Western Bridge Engineers Seminar September 6-8, 2017

Method of Improving Concrete Durability in Bridges and Structures

- By Philip Rhodes, Jason Tuerack,

Fazal Wahab & Andrew Rhodes

- Hycrete Inc.

Introduction

- The longer we can extend the structural life of concrete infrastructure, the more government spending, both Federal and Local, can be reduced.
- Less necessary concrete repairs ➔
- - less disruptions in traffic
- - less noise pollution
- - longer lasting, better looking structures
- - less government spending needed
- Extending the structural and cosmetic life of concrete benefits us all.

Root causes of concrete Degradation

- Focus of Nature
- Traffic/Vibration
- Destructive Chemistries
- Efflorescence
- Corrosion
- Sulfate Attack
- Freeze Thaw
- ASR
- Carbon Dioxide

Theoretical Solution

- Understand Causes
- How do harmful agents enter concrete?
  - Water is absorbed through capillary action
  - Harmful agents are solubilized in water
- What is needed to stop penetration through the concrete?
  - We must find a way to plug the cracks and capillaries throughout the concrete
- How is rebar protected?
  - We need to stop the formation of rust

THEORETICAL SOLUTION CONT'D

- A RUBBER PRE-POLYMER THAT IS WATER SOLUBLE.
- ABLE TO MIGRATE THROUGH THE CONCRETE TO THE PORES AND FISSURES.
- POLYMERIZE TO FORM INSOLUBLE RUBBER STOPPERS SEALING THESE POINTS OF ENTRY FOR WATER, CARBON DIOXIDE AND AIRBORNE CHLORIDES.
- ABLE TO REACT WITH AND COAT THE RE-BAR SURFACE AND STOP RUST FORMATION

WATER

- Concrete is a hard sponge.
- Water is absorbed Via Capillary ingress.
- The water may contain destructive chemicals such as: Sulfates and Chlorides. This results in Sulfate attack, Corrosion, efflorescence and freeze thaw damage.

Air/Vapor

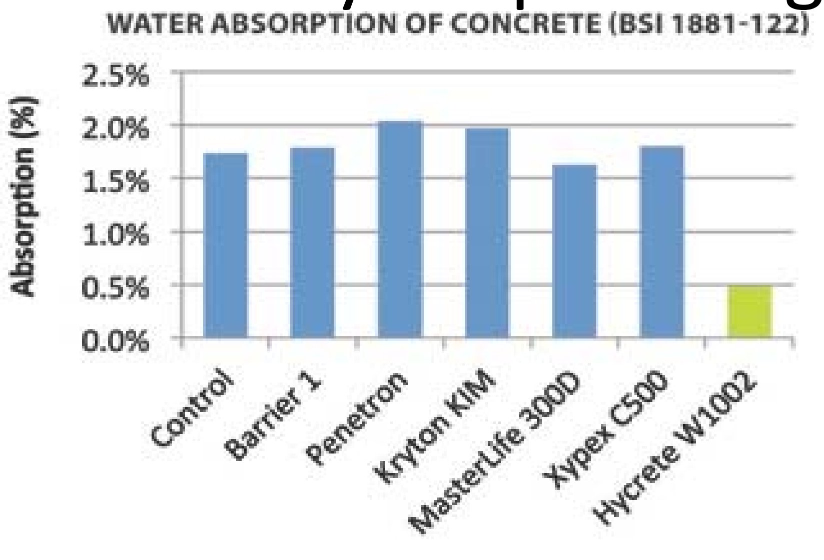
- Pervious concrete allows airborne chlorides +Carbon Dioxide to enter the concrete these result in Increased corrosion rates due to the chlorides and the carbonization

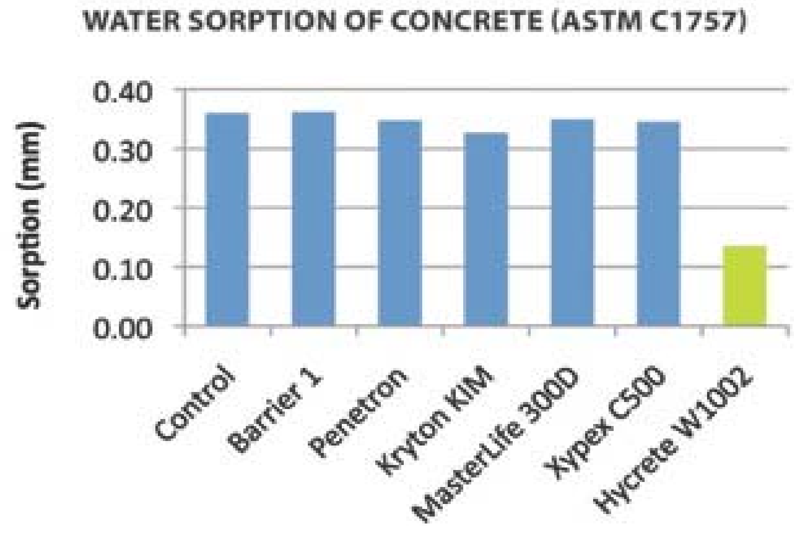
Vibration

- Concrete is rigid and brittle.
- Vibration extends small cracks caused by rebar exposure or calcium sulfate crystal growth.

Water Permeability and Absorption Tests

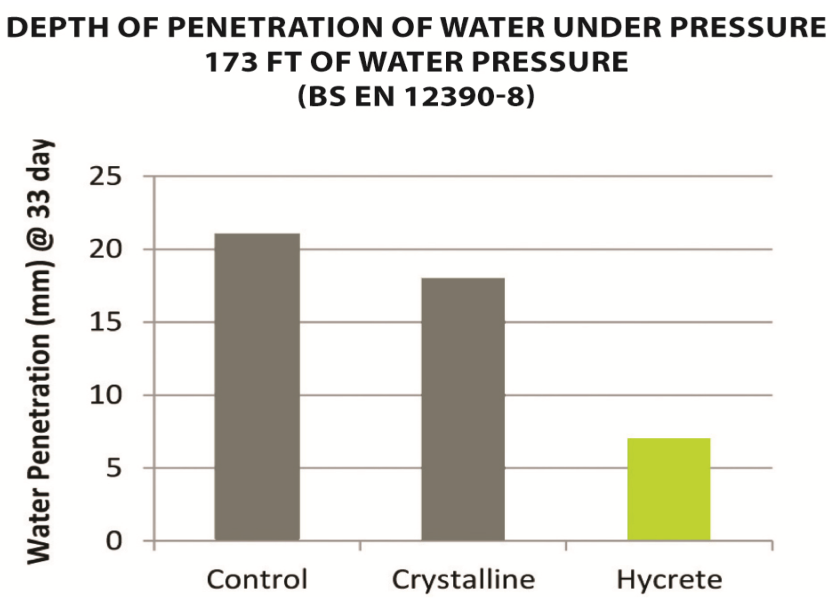
- BSI 1881-122 and ASTM C1757 performed by US Army Corps of Engineers (USACE)





Water Penetration Under Pressure

- BS EN 123090-8 performed by ACTS (Advanced Construction Technology Services) Beirut, Lebanon



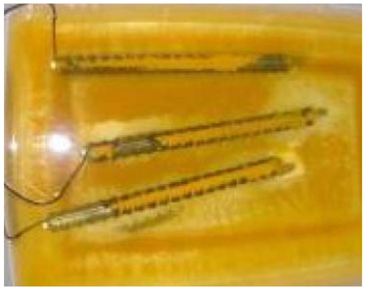
Salt Penetration

- Kansas DOT
  - Exposure to salt water for 5 weeks

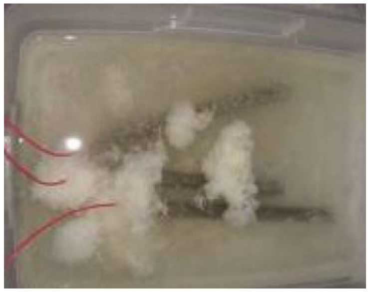
Corrosion Prevention

- Materials Service life LLC

NaCl Solution 0.11% Steel Loss.

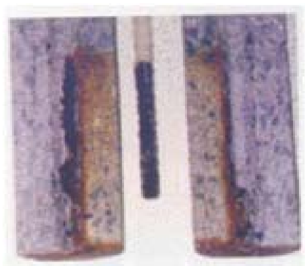


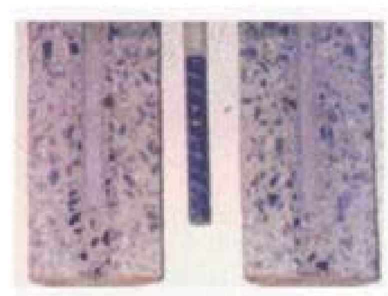
Rebar in 6% Hycrete admixture & NaCl solution. 0.00% steel loss



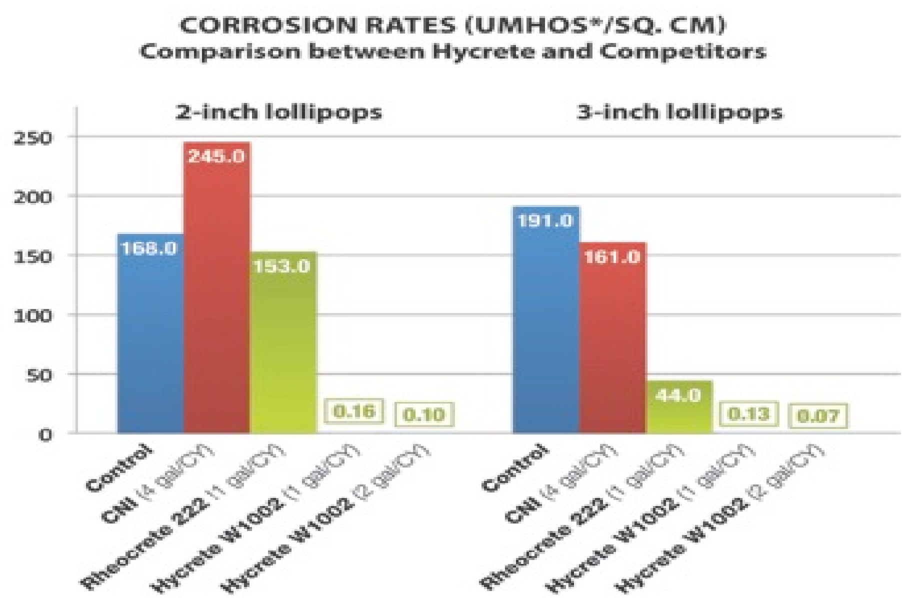
Corrosion Prevention Testing

- University of Connecticut 100 week salt solution
  - Under research grant from the US Highways Admin



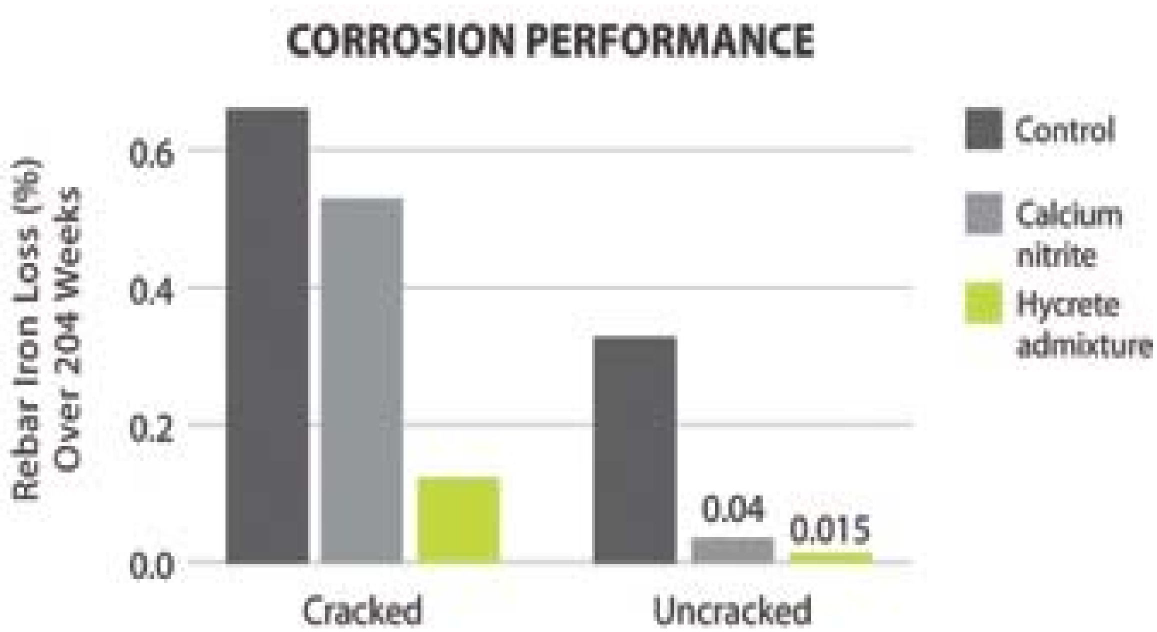


ASTM G109



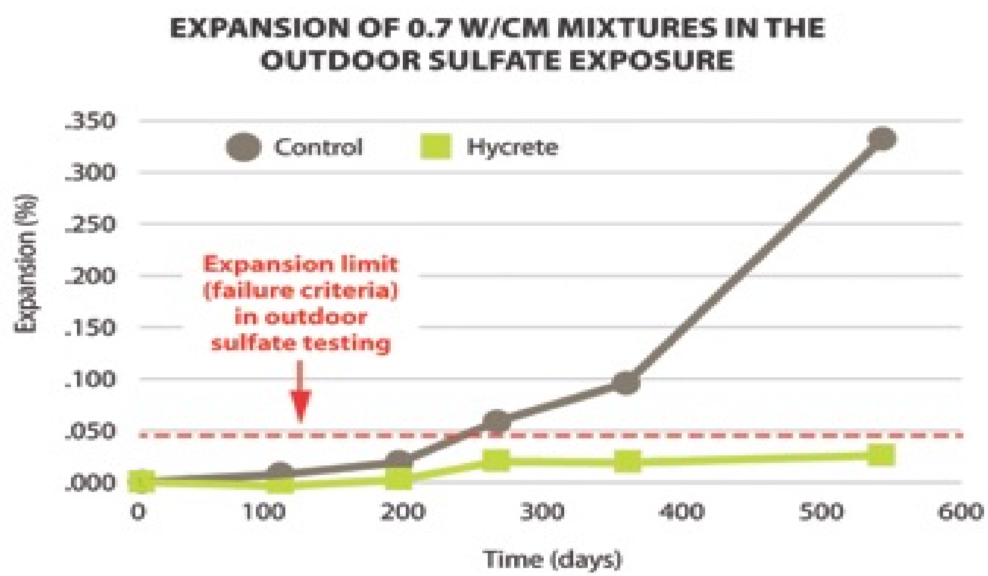
Corrosion Prevention Testing – 2

- University of Massachusetts
  - Under research grant from the US Highways Administration



Sulfate Attack

- University of Texas, Austin
  - Contracted by USACE to test expansion of concrete per ACI 318-08
  - ASTM 1012 Standard Test Method for Length Change oh Hydraulic-Cement Mortars Exposed to a Sulfate Solution



Sulfate Attack X-ray

- University of Texas, Austin
  - Contracted by USACE to test expansion of concrete per ACI 318-08

FIGURE 1: X-RAY DIFFRACTION AT DIFFERENT DEPTHS FOR SUBMERGED CONTROL SPECIMEN

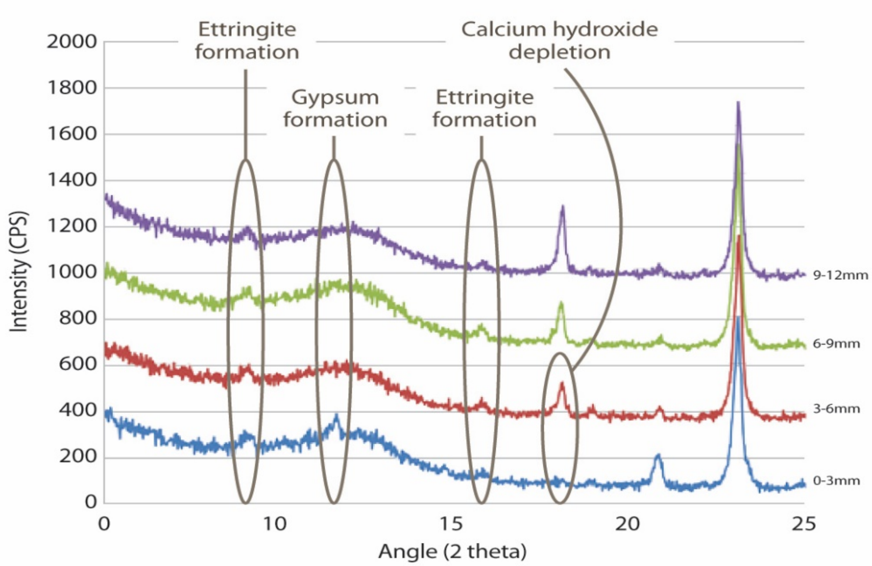
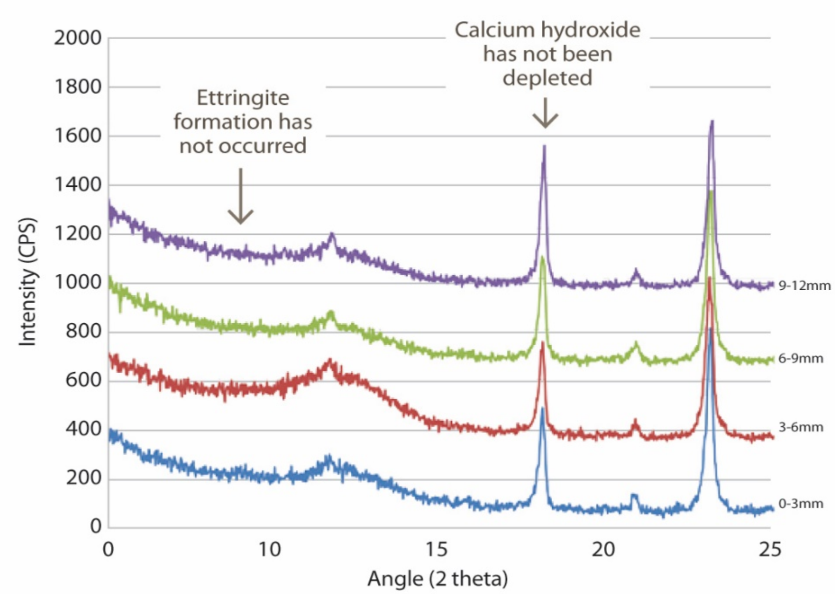


FIGURE 2: X-RAY DIFFRACTION AT DIFFERENT DEPTHS FOR SUBMERGED HYCRETE SPECIMEN



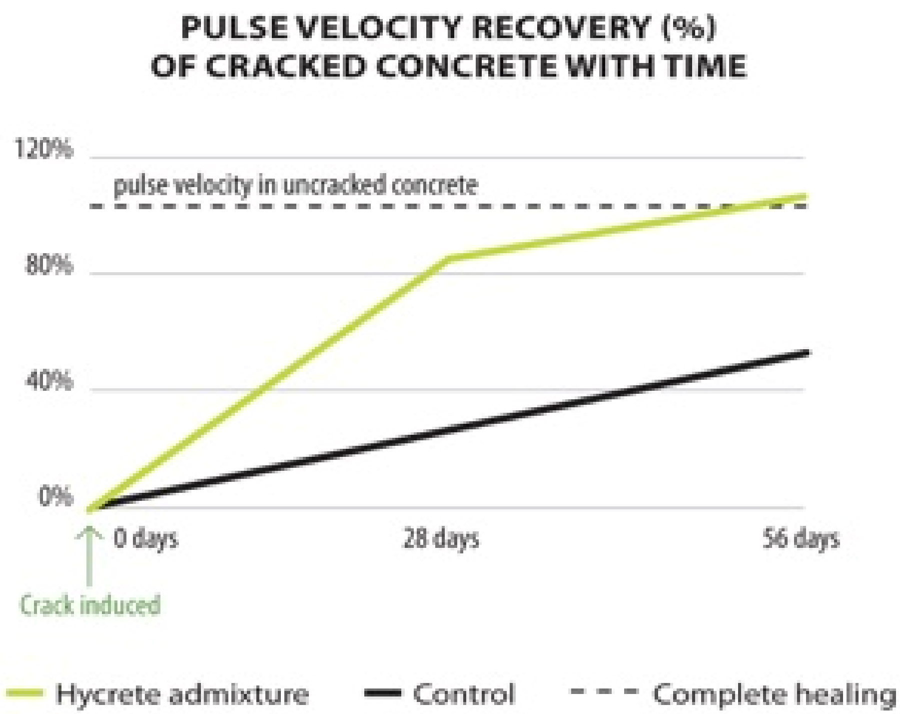
Freeze Thaw Cycling

- New Jersey Institute of Science and Technology (NJIT)
  - ASTM C666 Method For Resistance of Concrete to

FREEZE THAW TESTING (NJIT) w/ 15% Fly Ash		
	300 Cycles	
	% Air	Avg Wt. Change %
Control	6.2	1.1
Hycrete 1gal/yd^3 AE	6.3	1.3
Hycrete 1gal/yd^3 NA	2.5	0.3

Self Healing of Cracks

- Materials Service Life, LLC
  - Using a portable ultrasonic non-destructive digital indicating tester (PUNDIT device)



Alkali-Silica Reaction (ASR)

- The University of Texas, Austin
  - For USACE on JOBE and WRIGHT
  - ASTM C1293 METHOD FOR DETERMINATION OF LENGTH CHANGE OF CONCRETE DUE TO ALKALI-SILICA REACTION

ASR
EXPOSURE %
EXPANSION

WRIGHT
AGGREGATE

	40% Slag		**20% Fly Ash**	
	Control	1 gal/yd^3 Hycrete	Control	1 gal/yd^3 Hycrete
550 days	0.05*	0.01	0.009	0.000
200 days	0.02	0.00	0.005	0.000

* Estimated, testing still underway. Also, any negative expansions are reported as 0

JOBE AGGREGATE

	40% Slag		**30% Fly Ash**	
	Control	1 gal/yd^3 Hycrete	Control	1 gal/yd^3 Hycrete
300 days	n/a	n/a	0.013	0.020
250 days	0.017	0.022	n/a	n/a

Carbonation Test Results

- Performed by Takemoto Oil and Fat
  - Analyzing the depth of carbonation

CARBONATION DEPTH (mm) by Takemoto Oil Fat		
w/c ratio	**0.58**	**0.62**
Hycrete	**None**	**1gal / yd**
wk 1	4.0	5.5
wk 4	12.5	13.0
wk 8	17.0	17.0
wk 13	20.0	19.0
wk 26	23.0	20.5
wk 52	26.0	21.0

LIFE 365

- The USACE
  - Analyzed to predict the time until first repair
  - Multiple locations were analyzed to compare different climates and environments
  - Compared different w/c ratios

Table 1. Scenarios Modeled Using Life 365

Scenario	Structure Type	Location	Exposure	w/c
1	Seawall	Honolulu, HI	Tidal zone	0.35/0.45
2	Seawall	Honolulu, HI	Spray zone	0.35/0.45
3	Seawall	Honolulu, HI	Airborne Chloride 800 m	0.35/0.45
4	Seawall	Honolulu, HI	Airborne Chloride 1500 m	0.35/0.45
5	Bridge Deck	Chicago, IL	Deicing Salts	0.35/0.45
6	Parking Deck	Chicago, IL	Deicing Salts	0.35/0.45
7	Pavement	Chicago, IL	Deicing Salts	0.50
8	Supported Deck	Honolulu, HI	Airborne Chloride 800 m	0.50
9	Supported Deck	Honolulu, HI	Airborne Chloride 1500 m	0.50

LIFE 365 Honolulu, HI

- Forecasted time to initial Repair

Table 2. Service Life and Life Cycle Costs for Honolulu Seawall in Tidal Zone

Honolulu, HI Seawall In Tidal Zone				
Time to First Repair (yrs)				
		Concrete Cover (in.)		
Concrete	**w/c**	**2.0**	**2.5**	**3.0**
Control	0.35	8.2	9.3	10.5
Hycrete	0.35	12.9	19.7	27.3
Hycrete 2x	0.35	22	38.8	54.8
Hycrete 3x	0.35	41.1	70.9	81+
Control	0.45	7.4	8.1	8.7
Hycrete	0.45	9.5	12.2	15.3
Hycrete 2x	0.45	13.2	20.2	28.2
Hycrete 3x	0.45	21.2	37.3	52.8

Table 3. Service Life and Life Cycle Costs for Honolulu Seawall in Tidal Zone

Honolulu, HI Seawall In Spray Zone				
Time to First Repair				
		Concrete Cover (in.)		
Concrete	**w/c**	**2.0**	**2.5**	**3.0**
Control	0.35	11	12.9	14.4
Hycrete	0.35	19.7	27	34.7
Hycrete 2x	0.35	28.1	42.1	54.9
Hycrete 3x	0.35	40.5	62.2	81+
Control	0.45	9.6	10.8	11.8
Hycrete	0.45	15	18.8	22.4
Hycrete 2x	0.45	19.8	26.4	33.5
Hycrete 3x	0.45	25.8	37.8	49

Table 4. Service Life and Life Cycle Costs for Honolulu Seawall 800m from the Ocean

Honolulu, HI Seawall Airborne 800 m				
Time to First Repair				
		Concrete Cover (in.)		
Concrete	**w/c**	**2.0**	**2.5**	**3.0**
Control	0.35	14	16.6	18.8
Hycrete	0.35	29.2	41.2	52.1
Hycrete 2x	0.35	81+	81+	81+
Hycrete 3x	0.35	81+	81+	81+
Control	0.45	11.9	13.7	15.1
Hycrete	0.45	21.7	27.8	33.8
Hycrete 2x	0.45	33.3	47.2	60.1
Hycrete 3x	0.45	58.1	81+	81+

Table 5. Service Life and Life Cycles Costs for Honolulu Seawall 1500m from the Ocean

Honolulu, HI Seawall Airborne 1500 m				
Time to First Repair				
		Concrete Cover (in.)		
Concrete	**w/c**	**2.0**	**2.5**	**3.0**
Control	0.35	17.8	21.25	24
Hycrete	0.35	39.9	51.8	62.7
Hycrete 2x	0.35	81+	81+	81+
Hycrete 3x	0.35	81+	81+	81+
Control	0.45	15.1	17.3	19.2
Hycrete	0.45	30.5	38.3	44.6
Hycrete 2x	0.45	44.9	58.3	71
Hycrete 3x	0.45	69.1	81+	81+

LIFE 365 Chicago, IL

- Forecasted time to initial Repair

Table 6. Bridge Deck in Chicago

Chicago Bridge Deck				
Time to First Repair				
		Concrete Cover (in.)		
Concrete	**w/c**	**2.0**	**2.5**	**3.0**
Control	0.35	10.8	12.7	14.2
Hycrete	0.35	19.7	28.5	37.8
Hycrete 2x	0.35	31	48.9	65.2
Hycrete 3x	0.35	49.8	79.1	81+
Control	0.45	9.4	10.6	11.6
Hycrete	0.45	14.6	18.7	22.9
Hycrete 2x	0.45	20	28.8	38
Hycrete 3x	0.45	29.4	46.1	61.3

Table 7. Parking Deck in Chicago

Chicago Parking Deck				
Time to First Repair				
		Concrete Cover (in.)		
Concrete	**w/c**	**2.0**	**2.5**	**3.0**
Control	0.35	10.5	12.2	13.8
Hycrete	0.35	18.3	26	34.2
Hycrete 2x	0.35	26.9	42.1	56
Hycrete 3x	0.35	40.2	63.8	81+
Control	0.45	9.2	10.3	11.2
Hycrete	0.45	13.8	17.5	21.2
Hycrete 2x	0.45	18.2	26.2	32.8
Hycrete 3x	0.45	24.4	37.3	49.5

Table 8. Pavement in Chicago Subject to Deicing Salts

Chicago Pavement Deicing				
Time to First Repair				
		Concrete Cover (in.)		
Concrete	**w/c**	**2.0**	**2.5**	**3.0**
Control	0.5	9.2	10.2	11.1
Hycrete	0.5	13.8	17.2	20.7
Hycrete 2x	0.5	18.2	27.2	35.8
Hycrete 3x	0.5	30.7	48.2	64.2

LIFE 365 Honolulu, HI

- On Airborne supported decks

Table 9. Supported Deck 800m from the Ocean in Honolulu, HI

Honolulu, HI Supported Deck--800 m Airborne					
Time to First Repair					
		Concrete Cover (in.)			
Concrete	**w/c**	**2.0**	**2.5**	**3.0**	
Control	0.5	11.2	12.6	13.8	
Hycrete	0.5	19.2	23.8	28	
Hycrete 2x	0.5	28	38.2	47.9	
Hycrete 3x	0.5	46.4	68.8	81+	

Table 10. Supported Deck 1500m from the Ocean in Honolulu, HI

Honolulu, HI Supported Deck--1500 m Airborne					
Time to First Repair					
		Concrete Cover (in.)			
Concrete	**w/c**	**2.0**	**2.5**	**3.0**	
Control	0.5	14.1	15.9	17.4	
Hycrete	0.5	27	33.5	38.7	
Hycrete 2x	0.5	39.8	49.7	59	
Hycrete 3x	0.5	57.8	79.7	81+	

Conclusions

- Get the right material to polymerize within concrete and form a rubber plug
- Stop corrosion by preventing the ingress of chlorides as well as protecting rebar itself
- Self heal cracks
- Lower moisture permeability
  - Lower chloride penetration
  - Lower sulfate penetration
  - Improve freeze thaw resistance
- Neutral to ASR
- Reduce carbonation

Conclusions - 2

- Life 365
  - Trialed on bridge decks, parking decks, seawalls and pavement
  - Can increase time to first repair by a factor of 3 or more.
  - Significant cost savings over the lifespan of concrete
    structures.
  - Reduce traffic nightmares by reducing and/or eliminating maintenance and repairs.

Acknowledgments

- Jason Tuerack, Pres. Hycrete, Inc.
- Fazal Wahab, Dir. Of Engineering Hycrete, Inc.
- Andrew Rhodes Infrastructure Projects manager, Hycrete inc.
- Michael Munoz, Marketing, Hycrete, Inc.
- Joshua Warburton-Pitt, R&D Manager, Broadview Technologies, Inc.
- USACE
- University of Massachusetts
- University of Connecticut

Slide 27

THANK YOU!

Slide 28