Effect of Early-Age Cracking on Corrosion Initiation in Reinforced Concrete

March 27, 2018

ACI Spring 2018 Convention – Salt Lake City, UT

Matt O'Reilly

Osama Al-Qassag

Omid Farshadfar

James Lafikes

David Darwin

Sponsors


KU TRANSPORTATION RESEARCH INSTITUTE
The University of Kansas


BASF
We create chemistry


Strategic Development Council
aciFoundation


AMERICAN SOCIETY OF CONCRETE CONTRACTORS
Enhancing the Capabilities of Those Who Build with Concrete


BUILDING TRUST
Sika


BAKER
CONCRETE CONSTRUCTION
expect more


ActiveMinerals
INTERNATIONAL, LLC
Integrity. Innovation. Teamwork. Execution.


EUCLID CHEMICAL


gcp applied technologies
GRACE CONSTRUCTION & PACKAGING


PREMIERCPG
CONSTRUCTION PRODUCTS GROUP


FORTA


structural
group


ESCSI
Expanded Shale, Clay and Slate Institute
Rotary Kiln Structural Lightweight Aggregate


PNA
CONSTRUCTION TECHNOLOGIES


abcpolymer™
an international plastics group

Sponsors


AD ASTRA PER ASPERA
Kansas
Department of Transportation


MINNESOTA DEPARTMENT OF TRANSPORTATION


DOT


MDOT
MISSISSIPPI DEPARTMENT OF TRANSPORTATION


STATE OF OHIO
DEPARTMENT OF TRANSPORTATION


IDAHO
TRANSPORTATION DEPARTMENT


WISCONSIN
DEPARTMENT OF TRANSPORTATION


TRANSPORTATION RESEARCH INSTITUTE


SFA
SILICA FUME
ASSOCIATION


STATE OF DELAWARE
Department of Transportation


New Hampshire
DOT
Department of Transportation


South Dakota
DOT


Department of
MDOT Transportation


OP


INDIANA
DEPARTMENT OF TRANSPORTATION
INDOT


Montana Department of Transportation
MDT
serving you with pride


OKLAHOMA DEPARTMENT OF TRANSPORTATION


BASF
The Chemical Company


NDDOT
North Dakota
Department of Transportation


MoDOT


Texas
Department
of Transportation


U.S. Department of Transportation
Federal Highway
Administration


WYOMING
DEPARTMENT OF
TRANSPORTATION


KU
THE UNIVERSITY OF
KANSAS

Outline

- Research Background
- Laboratory Testing
- Results and Discussion
- Summary

Significance of Study

- Bridge Deck Cracking
  - Allows a direct path for corrosive materials
  - Compromised protection of reinforcing steel
  - Accelerates freeze-thaw damage / additional cracking

The Typical Cracked Concrete Bridge Deck

- Rough cracks, randomly oriented
- Typically < 10 mils (0.25 mm) in width
- Can be constant width or taper
- Initiation time varies, though often occurs early

The Typical Cracked Corrosion Test Specimen

- Smooth cracks from steel shims
- Typically > 10 mils (0.25 mm) in width
- Constant width
- With conventional reinforcement, corrosion initiates immediately

The First Question…

What effect do these cracks have on the service life of concrete?

The Second Question…

Does the “steel shim” crack accurately model cracking in concrete?

Can we ignore ‘small’ cracks in concrete?

or

When is a crack really a crack?

Cracking and Chloride Transport

- Rodriguez and Hooton (2003) examined chloride transport through cracks made in concrete cylinders.
  - Smooth-cut in half
  - Rough-split w/ hydraulic press
- Shimmed cylinder pieces to form cracks from 3 to 27 mils (0.08 to 0.68 mm)
- Chloride transport occurred at the same rate regardless of crack size or roughness

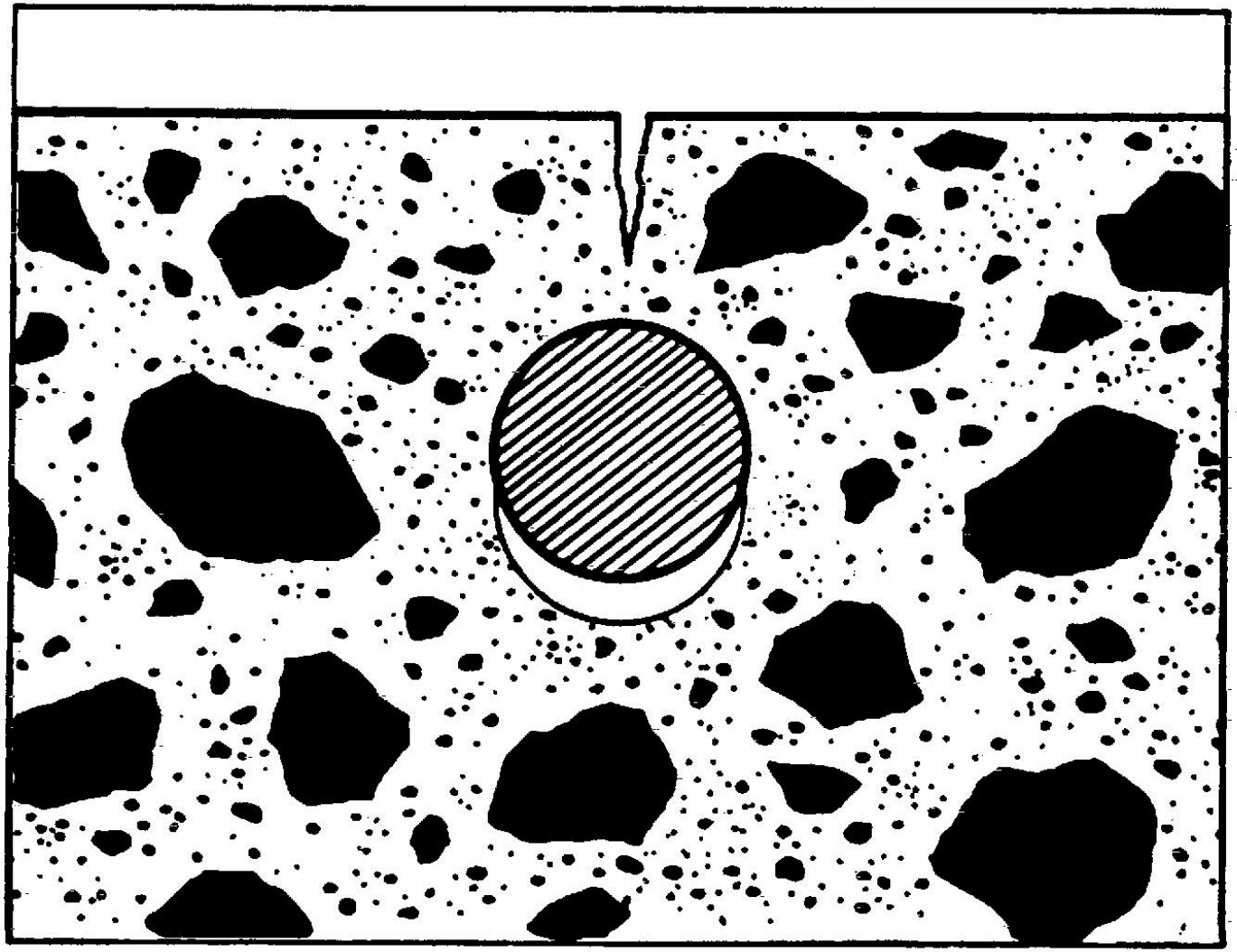
The Counter-Argument

- Cracks didn't taper
  - Many cracks become narrower below the surface and don't reach the reinforcement
- Not all structures see corrosion immediately, even with cracking

The Counter-Argument:

- Settlement
- Plastic Shrinkage
- Rapid Evaporation
- Autogenous Shrinkage
- Thermal Effects
- Moisture Differential
- Loading (flexure, tension, shear)
- People putting steel shims in your concrete

Settlement Cracking

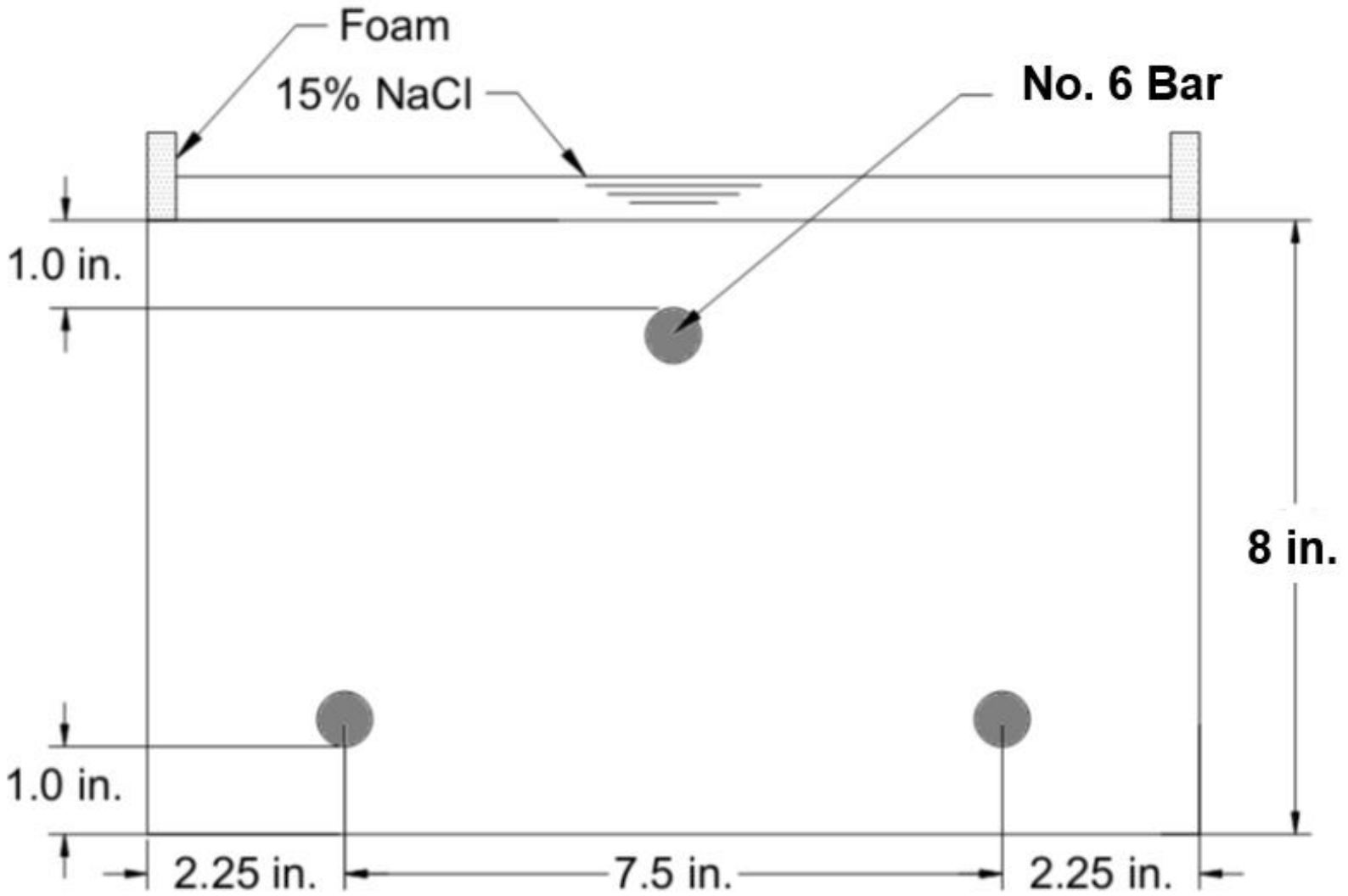


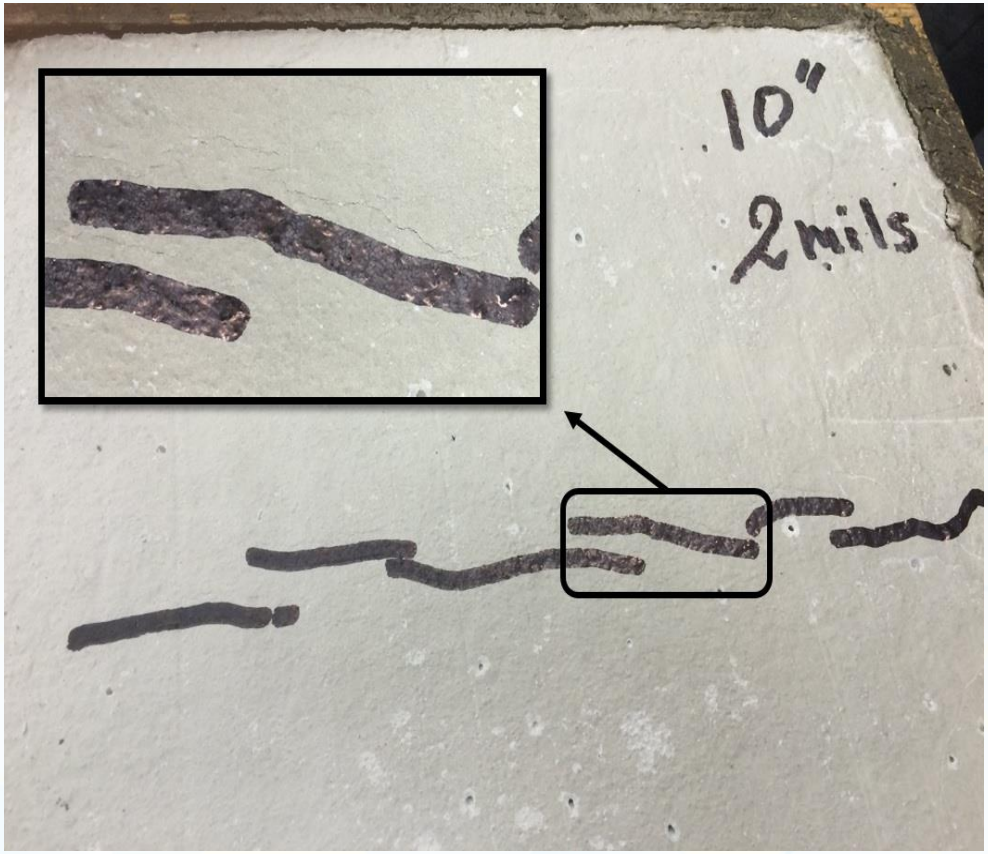
Settlement Cracking Test Specimen

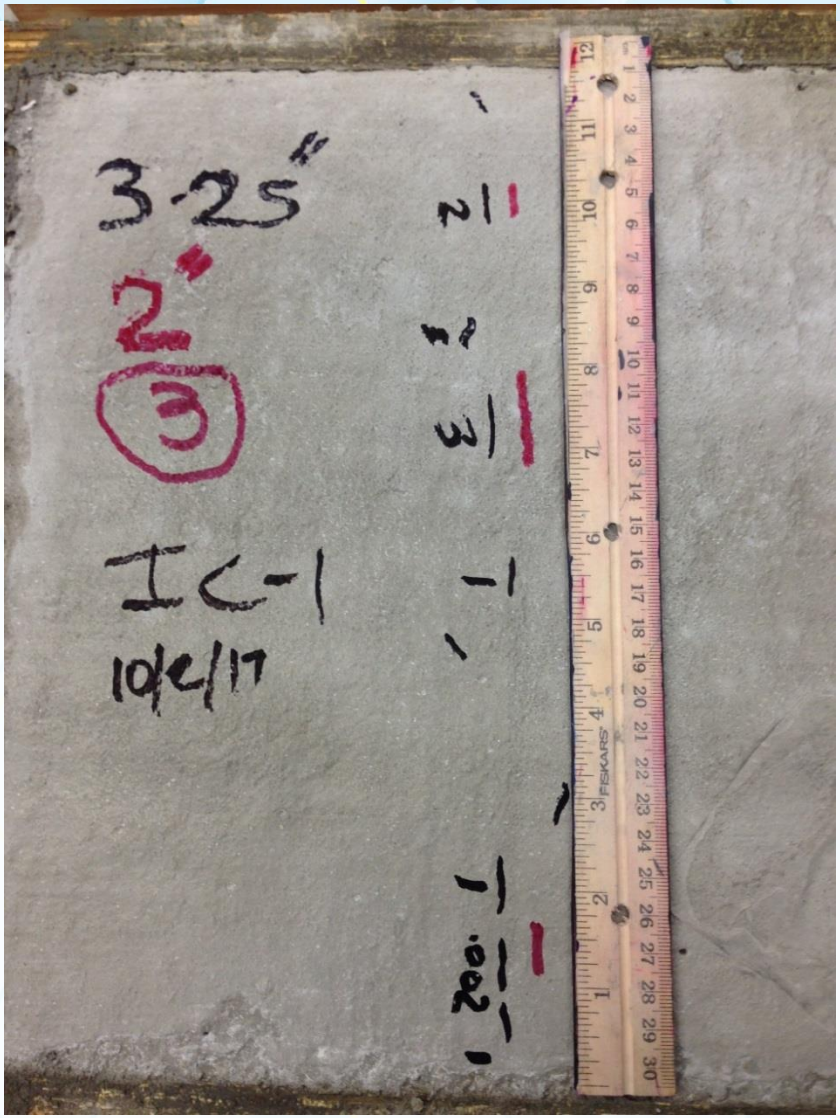
- Developed at KU
- Dimensions: 12 in. (305 mm) square
- Depth: 8 in. (203 mm)
- No. 6 (No. 19) Bars
- Top Bar Cover: 1 in. (25.4 mm)
- Cured 24 hours:

  50±5% humidity, 73±3°F (21-24°C) temperature

Test Specimen

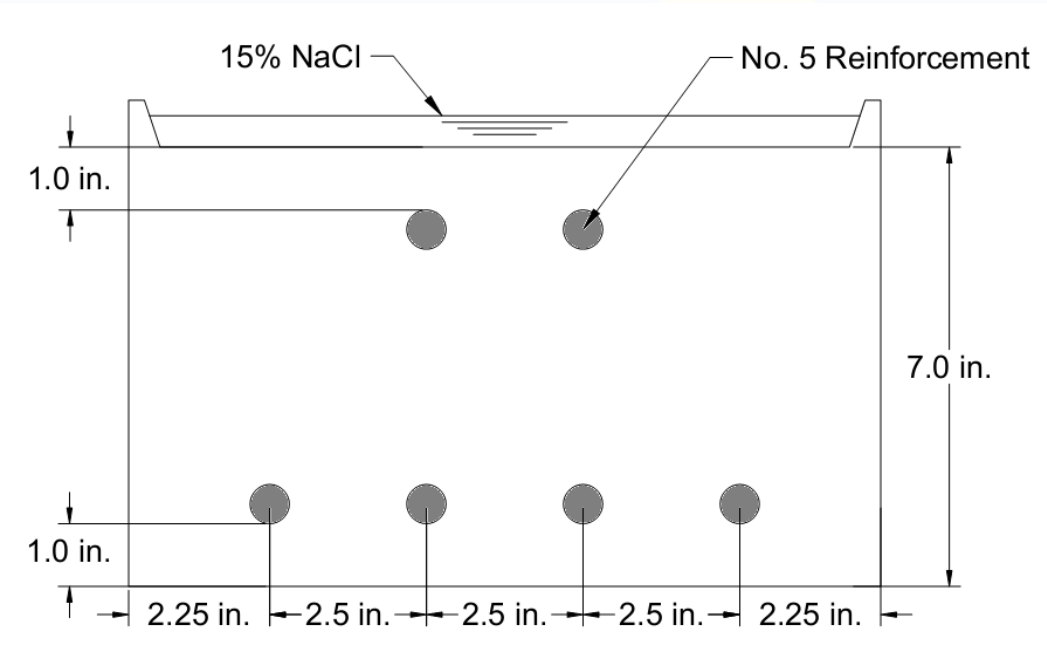



10"
2 mils

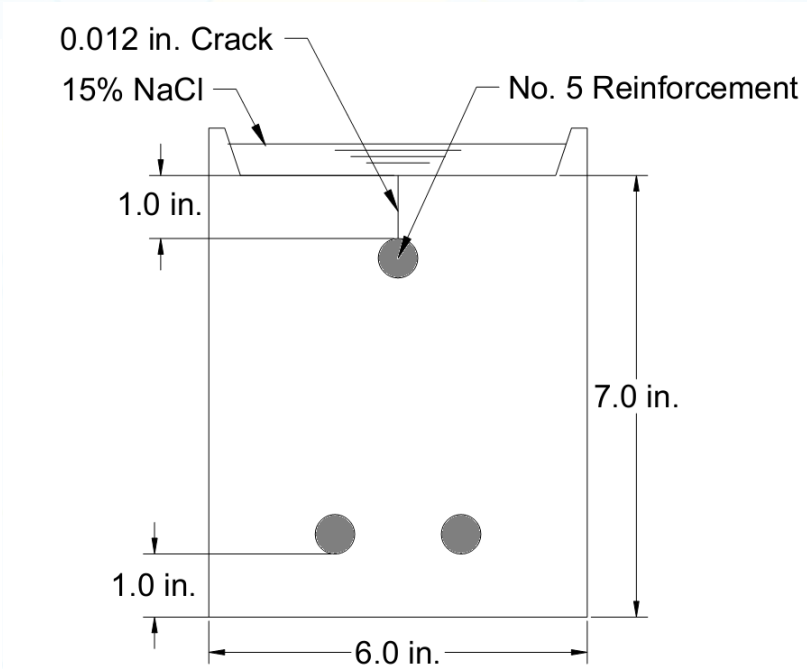

3.25"
2"
3
IC-1
10/2/17

Comparison Specimens

- Un-cracked:



- Cracked with shim:



Mixture Proportions

- *w/cm* = 0.45
- Air Content Range: 6.5 – 9.5%
- 27% paste content
  - 100% portland cement
  - 30% slag cement (by volume)
  - 30% slag cement + 7 lb/cwt internal curing water via pre-wetted fine lightweight aggregate

Settlement Cracking Corrosion Specimens

- Sealed for first 24 hours
- Settlement cracks measured, recorded
- Wet cured for 2 more days, dry cured for 25 days

Test Procedures

- Specimens underwent alternate 12 week cycles:
  - Cycle 1: Ponding with 15% NaCl solution w/ weekly dry periods at 100°F
  - Cycle 2: Continuous ponding with NaCl (no dry period)

Results

- Crack Size
- Corrosion Initiation
- Corrosion Rate

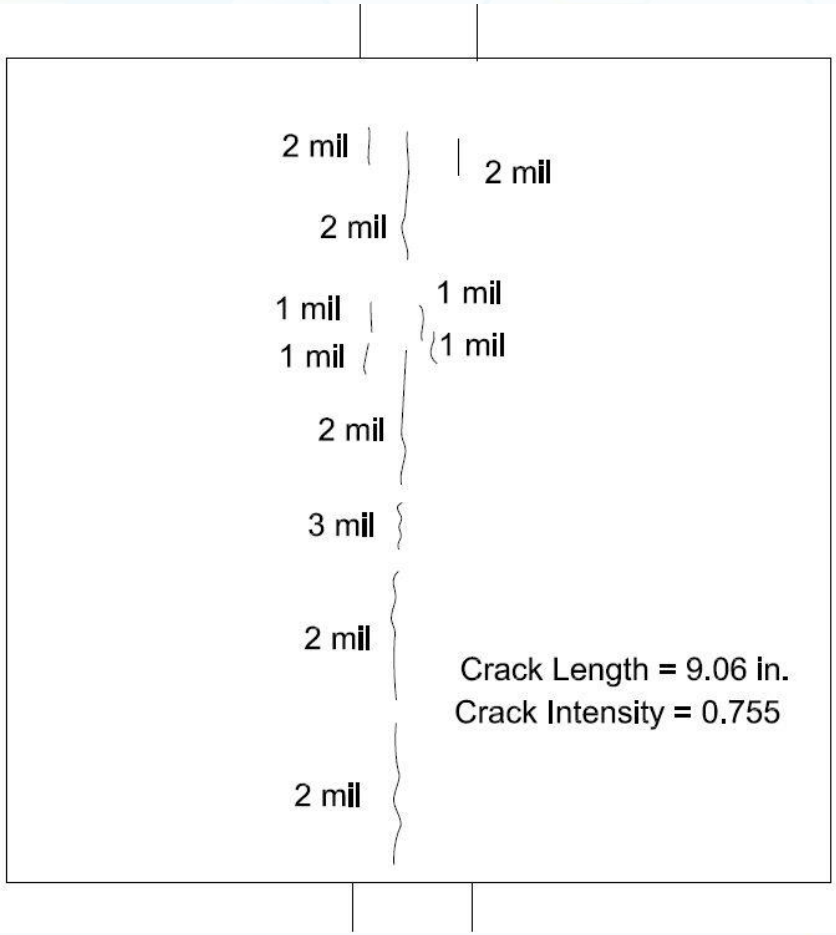
Specimen Crack Data

Mixture	Variable	Range	Average
100% portland cement	Max. Crack Width (in.)	0.002-0.004	0.003
	Crack Length (in.)	2.17-10.6*	7.5
30% Slag	Max. Crack Width (in.)	0.002-0.003	0.002
	Crack Length (in.)	2-4*	3.0
30% Slag + 7 lb/cwt IC Water	Max. Crack Width (in.)	0.001-0.003	0.002
	Crack Length (in.)	1.25-5.5*	2.5
Cracked Beam Corrosion Specimen	Max. Crack Width (in.)	0.012	
	Crack Length (in.)	6**	

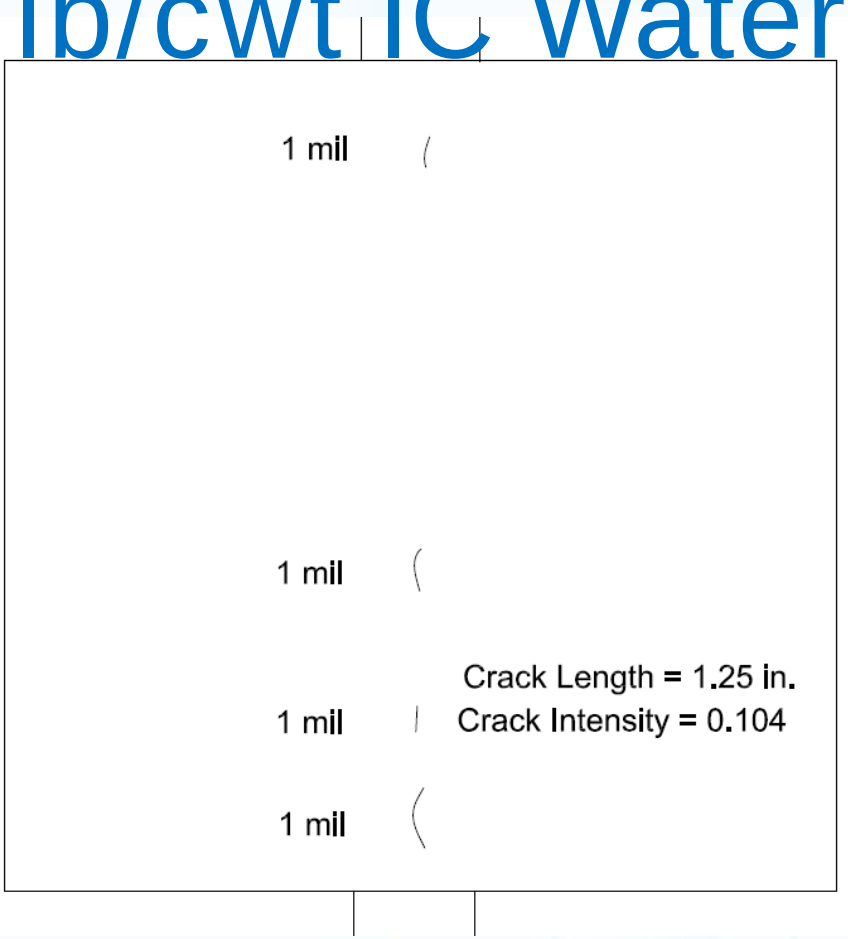
*Sum of numerous small cracks
**One continuous crack

Example Specimens

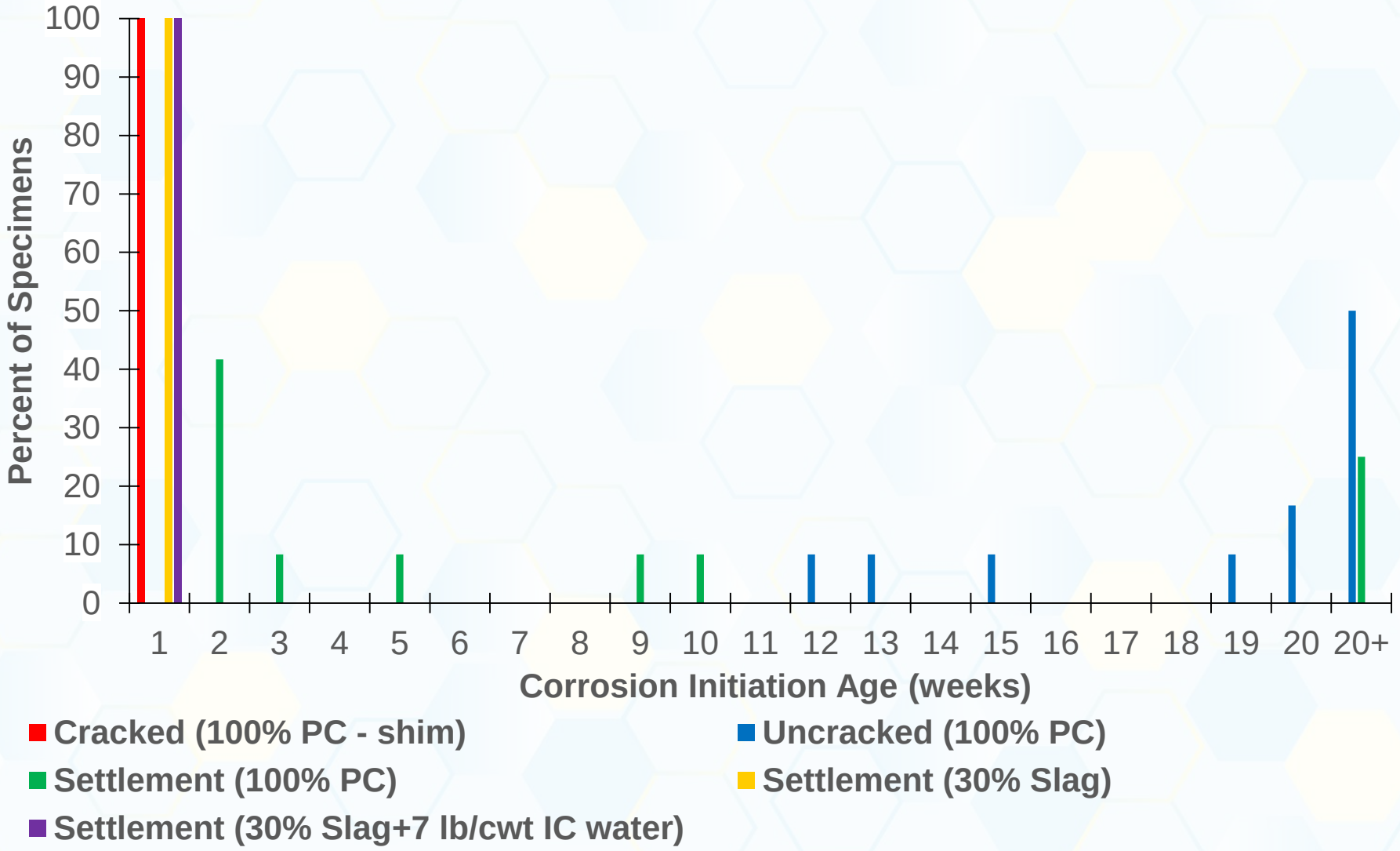
100% PC



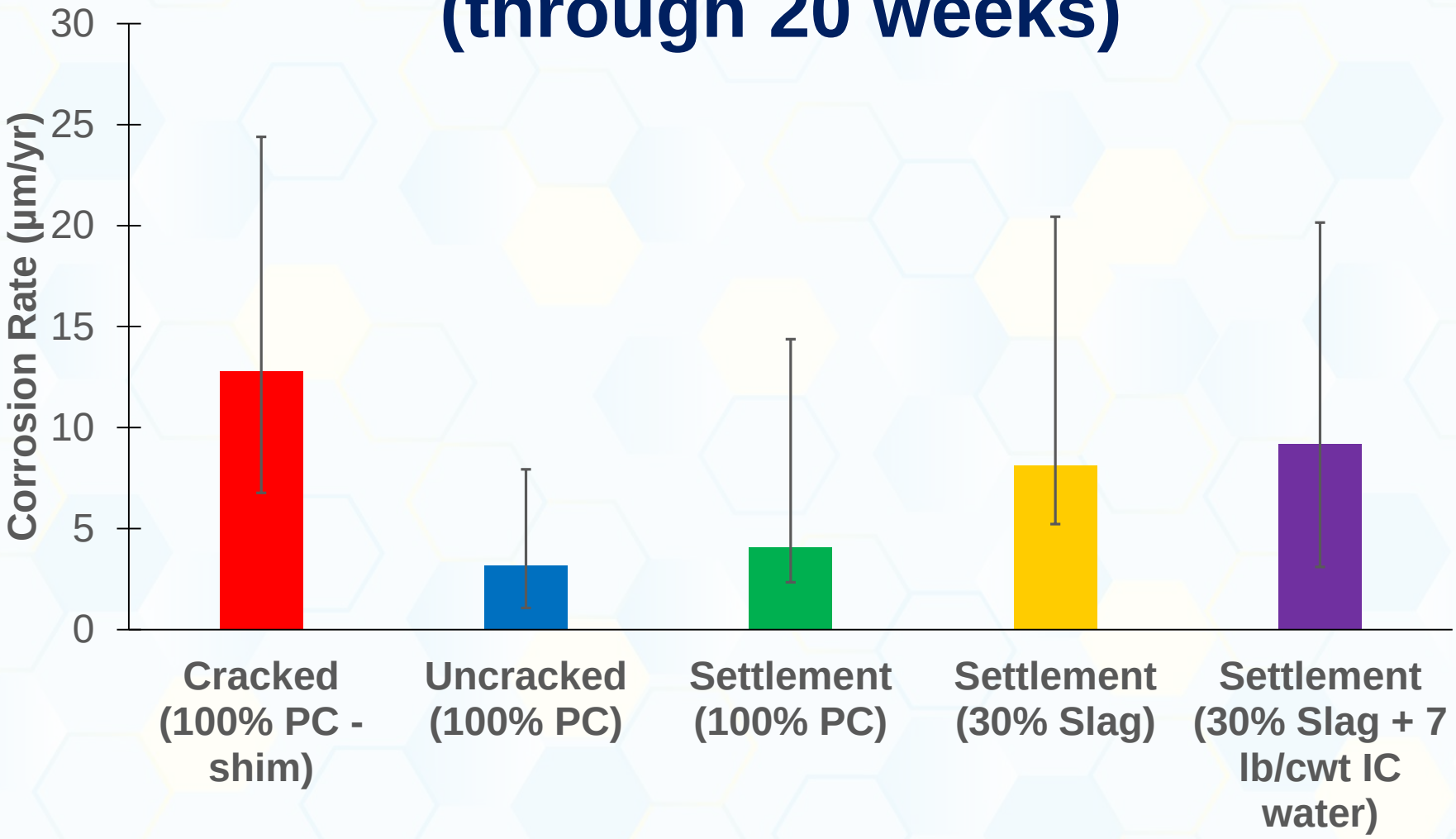
30% Slag + 7 lb/cwt IC Water



Corrosion Initiation



Average Corrosion Rate (through 20 weeks)



Summary

- Even small (0.001 in. width) cracks result in early corrosion initiation and increased corrosion rate relative to un-cracked concrete
- Artificial ‘steel shim’ cracks do not accurately model these types of cracks

Summary

- A wide variation in behavior was noted in settlement cracking specimens
  - 25% of specimens with 100% portland cement behaved similar to un-cracked concrete in terms of corrosion initiation
  - ALL specimens with 30% slag, including internal curing initiated at week 1 and behaved more similarly to cracked beam specimens

Future Work

- Vary curing time with mixtures containing SCMs
- Attempt to vary crack width
- Specimens with greater cover over the bar
  - Closer to that of real-world structures
- Other crack reduction technologies

Questions?

James Lafikes, P.E.

Graduate Research Assistant
CEAE Department
2142 Learned Hall
1530 W. 15th St.
Lawrence, KS 66045
(314) 401-2911

lafikes@ku.edu