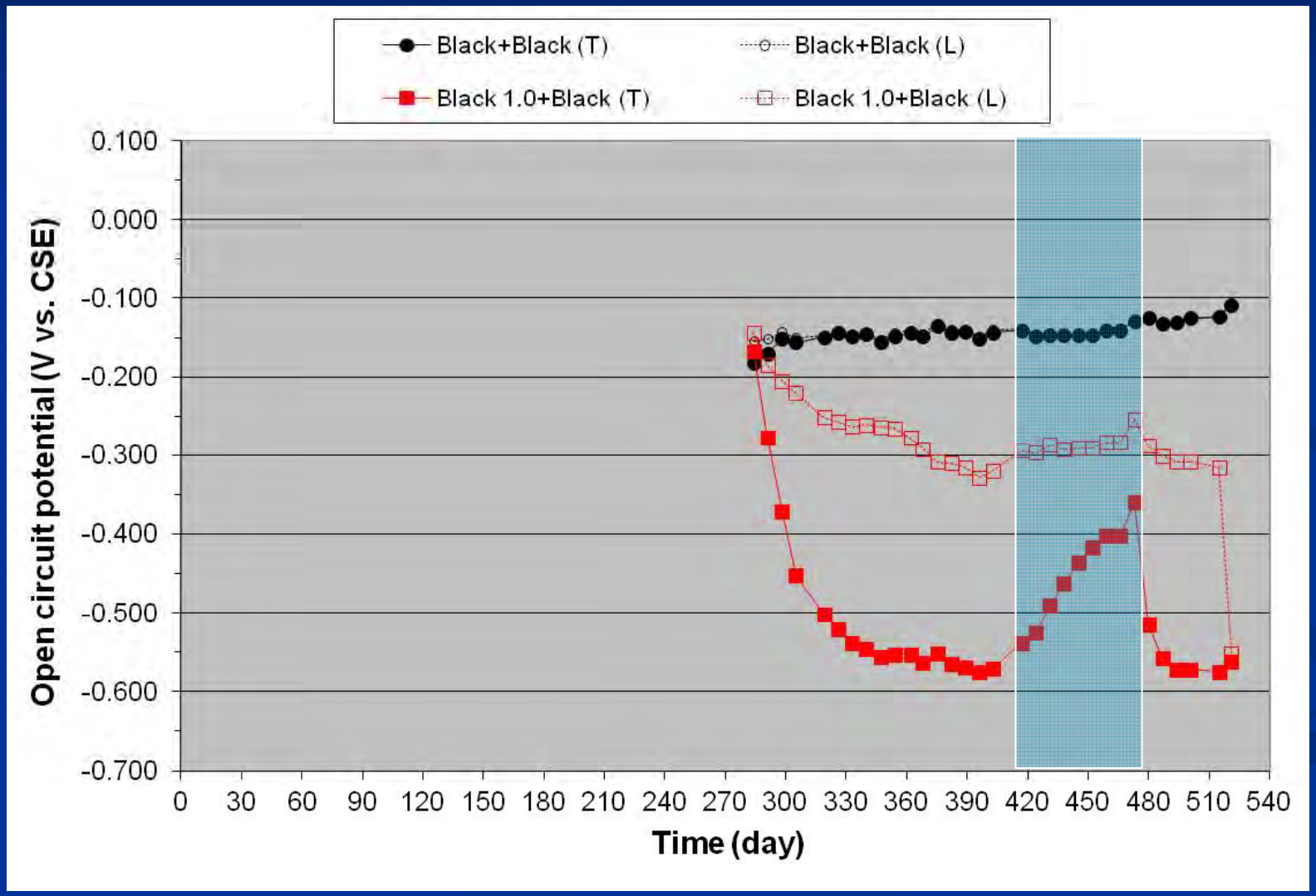
Corrosion Potential



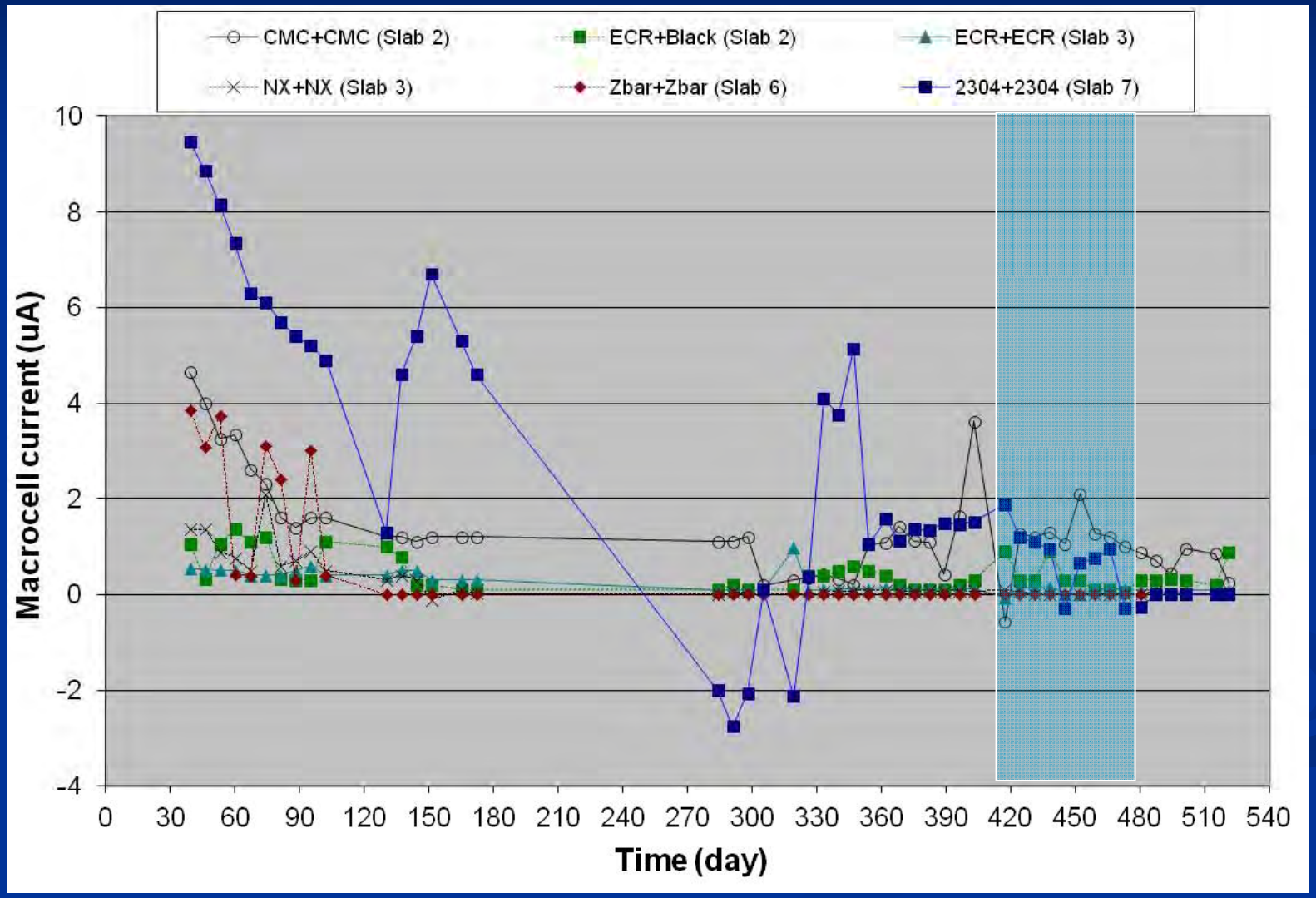
Corrosion Potential



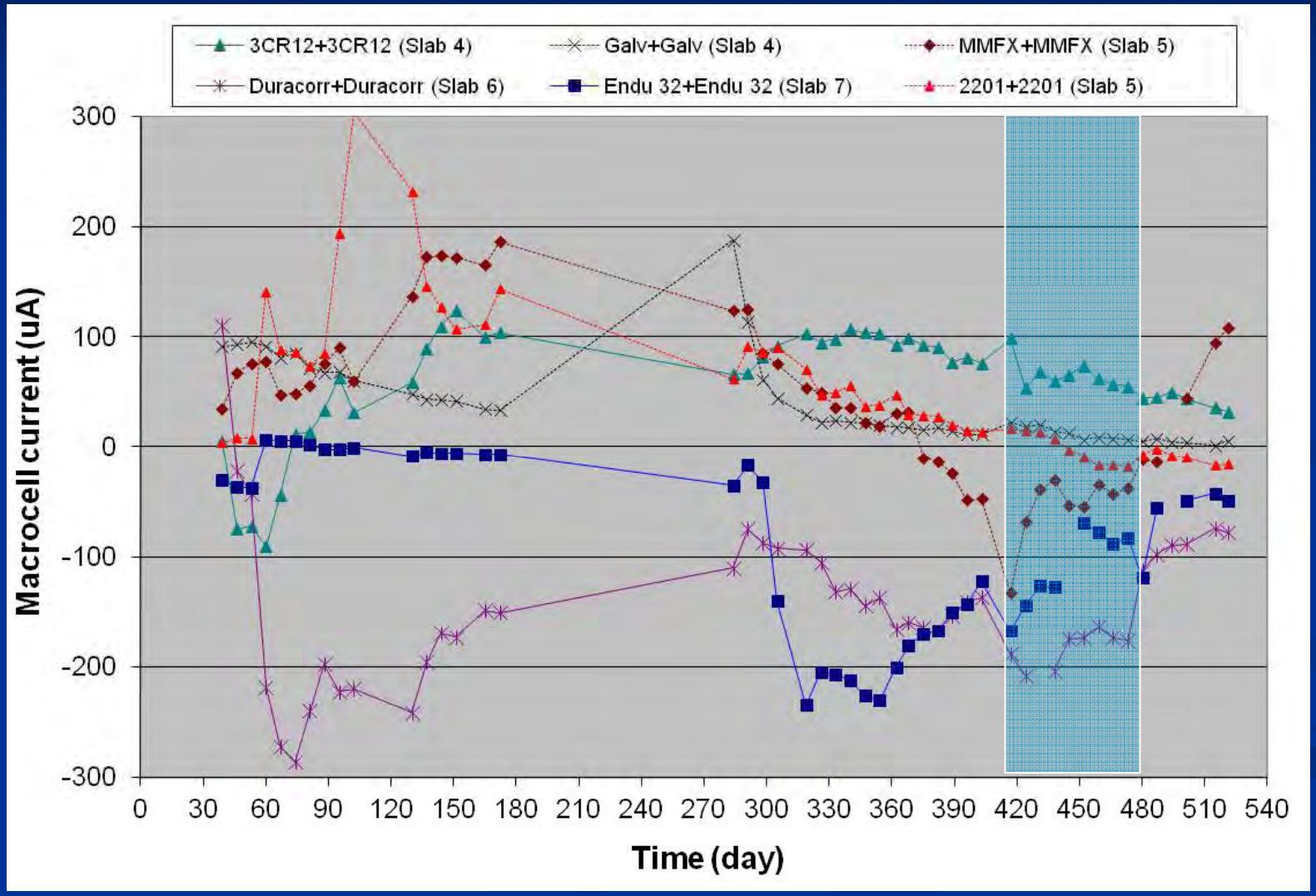
Corrosion Potential



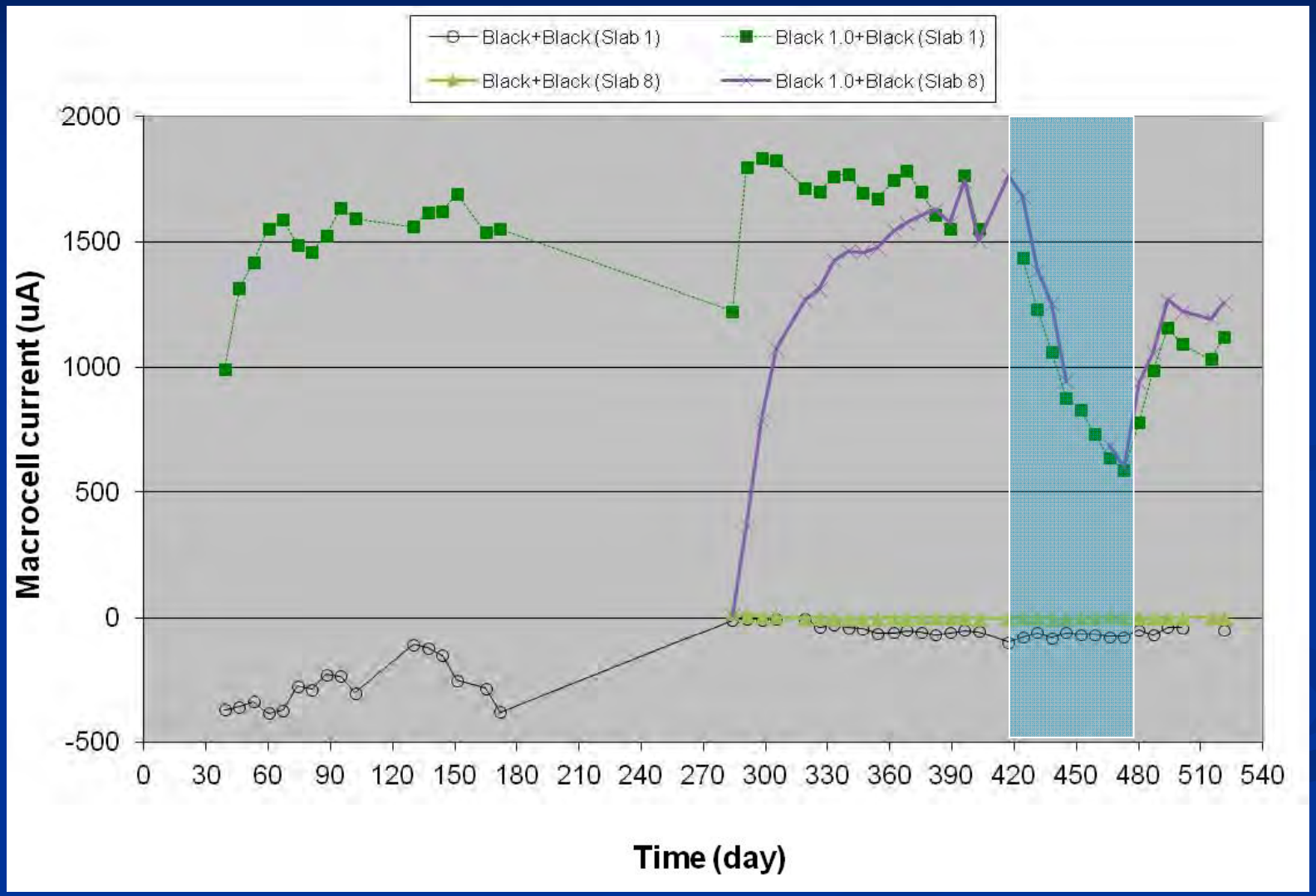
Macro-cell Current (Low)



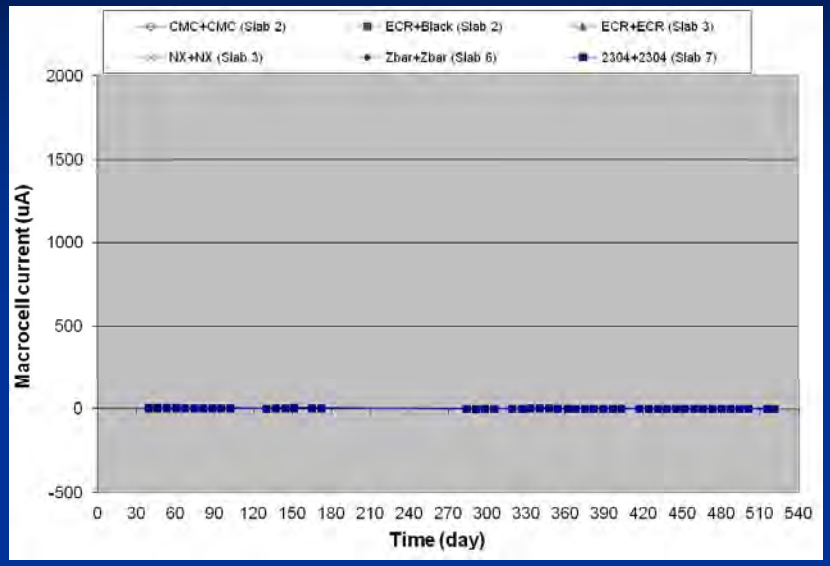
Macro-cell Current (Intermediate)

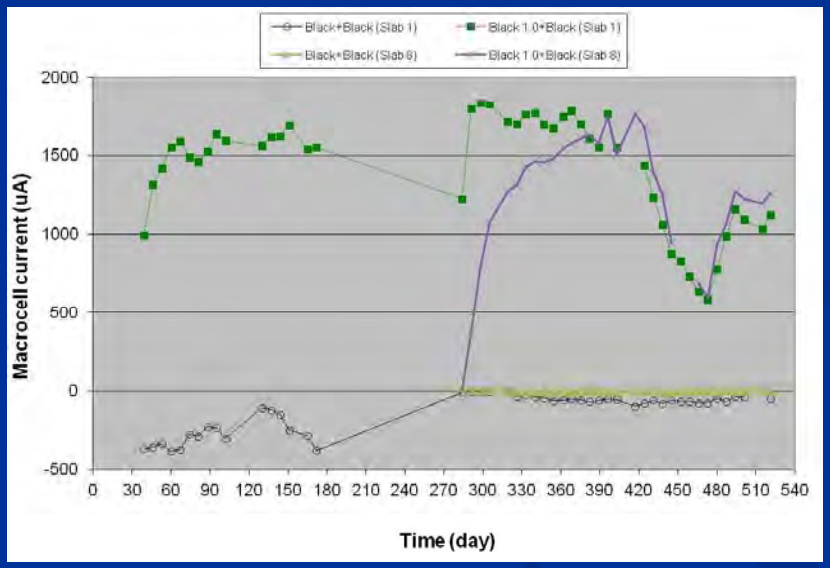


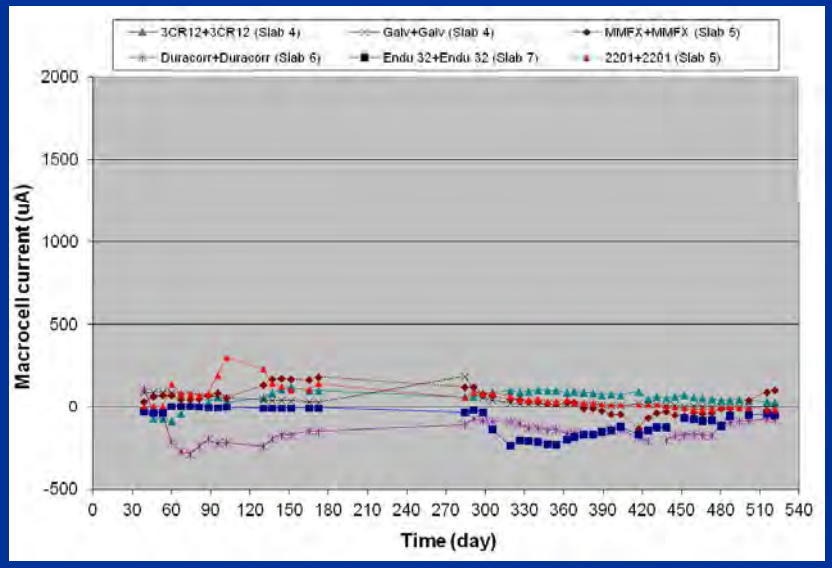
Macro-cell Current (High)



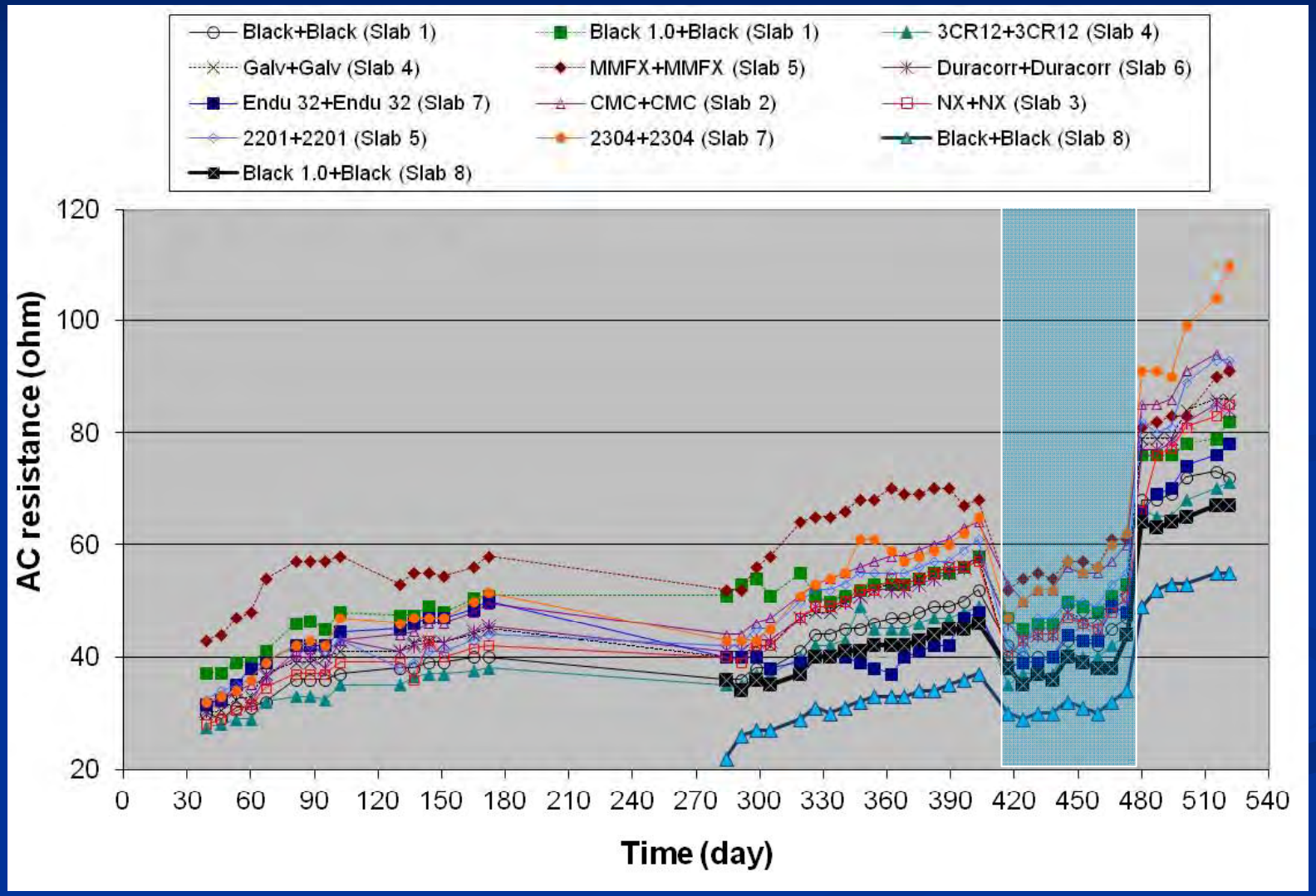
Macro-cell Current (Combined)



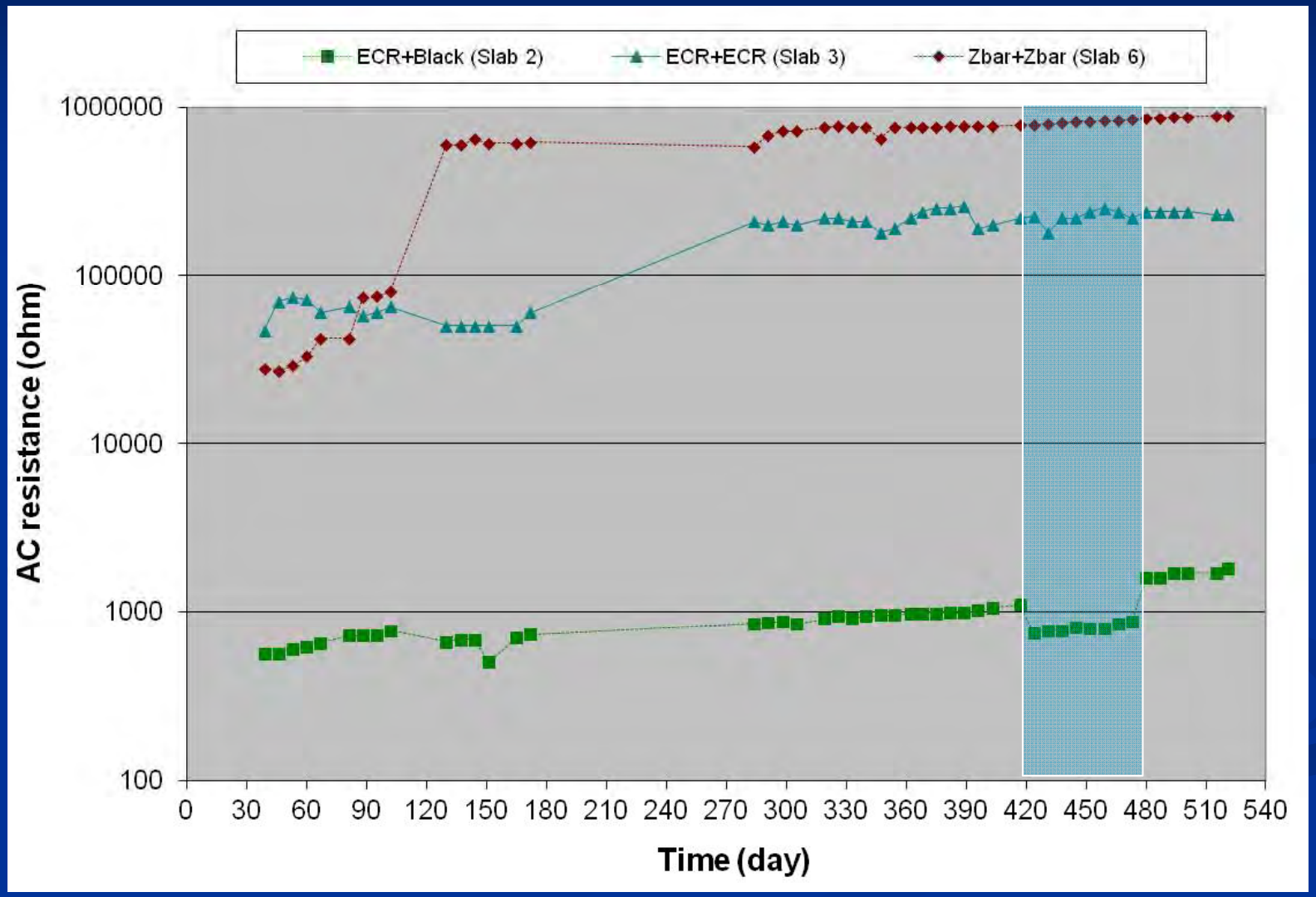




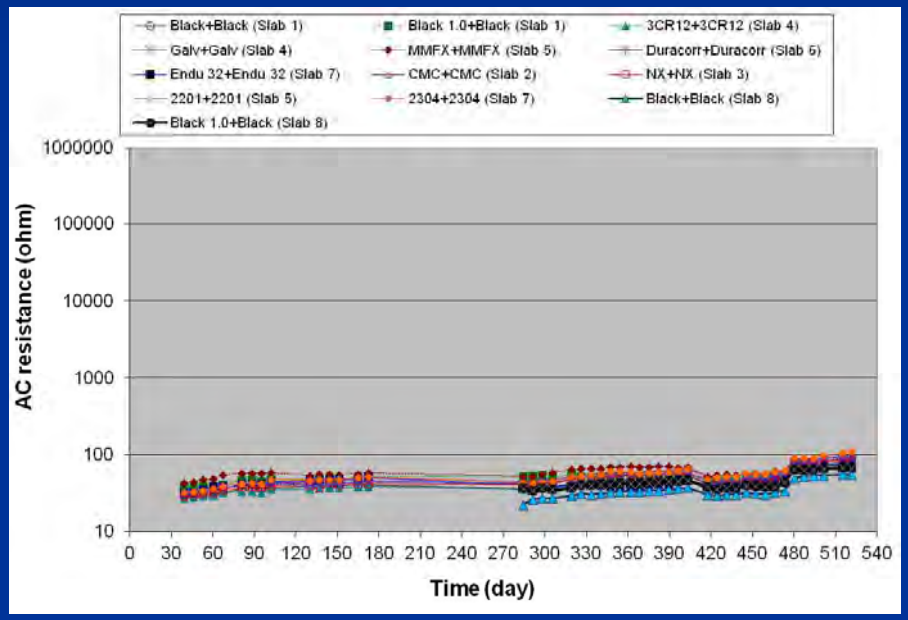
AC Resistance (Low)

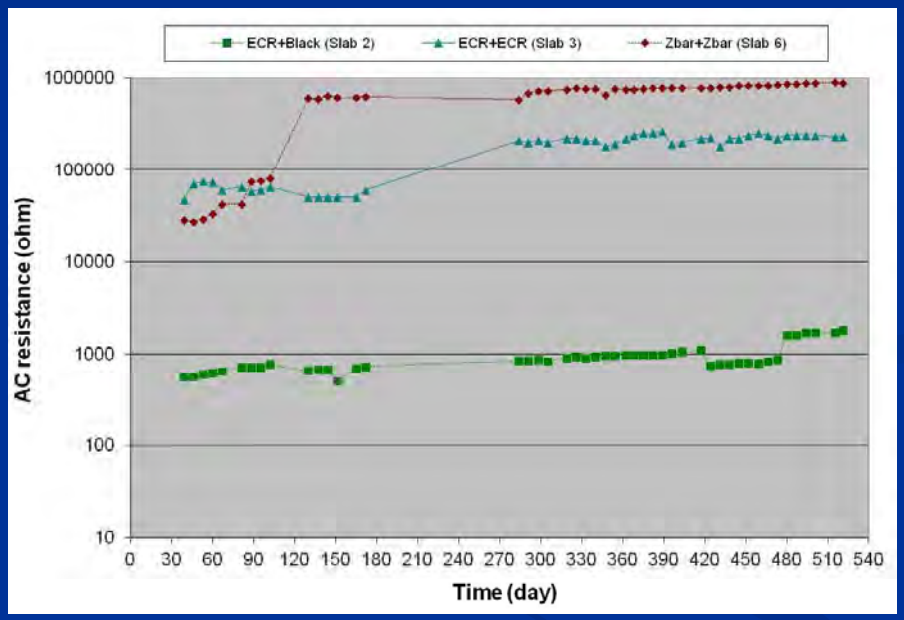


AC Resistance (Large)

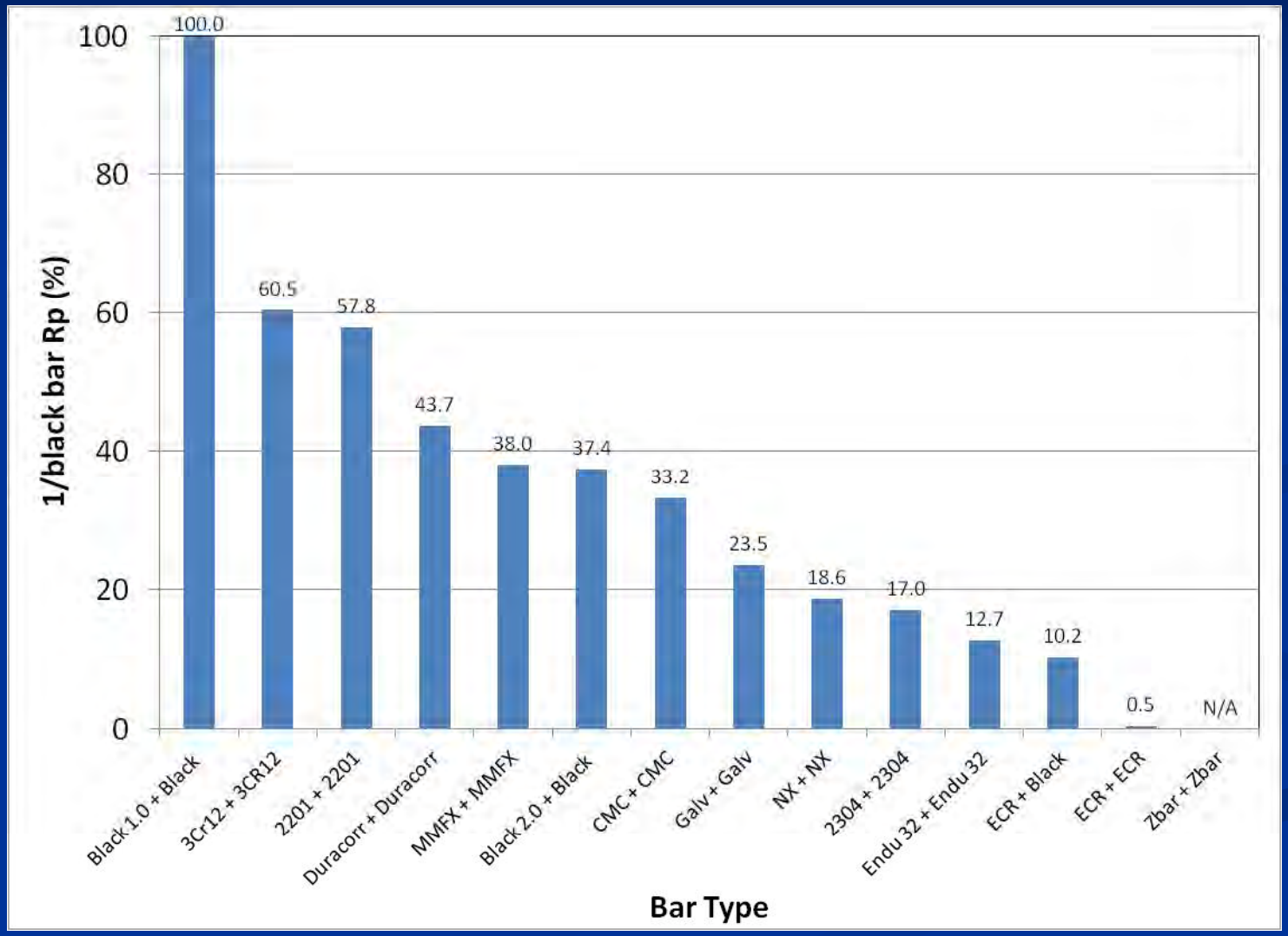


AC Resistance (Combined)





Mean Corrosion Rate by LPR



Comparative Performance Data

Ranking (Best to Worst)	Rebar Material	Mean Macro-cell Current (uA)	1/Black Rp (%)
1	ECR+ECR (Slab 3)	0.2	0.5
2	NX+NX (Slab 3)	0.3	18.6
3	ECR+Black (Slab 2)	0.4	10.2
3	Zbar+Zbar (Slab 6)	0.4	N/A
5	CMC+CMC (Slab 2)	1.4	33.2
6	2304+2304 (Slab 7)	2.9	17.0
7	Galv+Galv (Slab 4)	38.3	23.5
8	Endu 32+Endu 32 (Slab 7)	84.3	12.7
9	MMFX+MMFX (Slab 5)	68.9	38.0
10	2201+2201 (Slab 5)	59.1	57.8
11	3CR12+3CR12 (Slab 4)	70.6	60.5
12	Duracorr+Duracorr (Slab 6)	150.9	43.7
13	Black +Black (Slab 1)	128 ~ 1413	37.4 - 100

Preliminary Findings

Preliminary Findings

- The evaluated bar materials exhibited a wide range of corrosion resistance in terms of macro-cell current and linear polarization resistance (corrosion rate).
- Conventional corrosion potential (E_{corr}) criteria are not applicable to some CRRB per ASTM C876:
  - $E_{corr} < -200\ mV_{CSE}$: <10% probability of corrosion
  - $E_{corr} > -350\ mV_{CSE}$: >90% probability of corrosion

Preliminary Findings

- Use of fusion-bonded coated bars (conventional epoxy-coated and dual coated Zbar) in both mats offered the best corrosion resistance.
- According to AC resistance data, their superior corrosion resistance must be attributed, in part, to large electrical resistance between top and bottom mats.

Preliminary Findings

- As expected, solid stainless steel and stainless steel clad bars also exhibited very good corrosion resistance. However, further investigation of Enduramet 32 is needed for its relatively high macro-cell current.
- Galvanized bar may be used in moderately corrosive environments.

Preliminary Findings

- The alloyed CRRBs did not provide adequate corrosion resistance evidenced by high macro-cell current and/or low LPR (high corrosion rate).
- Once chloride data and autopsy results are available, final conclusions will be made. With subsequent life-cycle analysis, a matrix of recommended bar materials in various service environments will be developed.

THANK YOU!