Premature Joint Deterioration in Concrete Pavements

And Methods to Prevent It

Jason Weiss, Edwards Distinguished Professor, Oregon State University

Abstract

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- Concrete pavements and flatwork generally provide excellent performance in all climates and exposures. However, in recent years, the industry has seen an increase in premature deterioration at joints and saw cuts in concrete pavements and flatwork in areas where winter storm events demand the application of deicing chemicals, which are most commonly chloride-based. This talk will discuss some of the recent changes in salting practices and how they can exacerbate this issue. Guidance will be provided as to how to improve the performance of the concrete in these challenging environments.

Premature Joint Deterioration in Concrete Pavements

And Methods to Prevent It

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Concrete Pavements

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- Concrete pavements can provide excellent service
- Many times these pavements are designed to last 30 years
- Frequently they last even longer

Rural Concrete Road Painting by Carl Rakeman ~ 1909

Concrete Damage

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Corrosion of Reinforcing Steel in Decks/Structures

Joint Damage in the Presence of Salts

Cracks spaced at 2.5 ft on the approaches to a bridge deck

Pavement Joints

- The majority of concrete pavement performs well; however some joints are failing/ need repair
- A problem for an otherwise healthy pavement
- The cost is approximately $1 million dollar per mile


Taylor 2013


Weiss 2005


Taylor 2013


Weiss 2008


Weiss 2005

Ideal Pavement Joint

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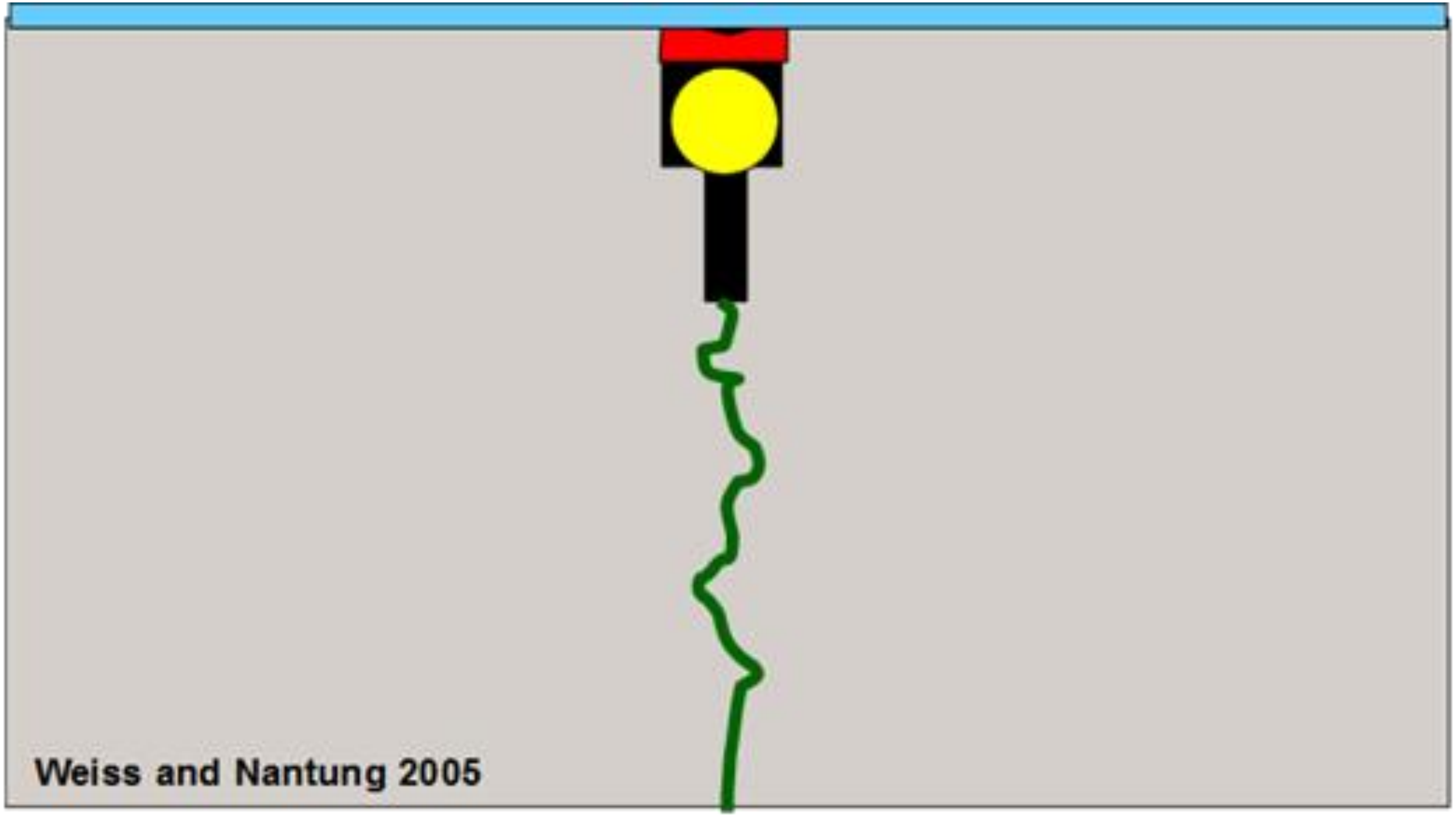

Pavement Joint Issue

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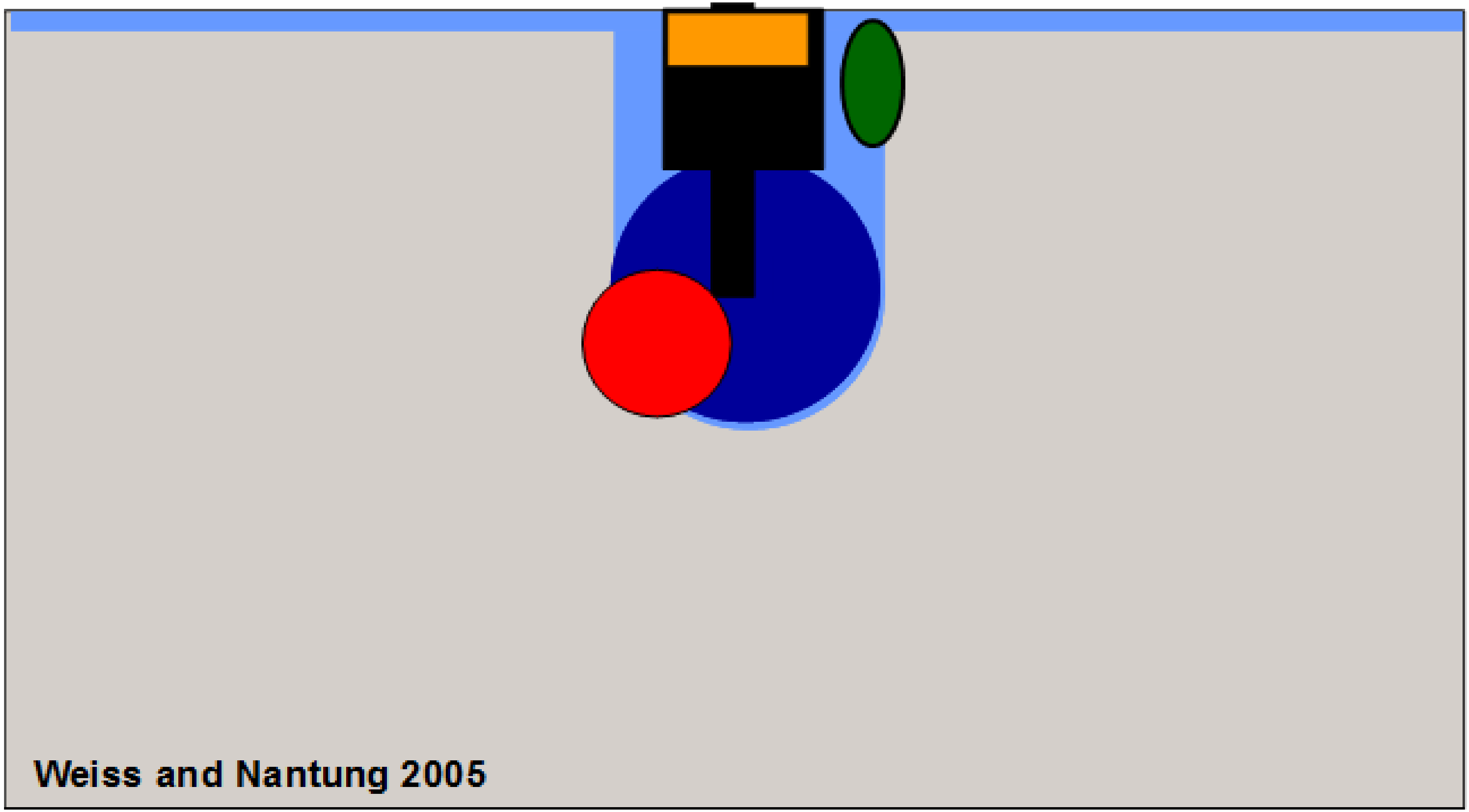
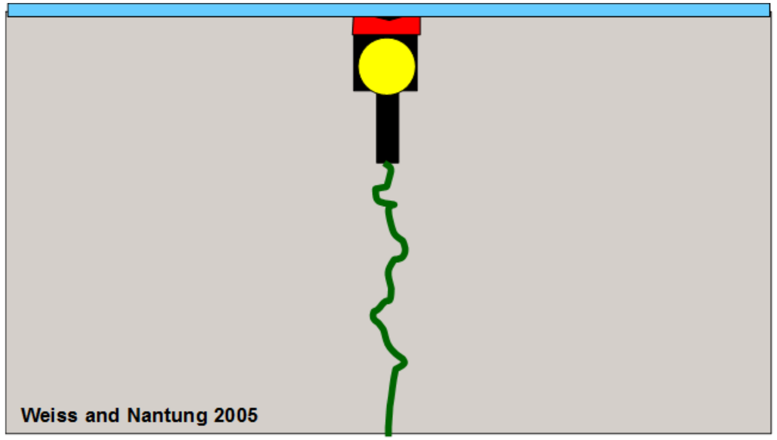
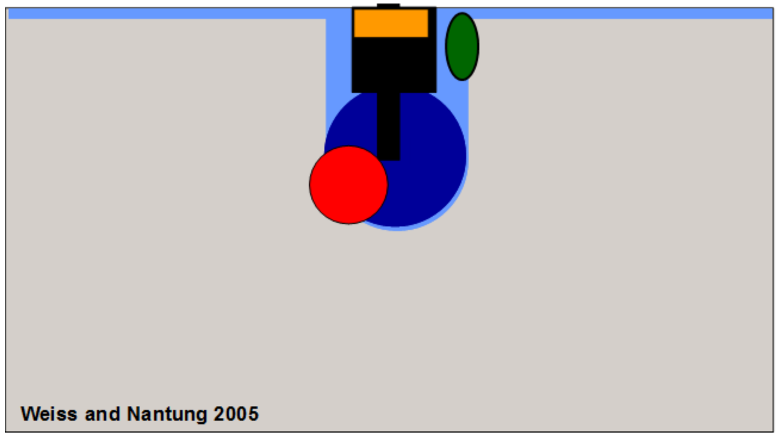
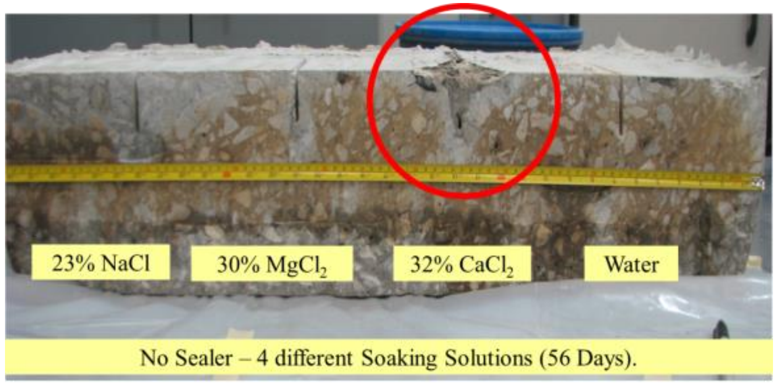


Toward a Working Mechanism

- Examined saw cutting and curing at joints
- Fluid enters joint is trapped
- Saw cut joints not opening to drain (higher early strength, thicker, increased tie bars)
- As a result, fluid can not drain out easily to drainable subbase under the PCCP
- Silicone sealant & backer rod limit drying of trapped fluid which can increase saturation and potentially lead to crystal growth, chemical reaction or pressure







Two Primary Factors Contributing to Premature Damage

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- Increase in Water Ingress
  - Increases saturation

- Increase in Salt Damage
  - Increase in potential reactions

Critical Saturation Based Approach

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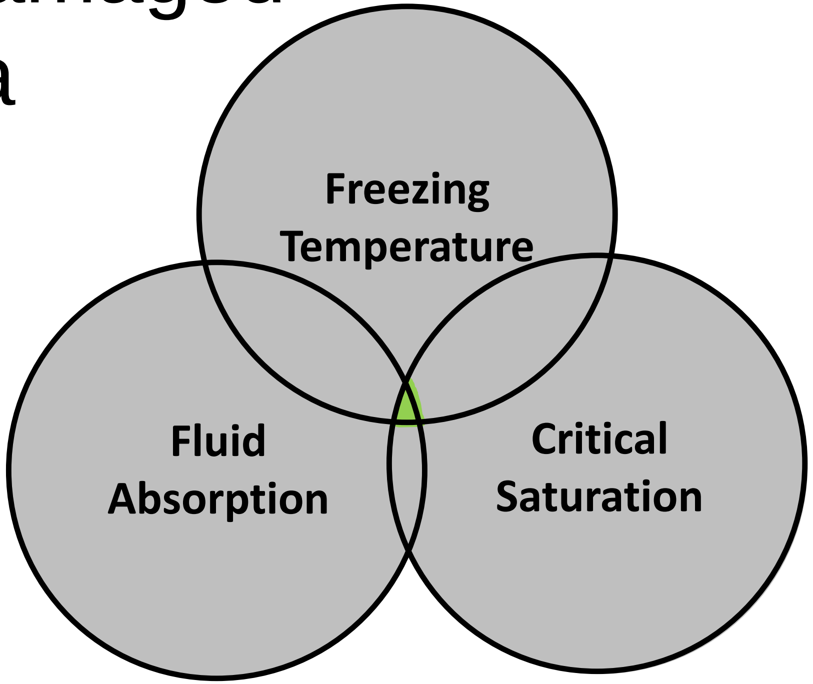
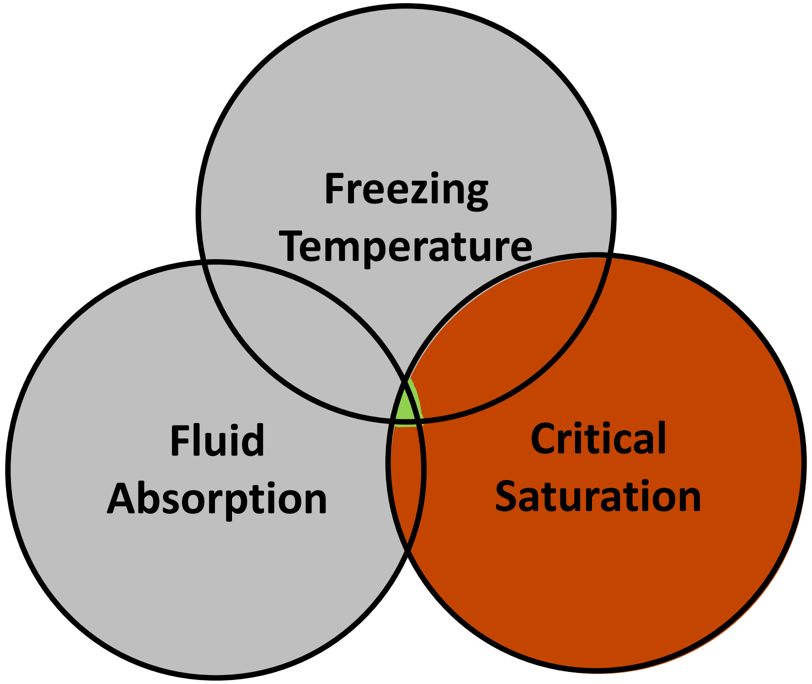
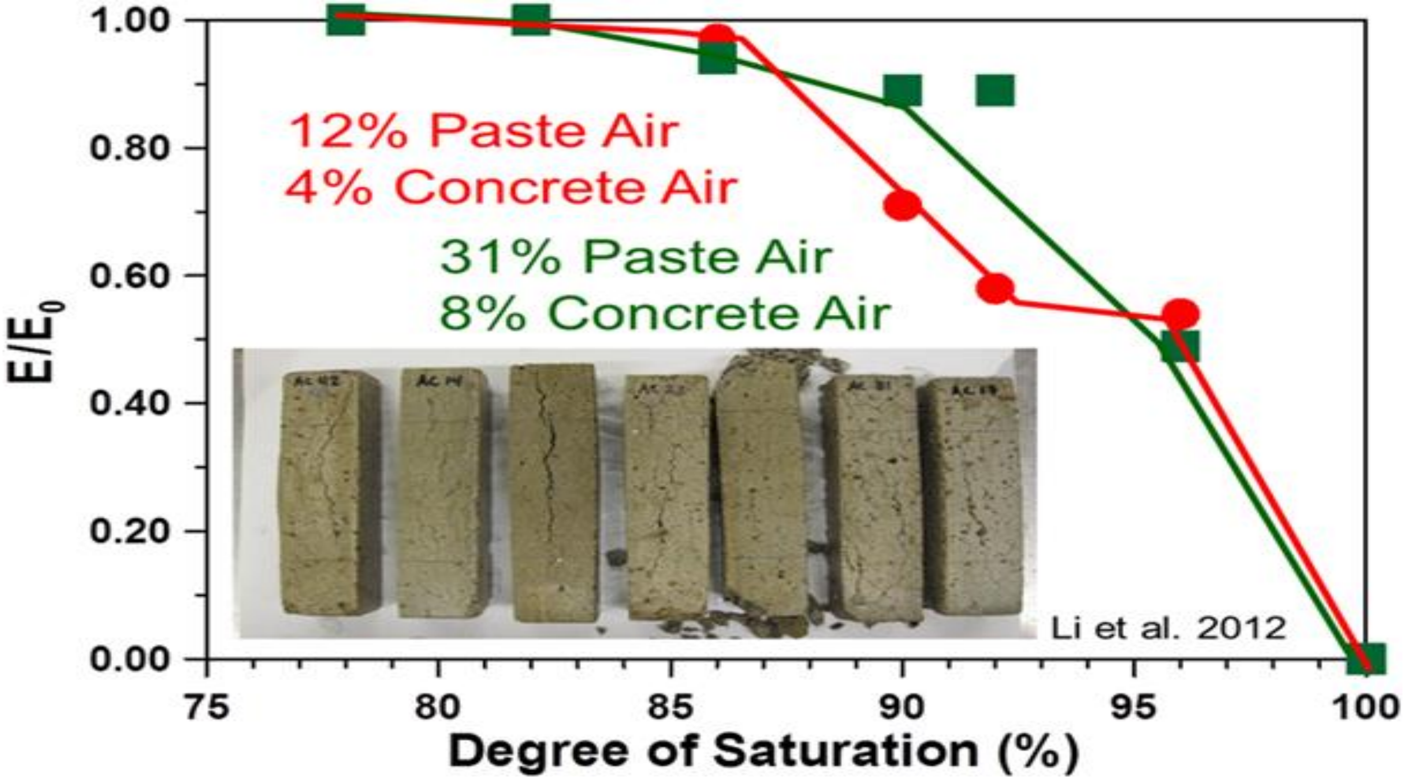
- General approach (Fagerlund et al., Weiss et al., others)
- Assumes the concrete becomes damaged when water is absorbed, reaches a specific degree of saturation, and freezes and thaws
- Can be related to sorption and saturation physical test methods



Critical Saturation

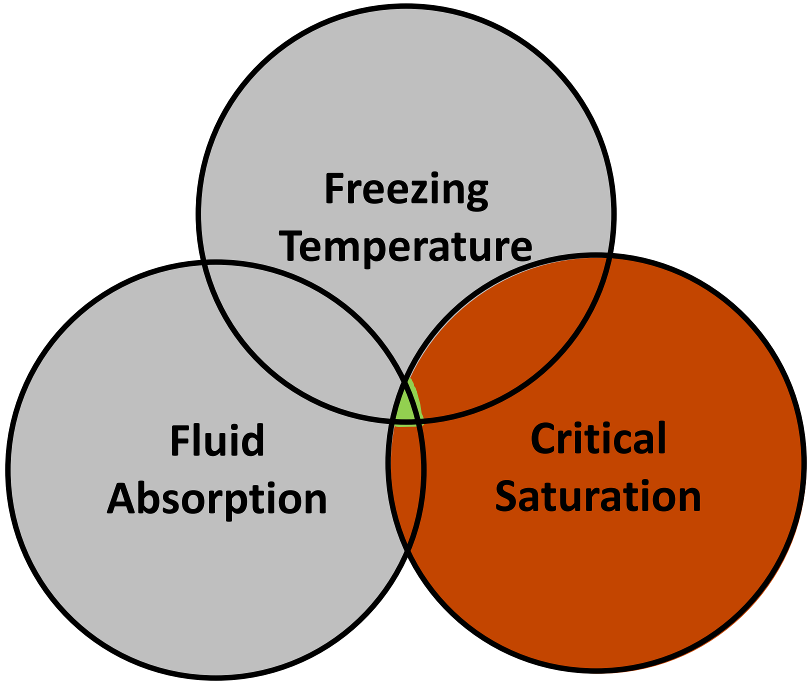
- The critical saturation is generally between 78 and 91% with higher values being a better air void system (85% is a good ref.)

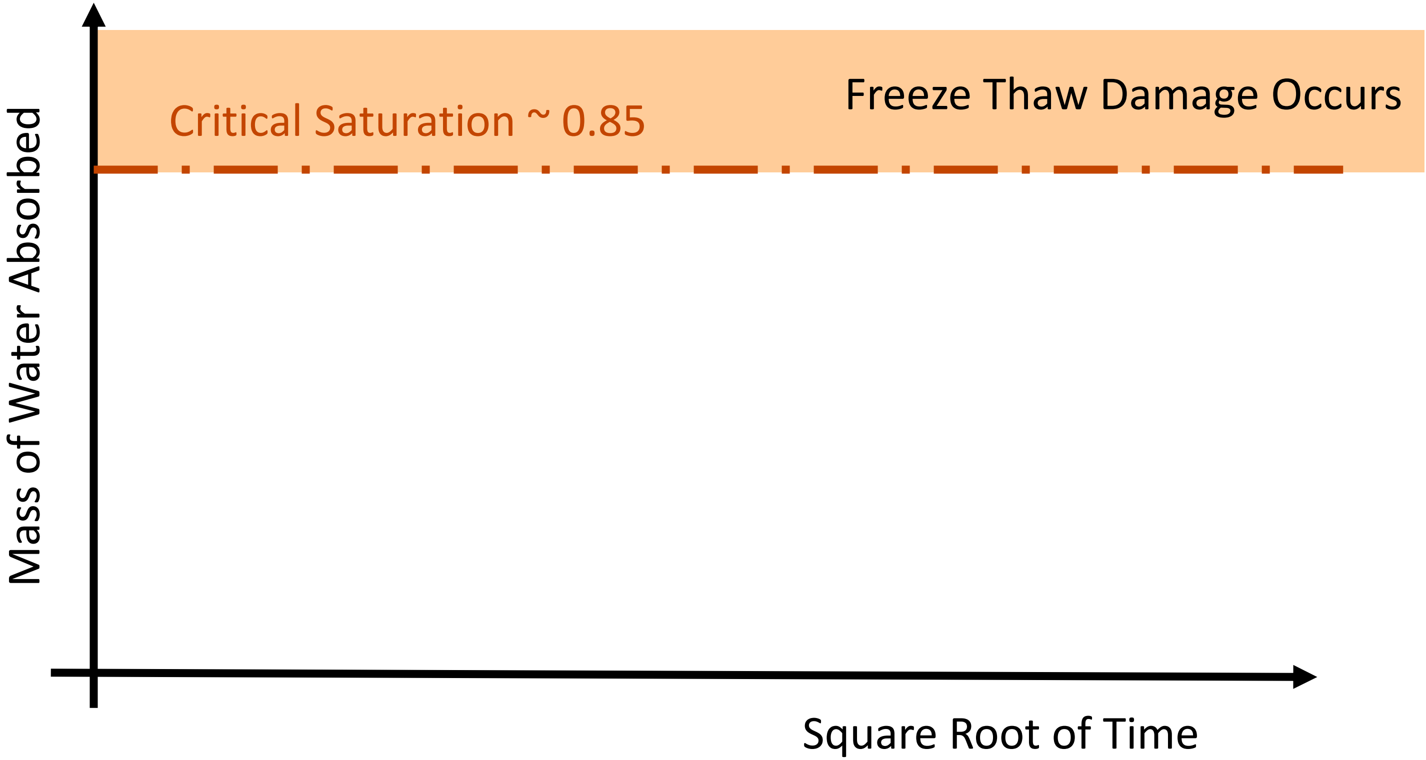




Critical Saturation

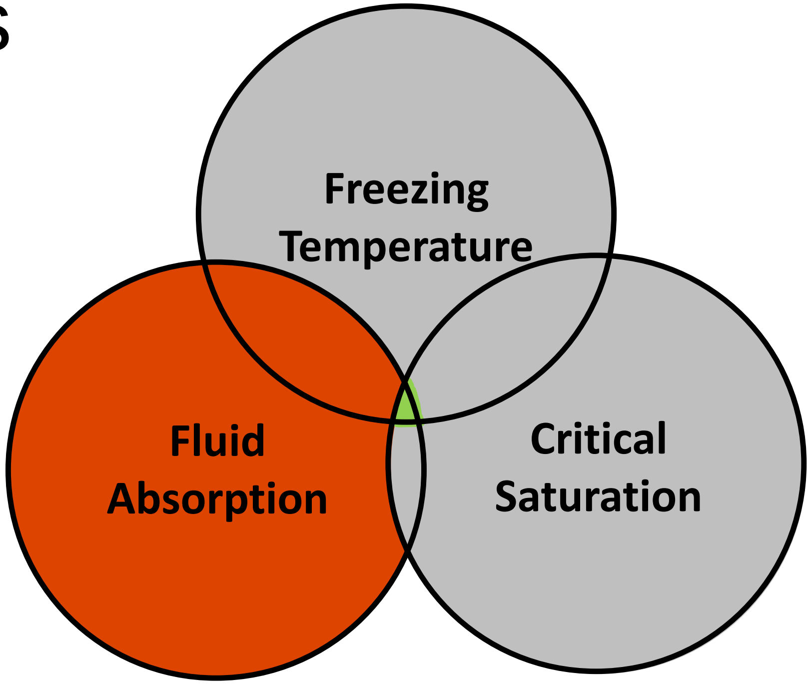
- A concrete becomes damaged when it absorbs fluid, *reaches a critical level of saturation*, and freezes



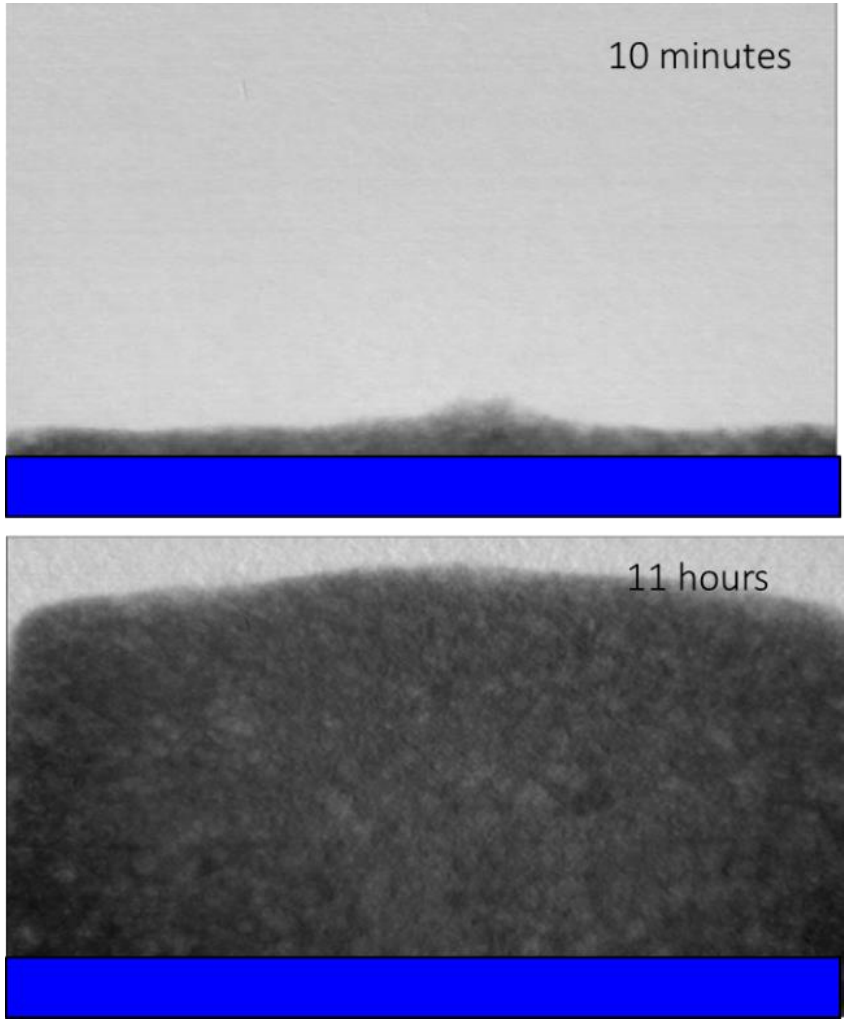


Fluid Absorption

- A concrete becomes damaged when it *absorbs fluid*, reaches a critical level of saturation, and freezes

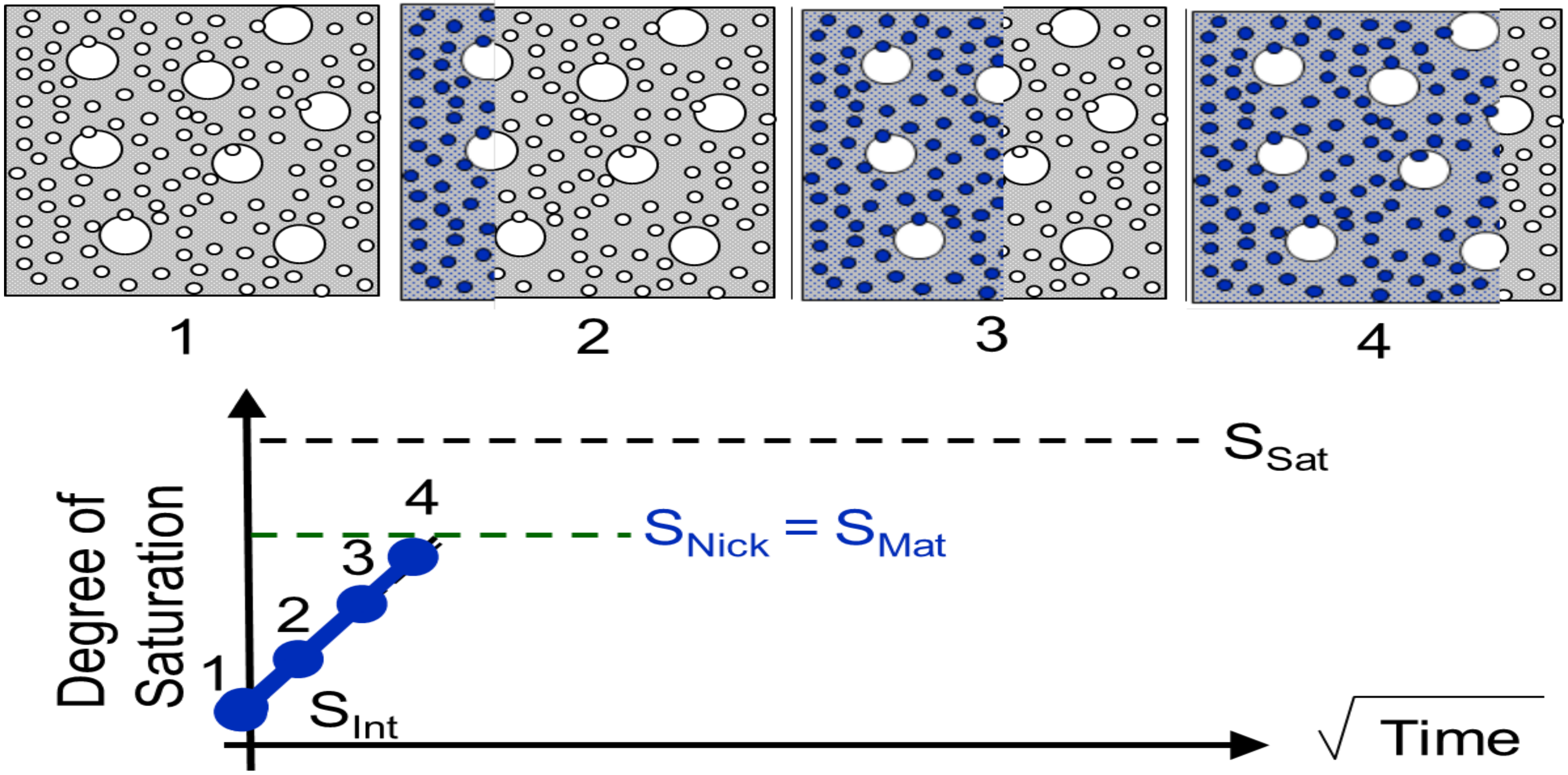


Neutron Images of Absorption



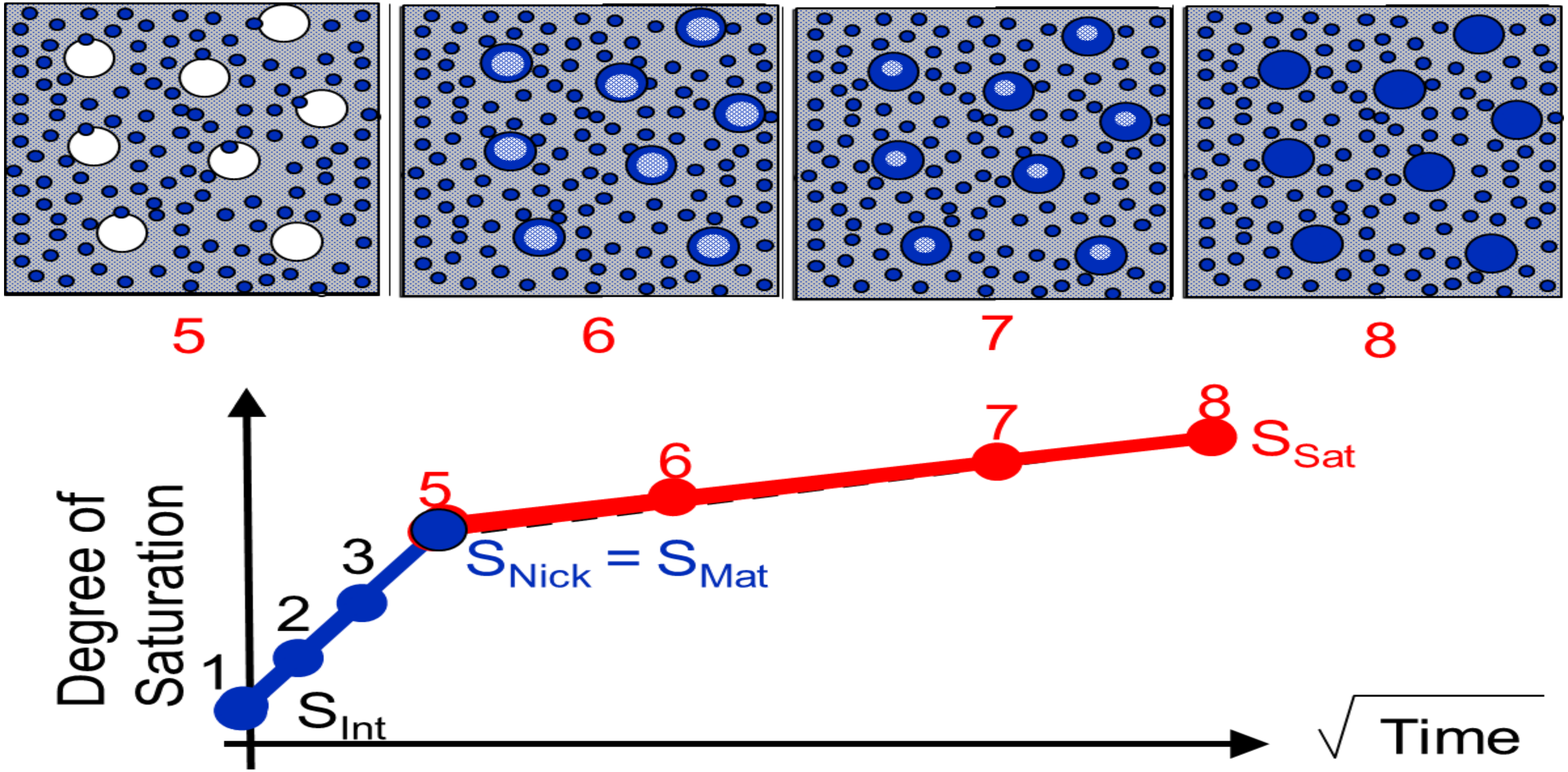
Lucero et al. 2014

Sorption Based Freeze-Thaw Model



Lucero et al. 2015

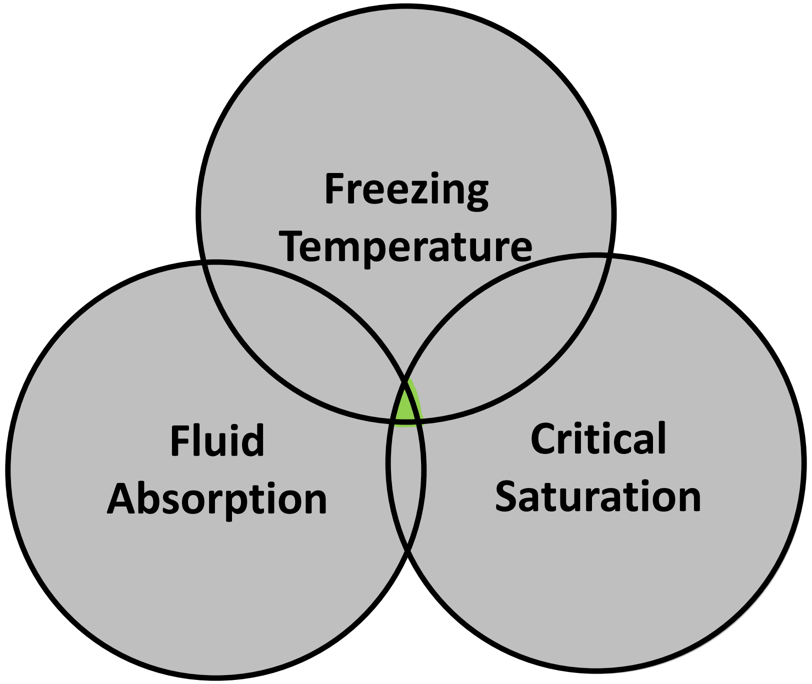
Sorption Based Freeze-Thaw Model

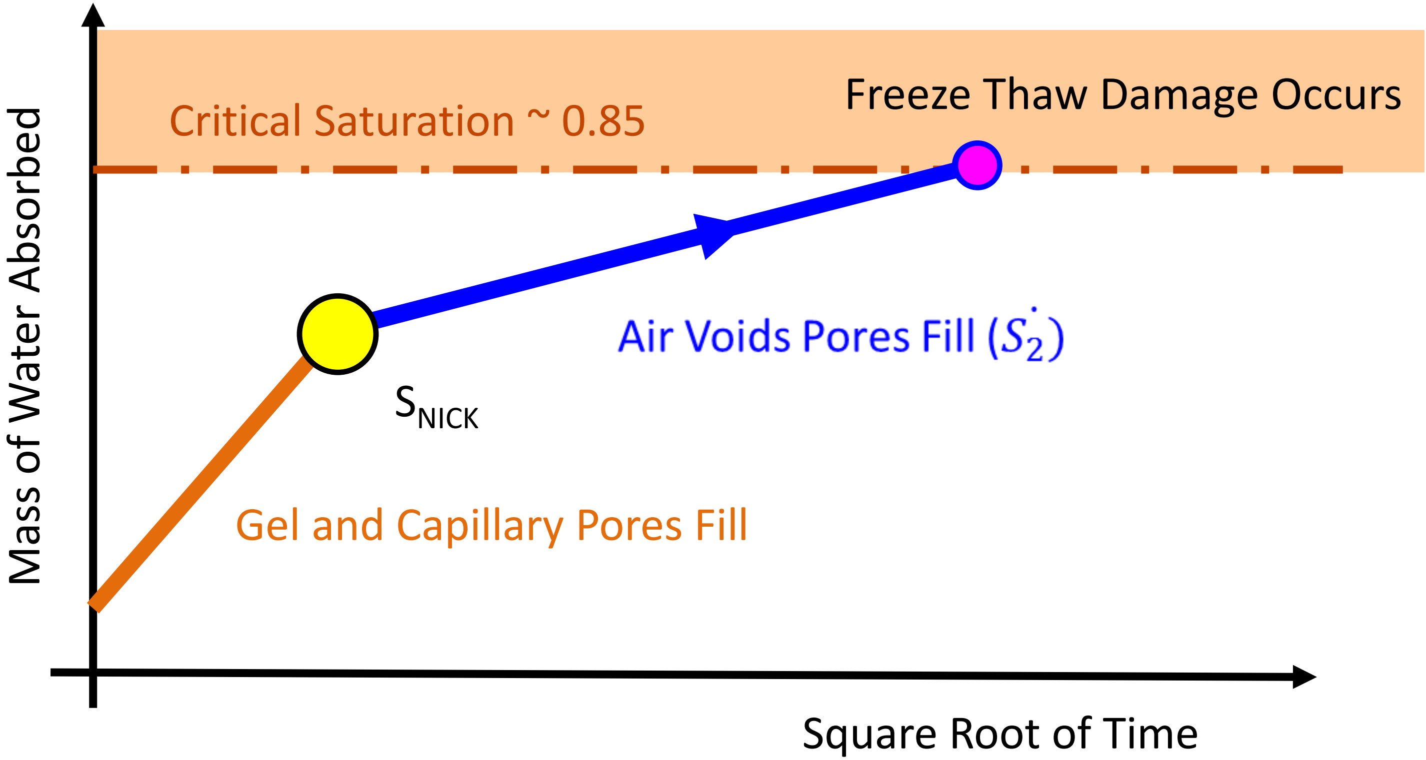


Lucero et al. 2015

Putting it All Together

- A concrete becomes damaged when it absorbs fluid, reaches a critical level of saturation, and freezes





Impact of Air

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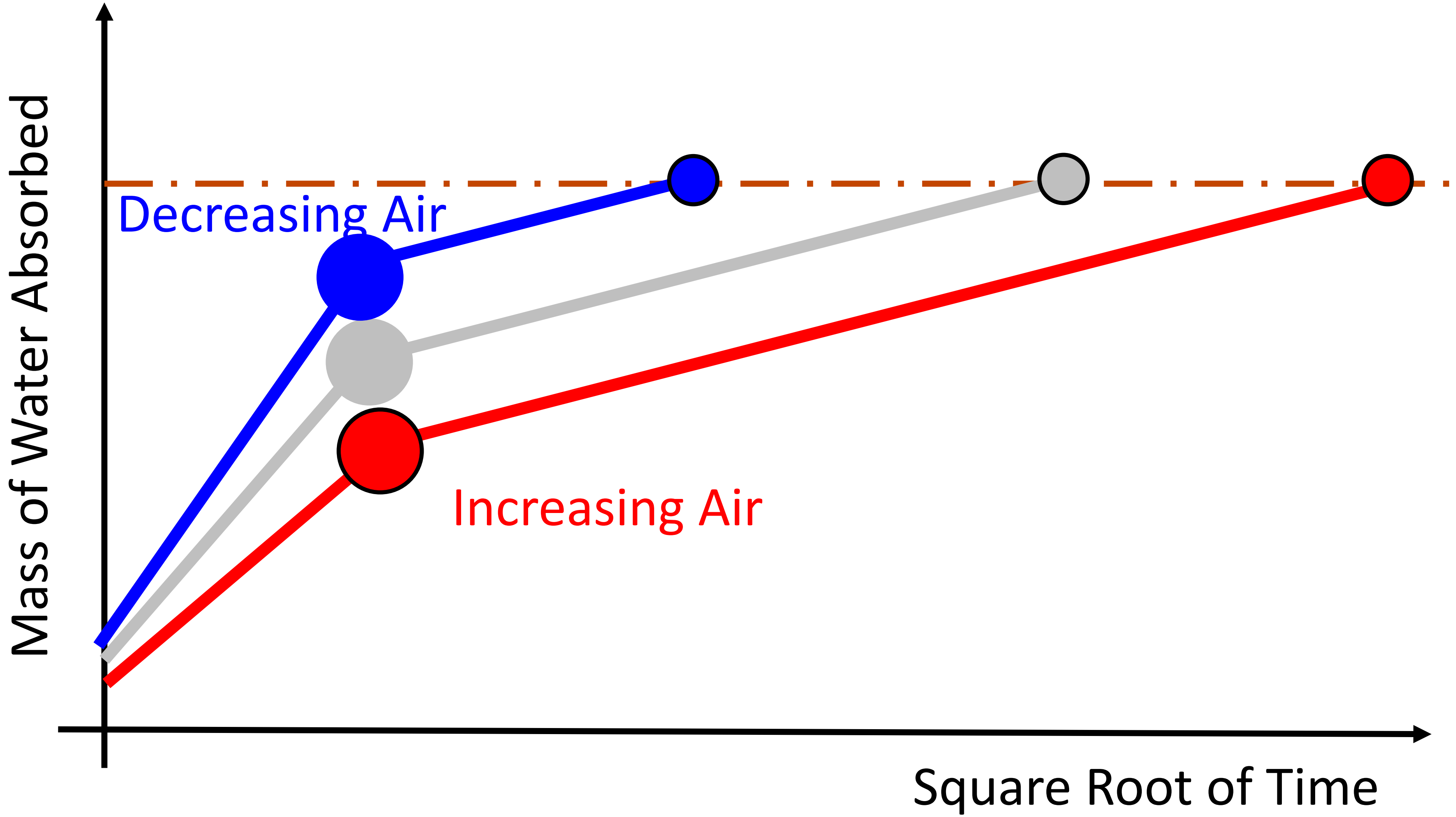

Two Primary Factors Contributing to Premature Damage

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- Increase in Water Ingress
  - Increases saturation
- Increase in Salt Damage
  - Increase in potential reactions

Salt Use is on the Rise

Photos from D. Rothstein

We think Freeze-Thaw; Salts Change Discussion

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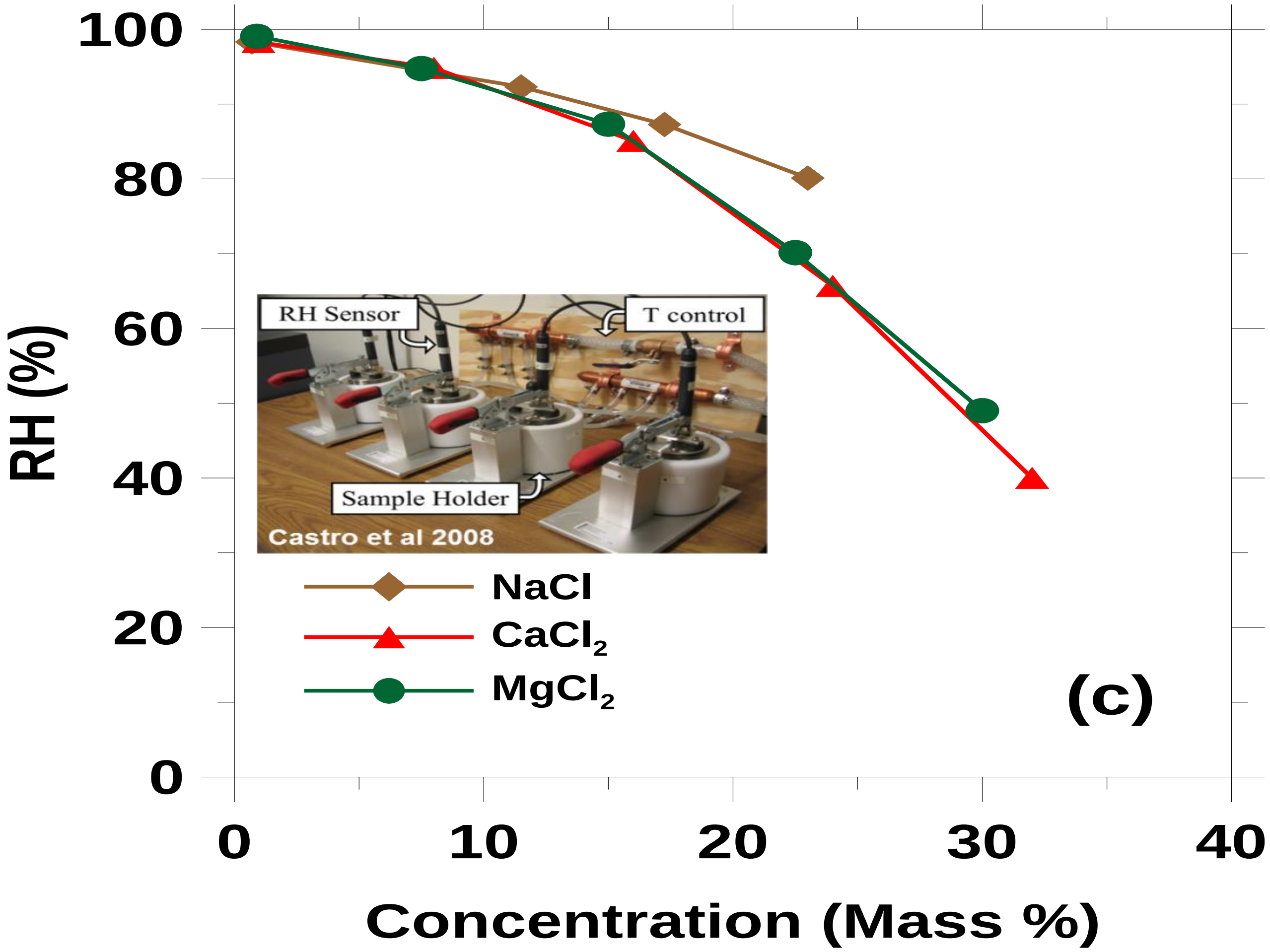
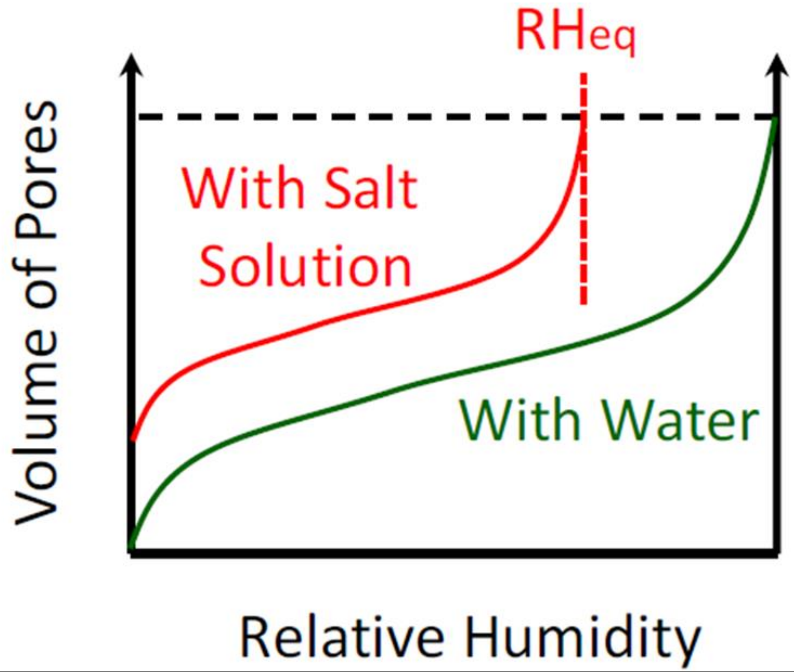
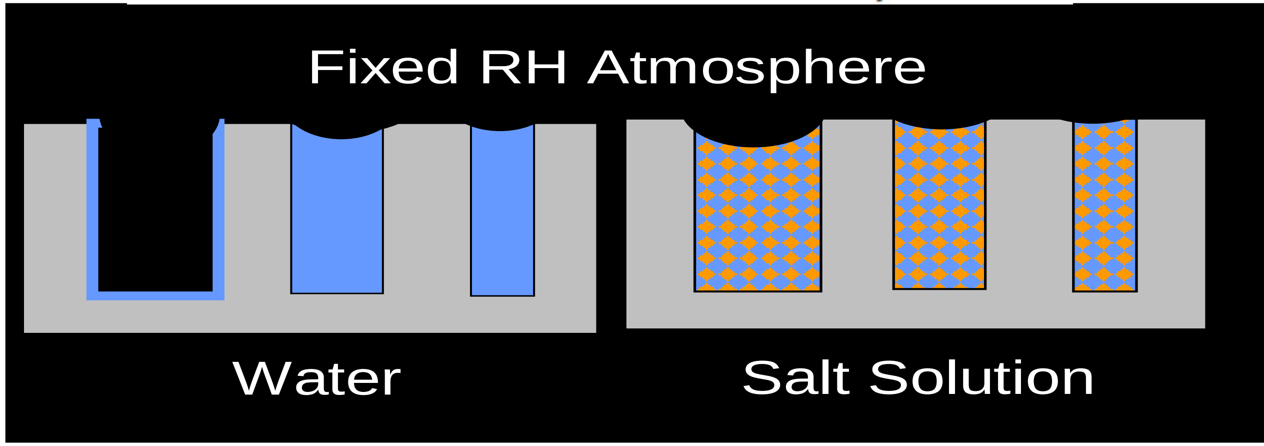
- One item that we noticed very early on is that water is part of the story, however the fluid is not just water, it is a salt soln.
- Changes to fluid properties
- Changes saturation
- Potential reactions

Whiting 2013

Salts Change Discussion







Spragg et al. 2010

'Drying' with Salts

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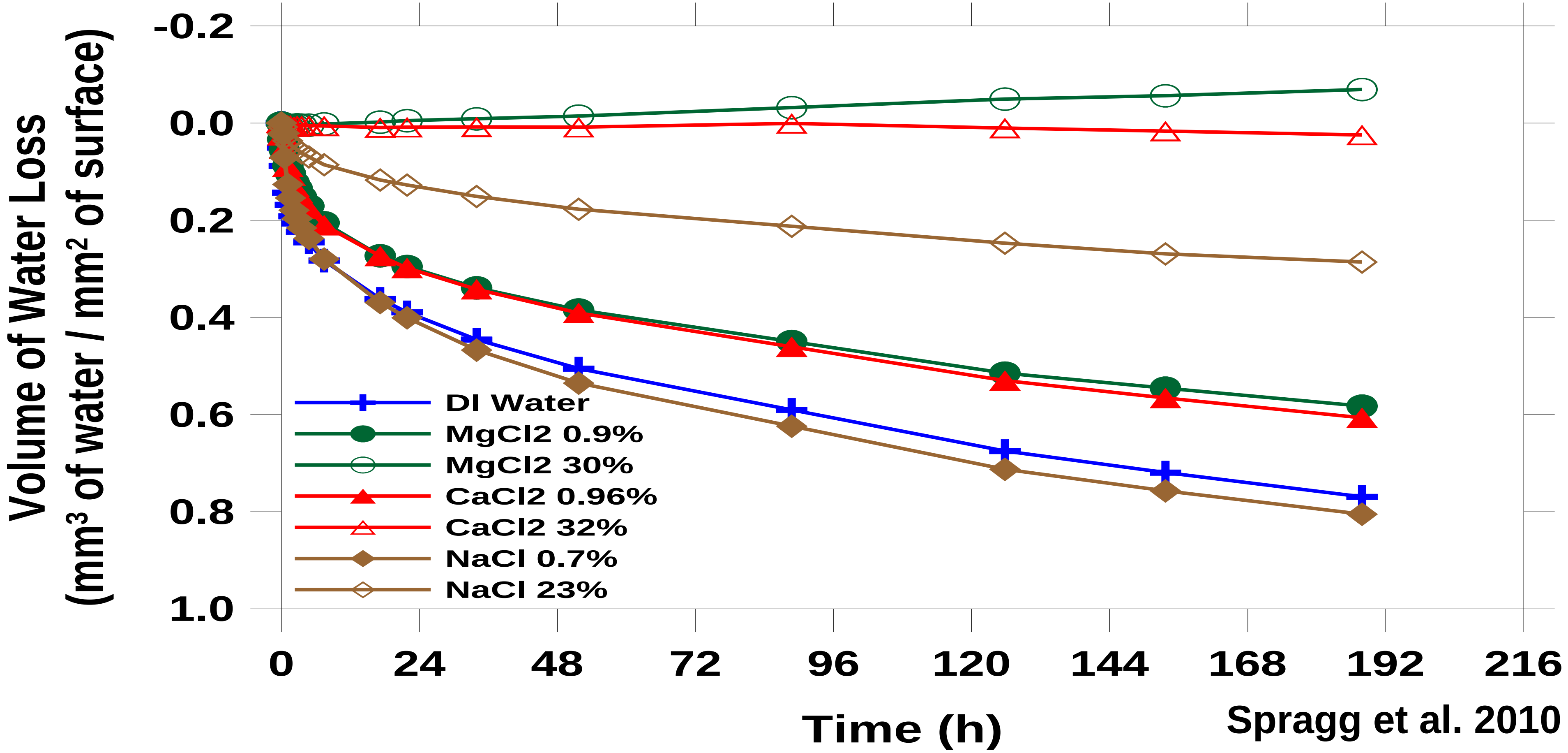
- Drying doesn't occur to RH_{EQ} is reached



Spragg et al. 2010

Reducing Joint damage

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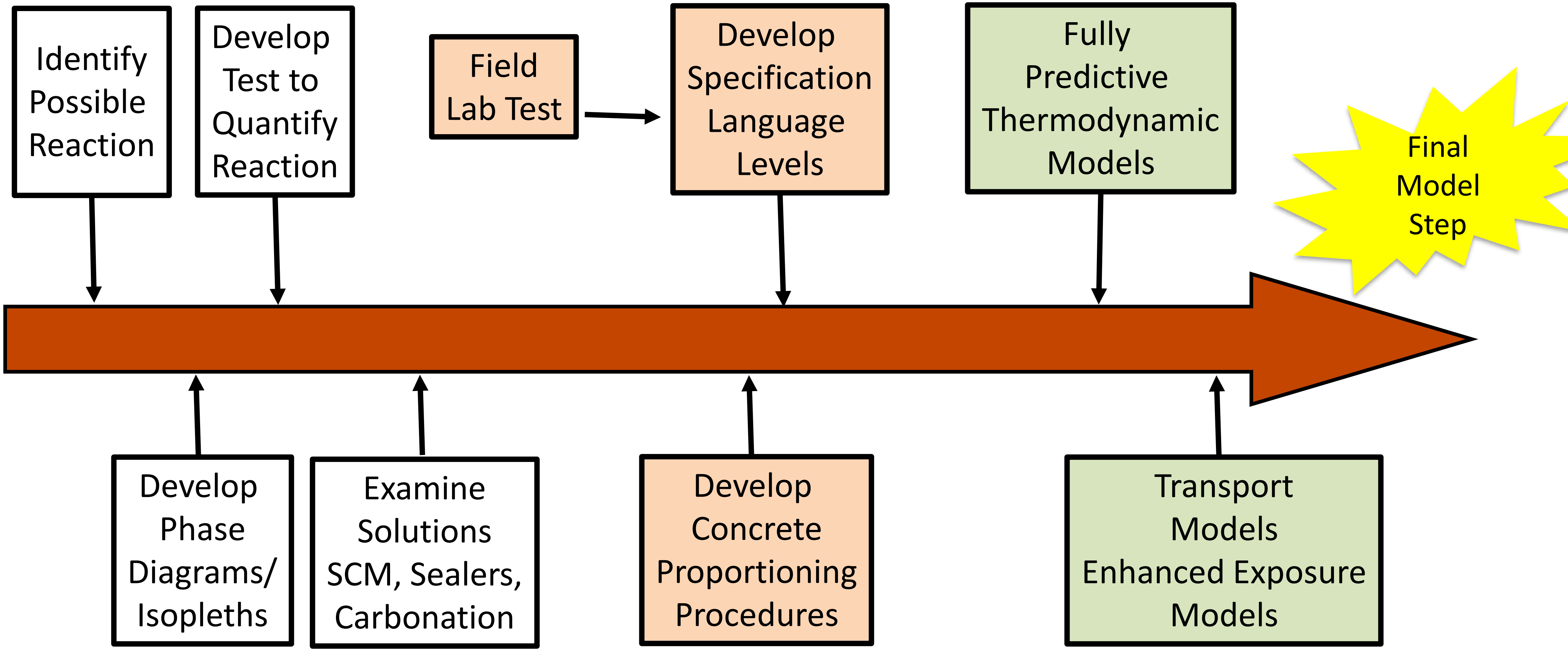

Reducing Joint Damage

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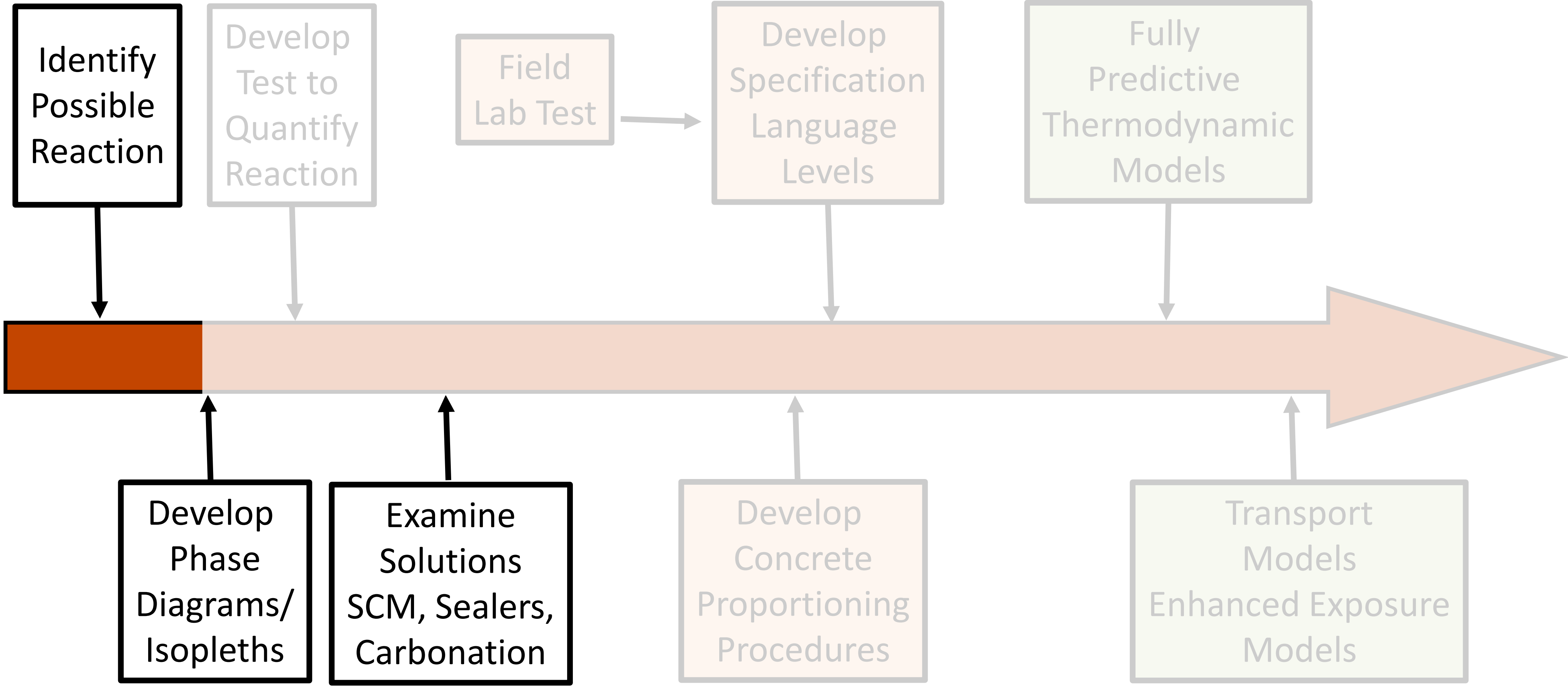

Pavement Joints

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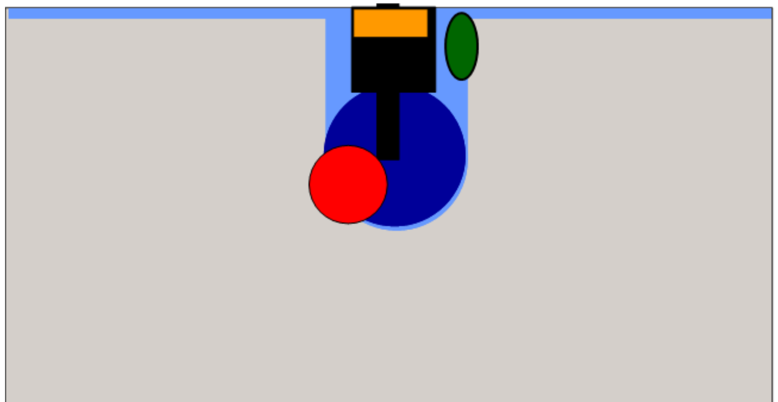
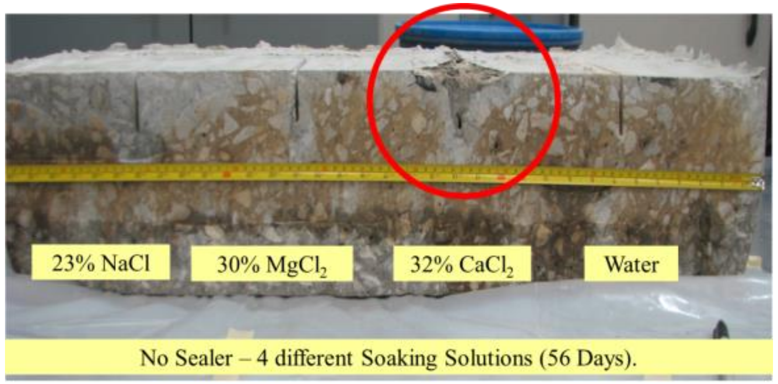
- This damage is largely due to changes in ‘exposure’ as the salts used have changed
- Calcium and Magnesium chloride is more widely used and in higher rates
- Calcium chloride reacts with calcium hydroxide from the paste



Weiss and Nantung 2005



$$3Ca(OH)_2 + CaCl_2 + 12H_2O \rightarrow 3Ca(OH)_2 \cdot CaCl_2 \cdot 12H_2O$$

Calcium Oxychloride

Classic $CaCl_2 – H_2O$ Phase Diagram

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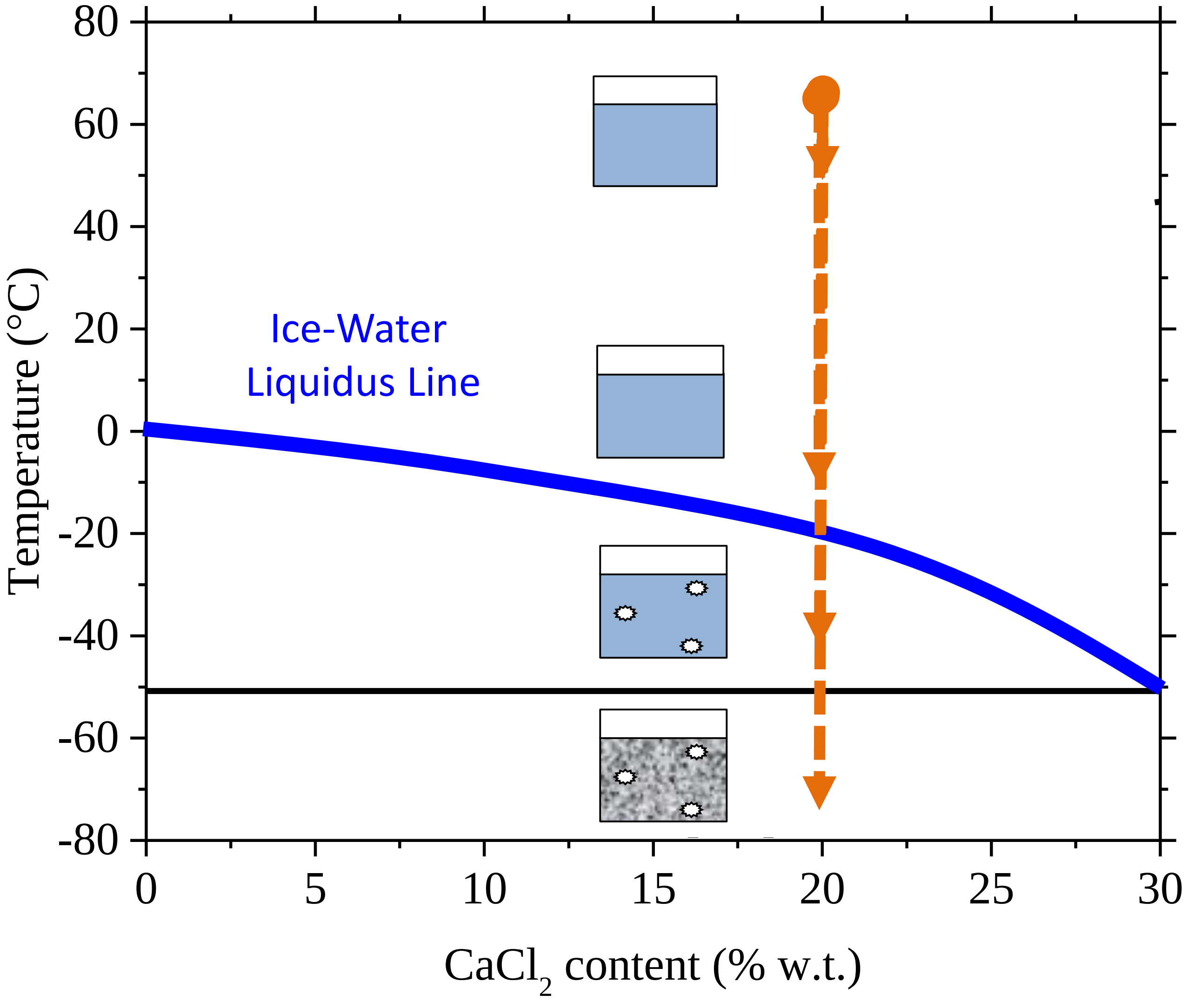
- We likely are not spending a lot of time thinking about the $CaCl_2$ phase diagram
- However this diagram is being used by many SHA as they prepare for deicing and anti-icing operations
- Many prefer $CaCl_2$ due to its lower melting temperature



$CaCl_2 – H_2O – Ca(OH)_2$ Phase Isopleth

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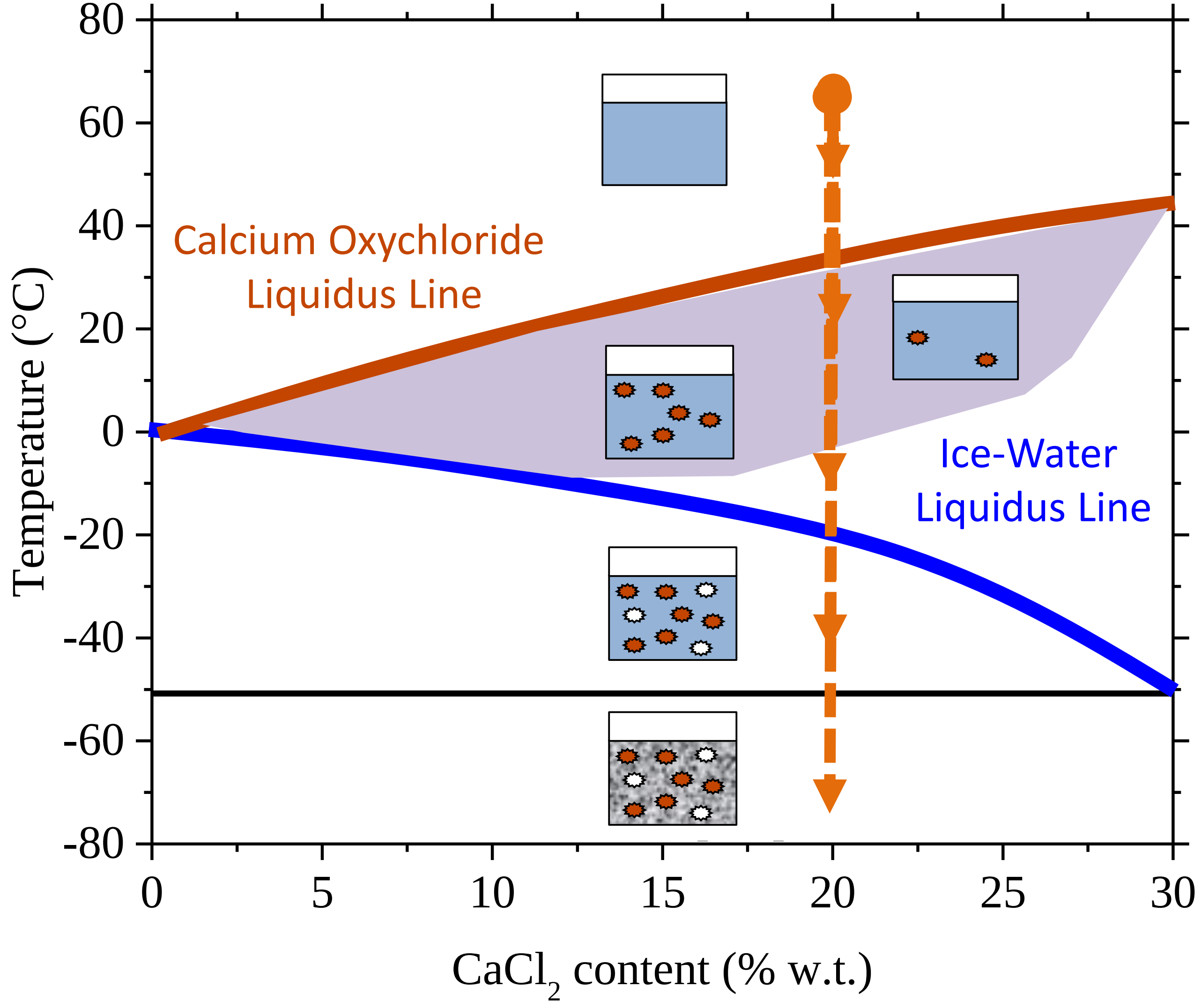
- Unfortunately however when we are working with cementitous systems we need to also consider the calcium hydroxide
- CaOxy is traced out and exhibits a 303% vol change

$$3Ca(OH)_2 + CaCl_2 + 12H_2O \rightarrow CaCl_2{\cdot}3Ca(OH)_2{\cdot}12H_2O$$



Reducing Joint Damage

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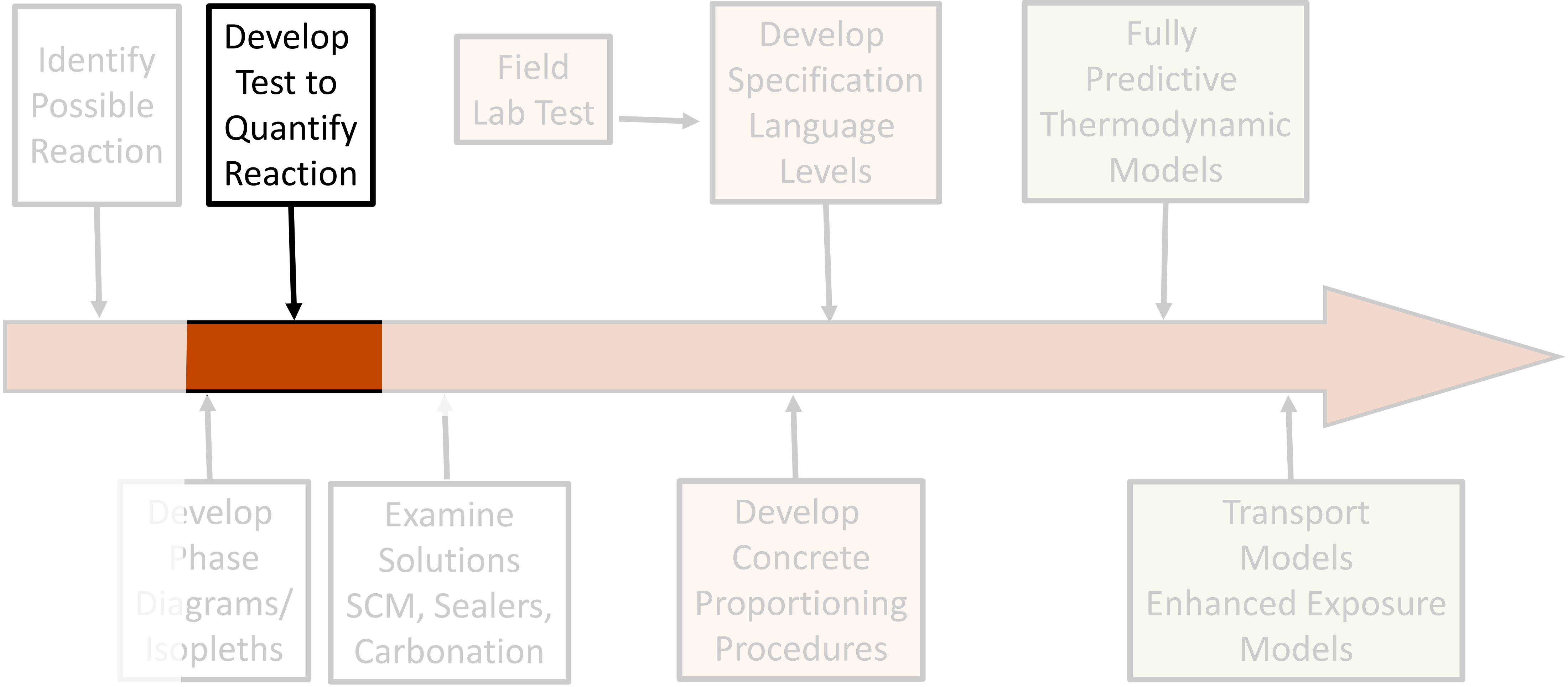

Test - AASHTO T365

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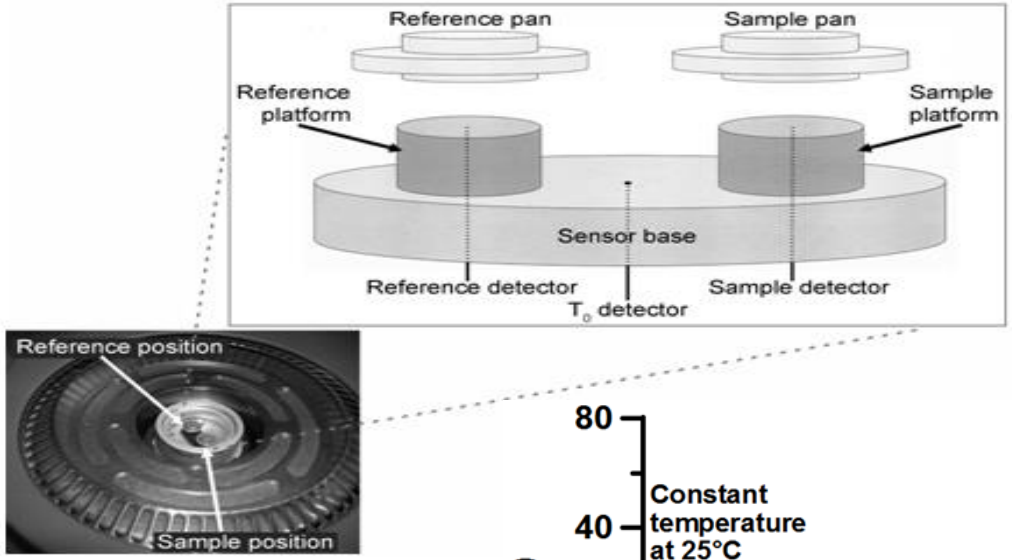
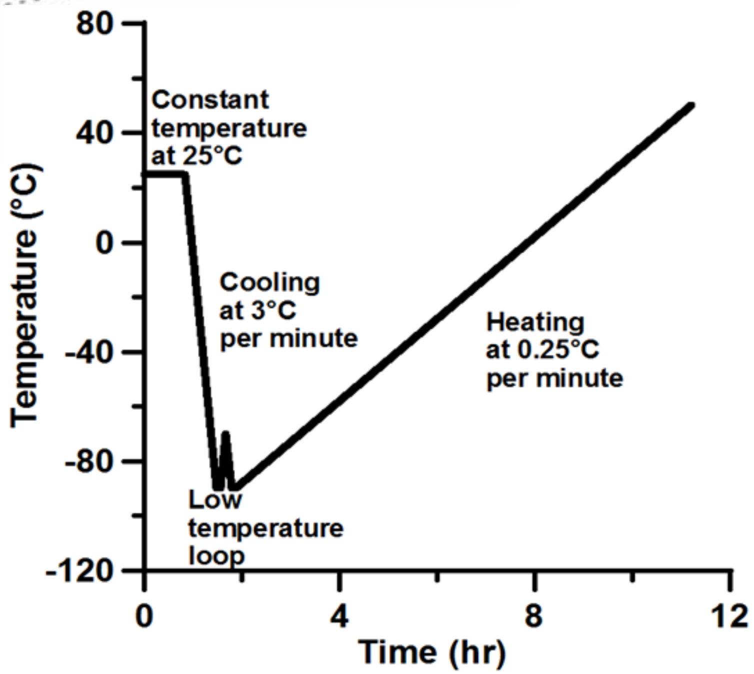
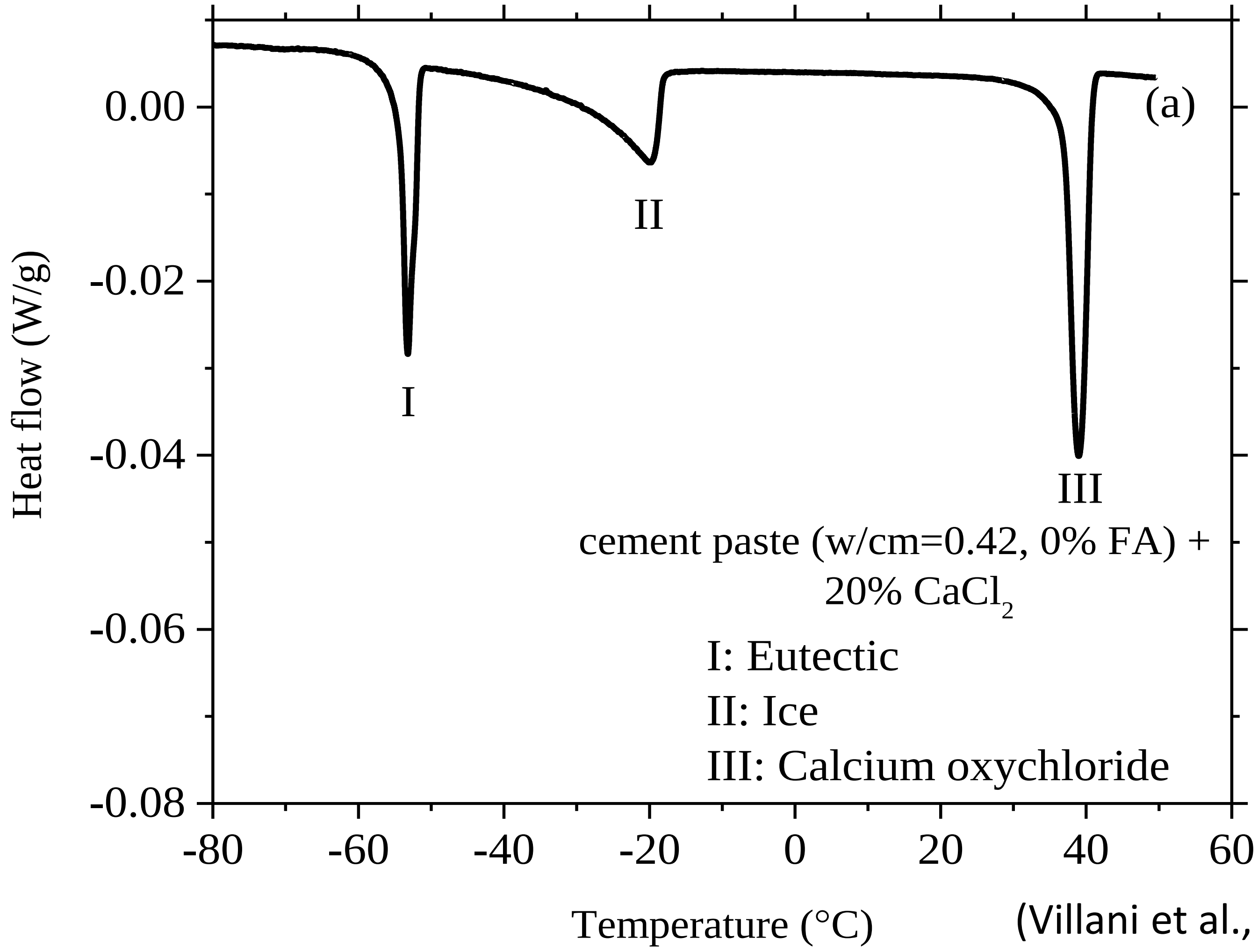
- Cement paste is ground and placed in a salt solution.
- Pan is moved into the cell.
- Thermal Cycle to cause CaOxy to form and we can quantify using heat





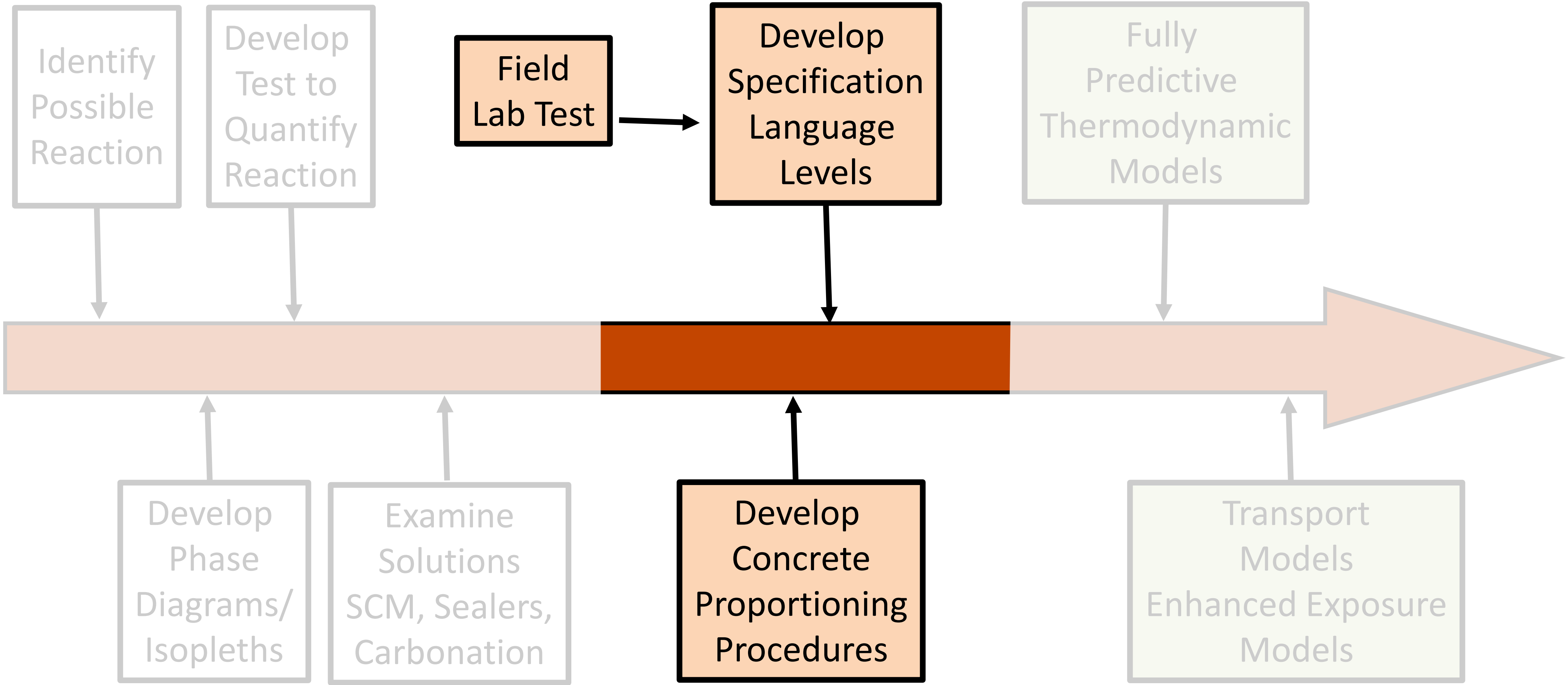
Results - AASHTO T365

– Temperature is decreased from 50 °C to -80 °C, the sample is then re-heated
– Uses powder with $CaCl_2$
– Notice heat flow peaks at various phase formations
– Recently extended to mortar and concrete



(Villani et al., 2014)

Overall Timeline



Designing Mixtures

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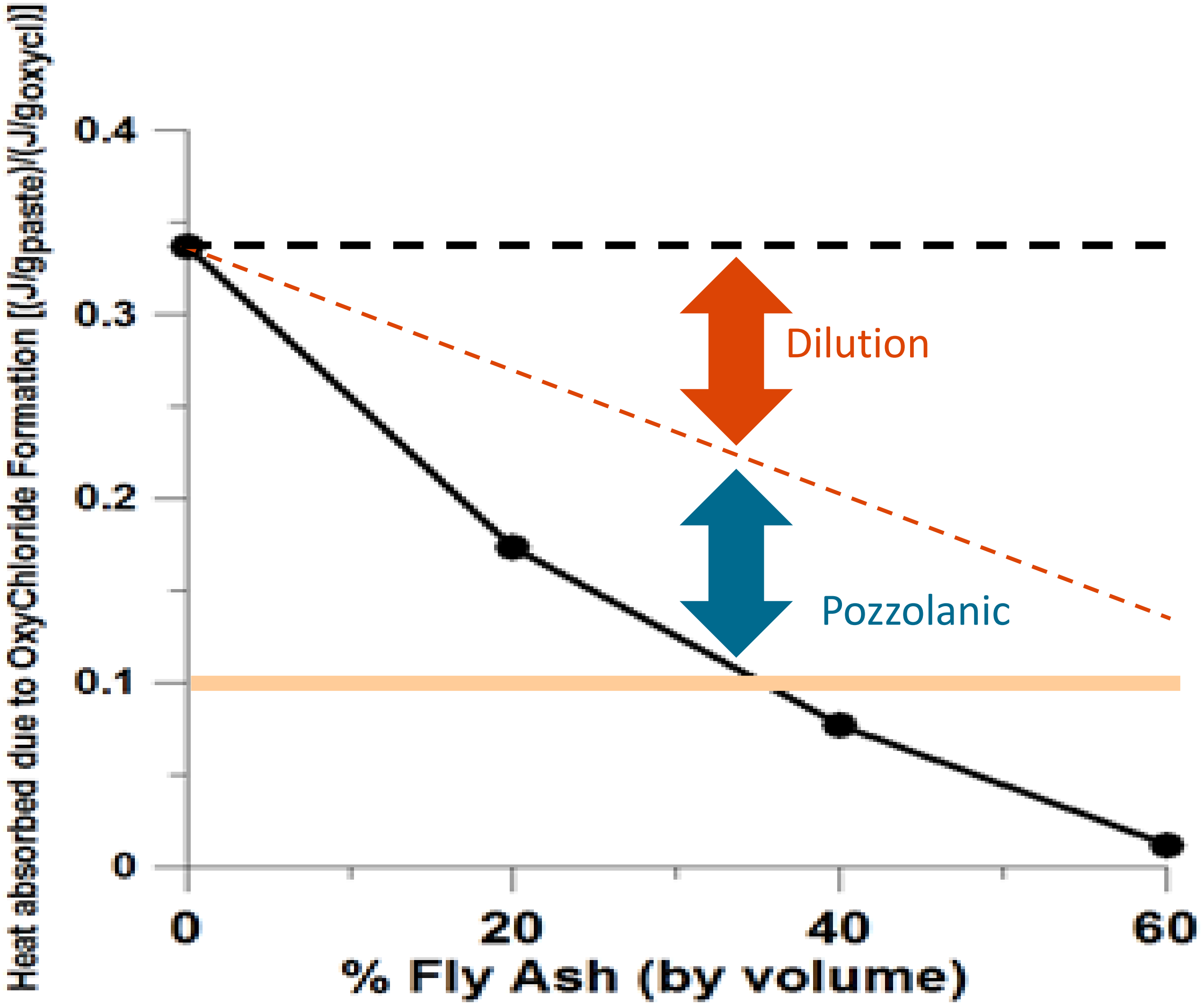
- Effect of Dilution (Less CH)
- Effect of Reaction (Less CH)
- Limiting Factor
- Mixture Design



Monical et al. 2016

Mixtures Considered

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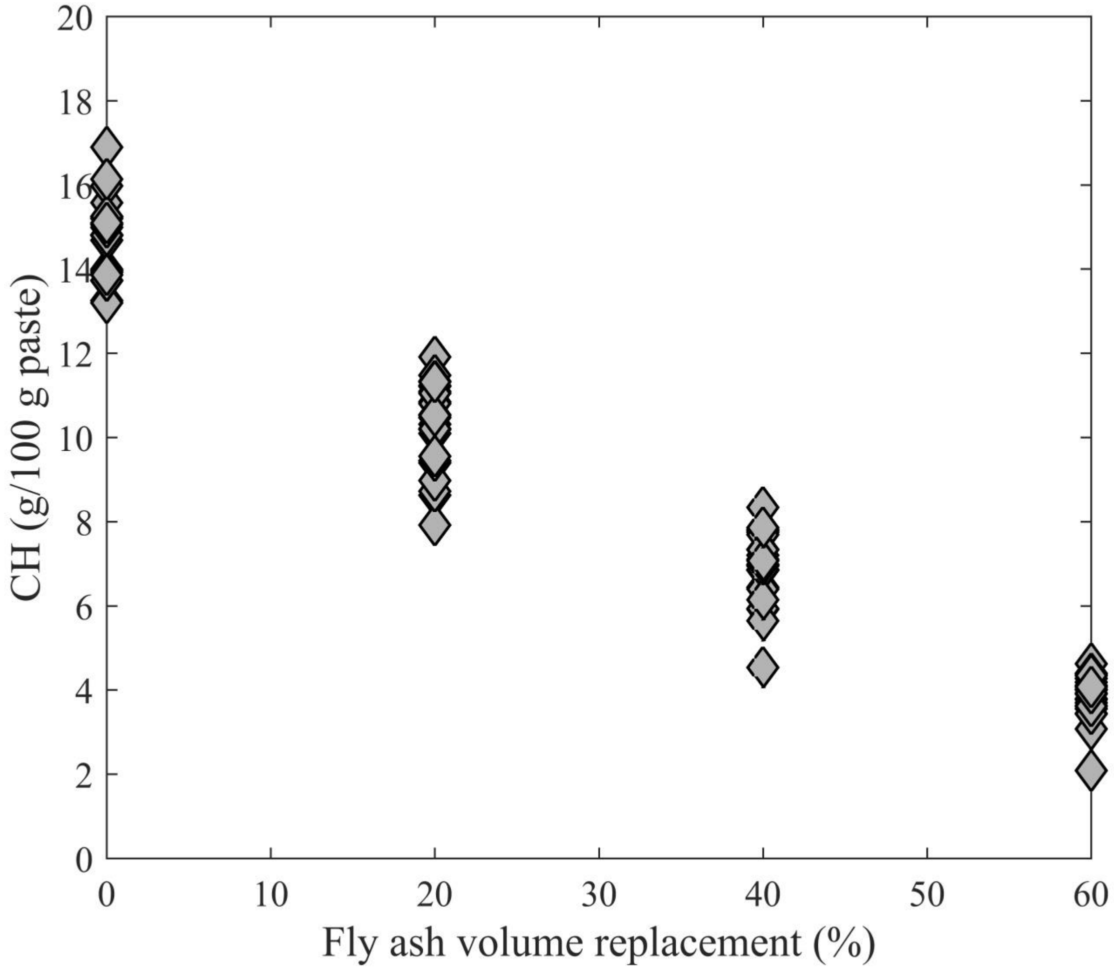
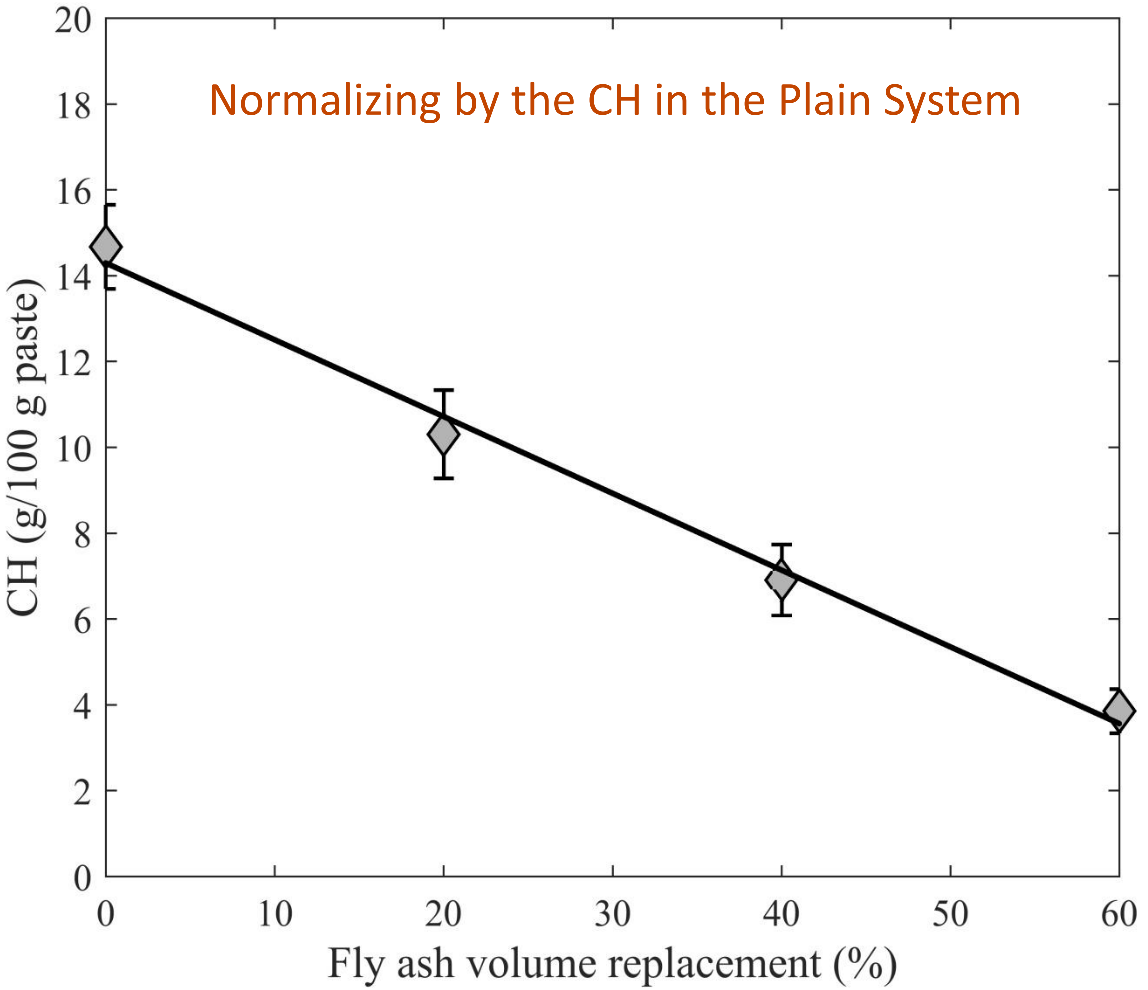
- 0, 20, 40, 60% Fly Ash Repl.
- 0.36 w/cm used (can be varied)
- '91 day equivalent hydration'

State	Name	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	Alkali
Kansas	FA1	15.9	54.4	19.3	5.7	2.2	1.57
Manitoba	FA2	9.4	57.0	23.3	3.5	0.1	2.78
Michigan	FA3	17.4	36.5	20.0	5.5	2.9	7.83
Michigan	FA4	17.0	42.1	21.8	7.8	1.8	2.09
Minnesota	FA5	–	–	–	–	–	–
Minnesota	FA6	–	–	–	–	–	–
Nebraska	FA7	8.7	54.5	22.9	4.8	0.4	1.97
Nebraska	FA8	8.7	54.5	22.9	4.8	0.4	1.97
Nebraska	FA9	13.0	54.9	20.2	6.6	0.6	1.17
North Dakota	FA10	13.2	53.1	16.4	6.0	0.6	3.49
Oregon	FA11	13.0	47.3	16.5	6.1	0.9	0.88
South Dakota	FA12	12.4	52.6	16.5	6.0	0.6	3.72
South Dakota	FA13	11.0	52.7	21.2	6.5	0.6	0.56
Virginia	FA14	–	–	–	–	–	–
West Virginia	FA15	–	–	–	–	–	–
Average	–	12.7	50.9	20.1	5.7	1.0	2.55

State	Name	Type	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	Alkali
Illinois	C1	–	–	–	–	–	–	–
Illinois	C2	–	–	–	–	–	–	–
Indiana	C3	I/II	62.7	20.0	5.1	3.4	3.6	0.51
Indiana	C4	I/II	63.3	19.8	4.9	3.5	2.7	0.51
Indiana	C5	I/II	64.3	19.6	4.4	3.2	3.5	0.50
Kansas	C6	I/II	62.6	20.3	4.3	2.9	2.7	0.57
Manitoba	C7	GU	62.3	19.5	5.1	3.3	3.9	0.60
Michigan	C8	I	64.2	19.4	4.9	2.9	2.8	0.59
Michigan	C9	I/II	64.1	19.9	4.3	3.2	3.5	0.55
Michigan	C10	I/II	61.2	19.9	5.3	3.3	3.7	1.09
Minnesota	C11	I/II	63.5	19.2	4.5	3.2	3.5	0.52
Minnesota	C12	–	–	–	–	–	–	–
Nebraska	C13	I/II	62.7	20.1	4.3	2.8	–	0.29
Nebraska	C14	I/II	63.5	19.9	4.3	3.1	3.4	0.52
Nebraska	C15	I/II	64.7	22.3	4.5	3.3	2.7	0.54
Nebraska	C16	I/II	63.8	21.2	4.7	3.4	2.9	0.57
North Dakota	C17	I/II	63.3	20.1	4.8	3.1	3.1	0.55
North Dakota	C18	I/II	64.0	20.6	3.8	3.2	2.2	0.25
North Dakota	C19	I/II	55.6	16.9	3.1	2.5	4.0	–
North Dakota	C20	I/II	62.9	19.6	4.6	3.1	3.2	0.53
Oregon	C21	I/II	63.7	20.2	4.7	3.3	3.1	0.56
South Dakota	C22	I/II	63.0	20.2	4.5	3.3	3.3	0.56
South Dakota	C23	I/II	64.4	20.9	4.3	3.2	2.8	0.52
Virginia	C24	–	–	–	–	–	–	–
West Virginia	C25	I	62.5	19.7	4.9	3.1	3.1	0.73
Average	–	–	63.0	20.0	4.5	3.1	3.2	0.55

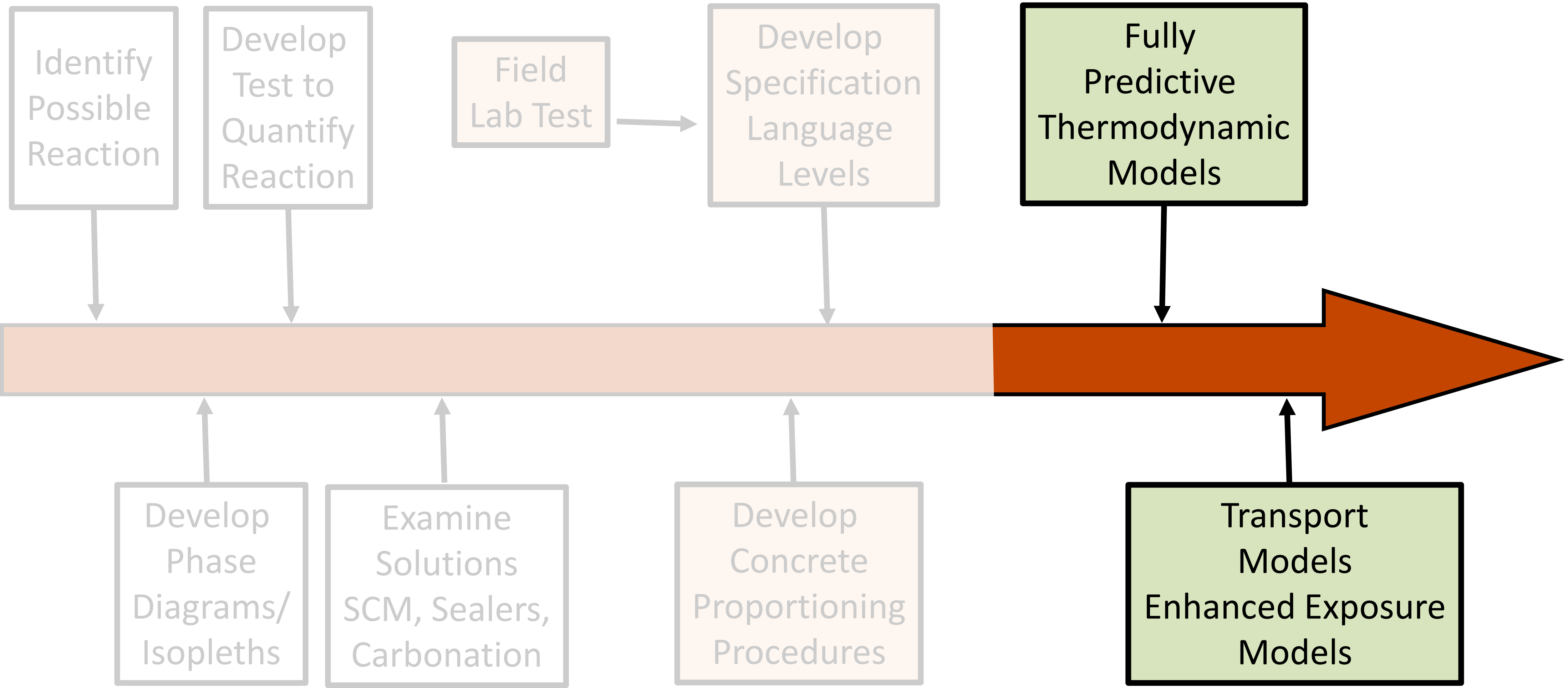
Results from Tests





Suraneni et al., 2016

Overall Timeline



Thermodynamic Model

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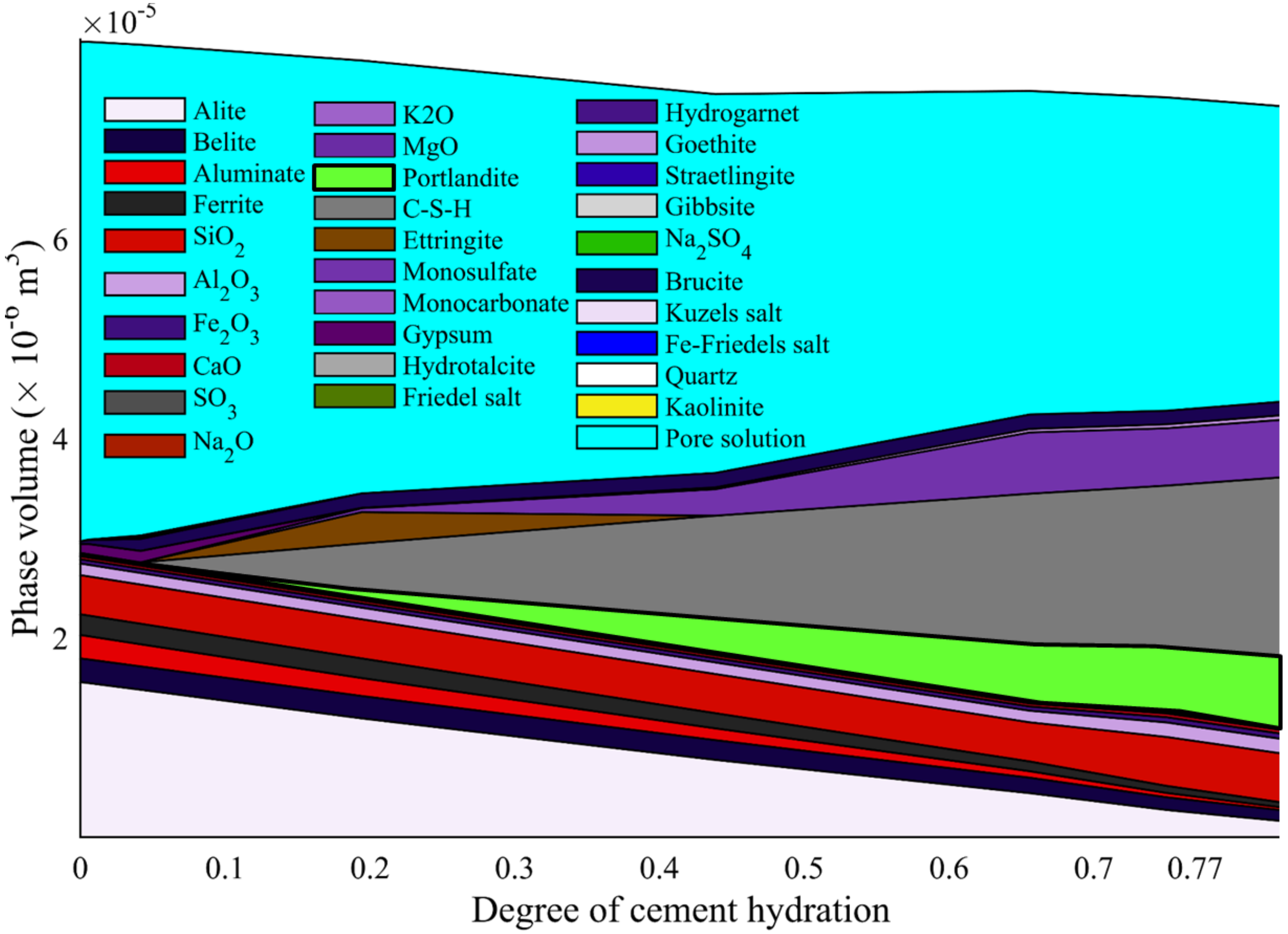
- Using GEMS to predict the reacted products
- Specifically examining the CH production



Azad et al. 2016

Reactivity is Important

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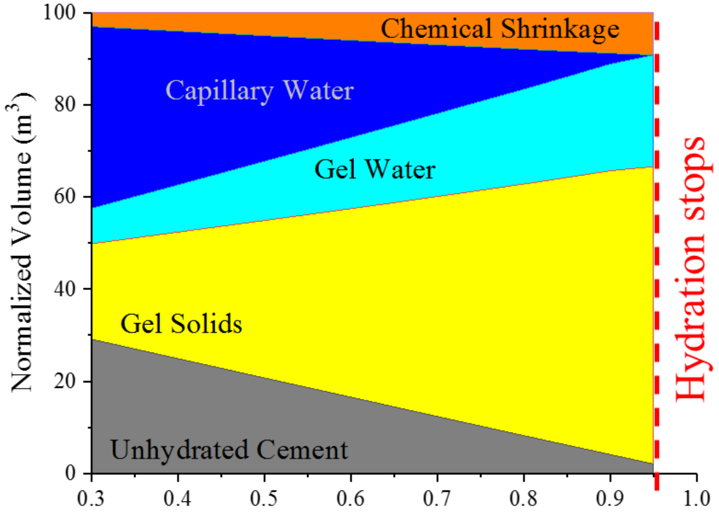
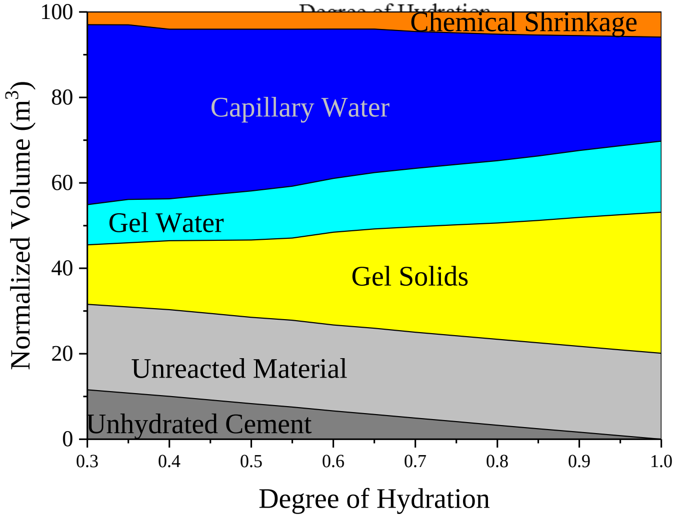
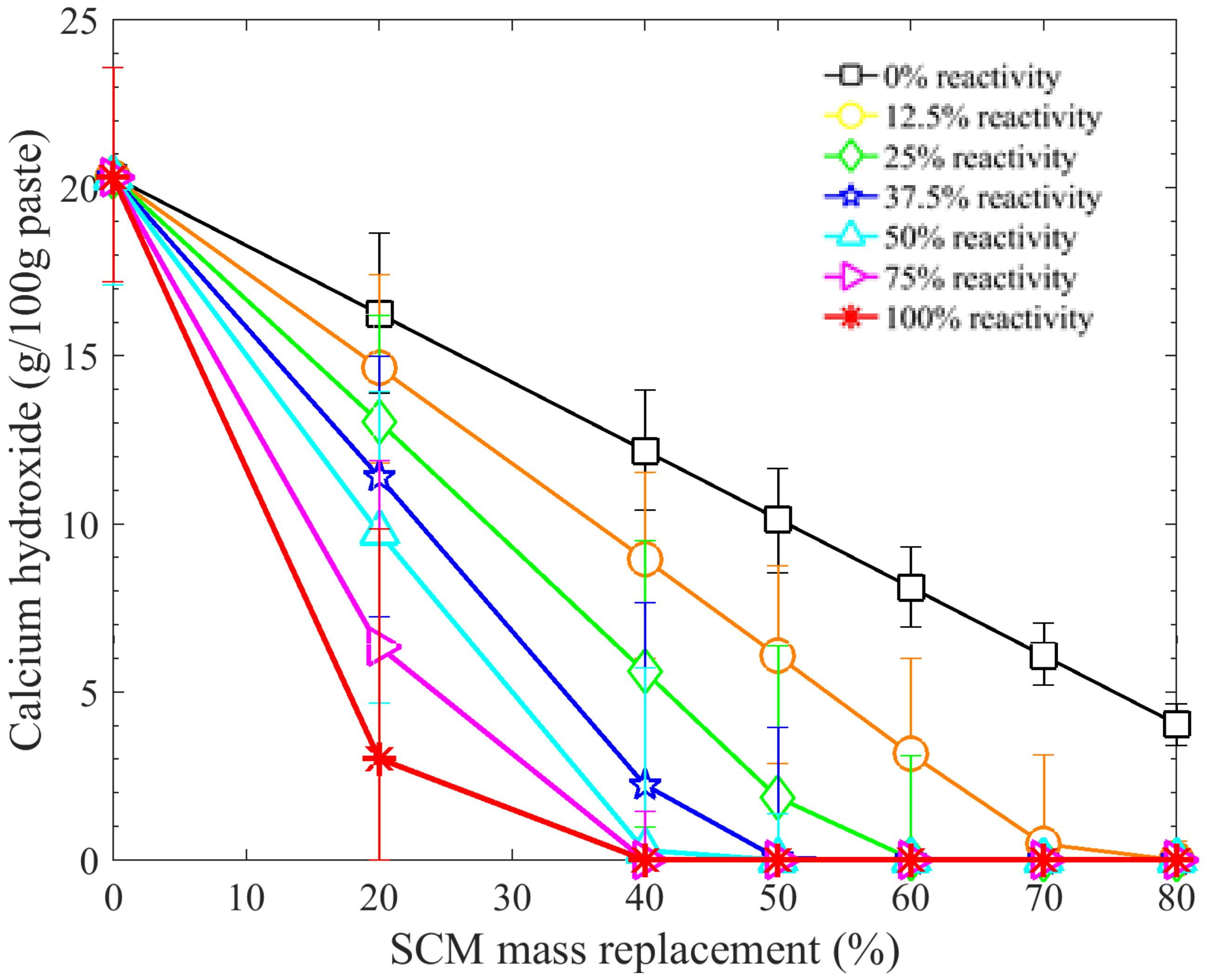


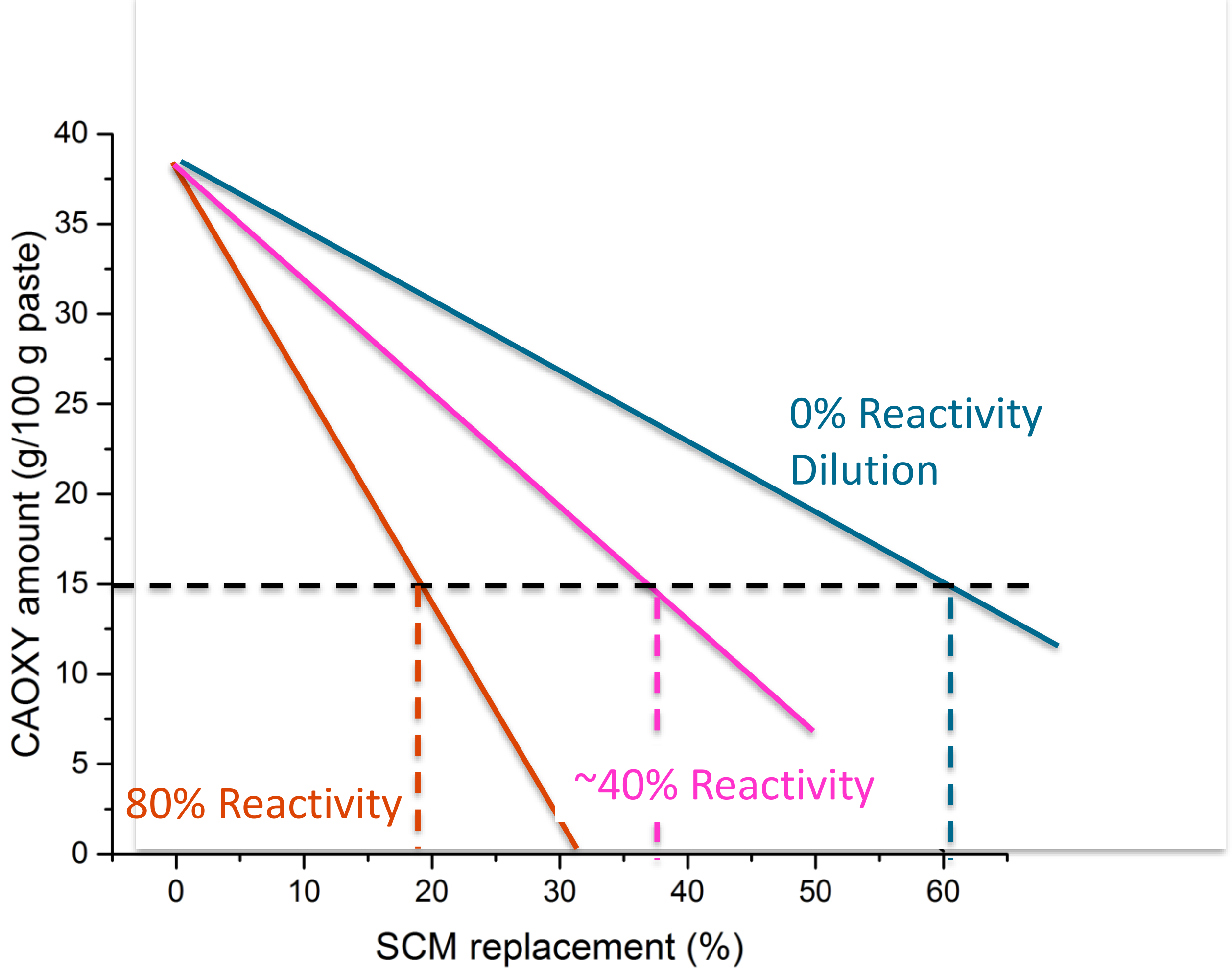




Azad et al. 2018

Examining Reactivity Practical Application

- To the right we see materials that would have a reactivity between 0 and 80%
- As a result it appears that the reactivity of a material may be able to be used to describe its efficiency



Key Point

- The reactivity of the SCM needs to be known
- As a result we are suggesting the use of two simple test methods to quantify performance
- Propose two simple tests that can be done as a qualification of the SCM-Cement System (Not daily QC/QA testing, rather at the time of qualification)

Approach Taken Here

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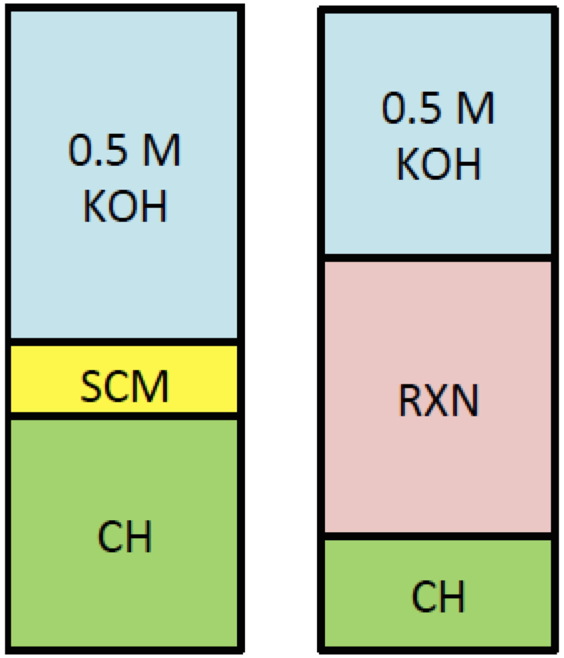
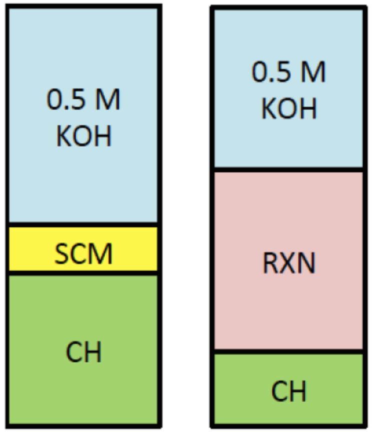
- Similar to that used by Snellings and Scrivner 2015 and the RILEM working group
- Simulating aspects of the environment in concrete
- We will be using two approaches to detect the reactivity of SCMs
  - Isothermal Calorimetery
  - Thermogravimetric Analysis
- Compare these results with Thermodynamic simulations



Test method

- CH/SCM = 3: 1 (by mass)
- 0.5 M KOH solution
- w/s = 0.9
- Temperature = 50 °C
- Measure heat release by IC and CH consumption by TGA for various SCMs
- Bound water and changing test conditions being evaluated, not discussed here



Examining Reactivity Practical Application

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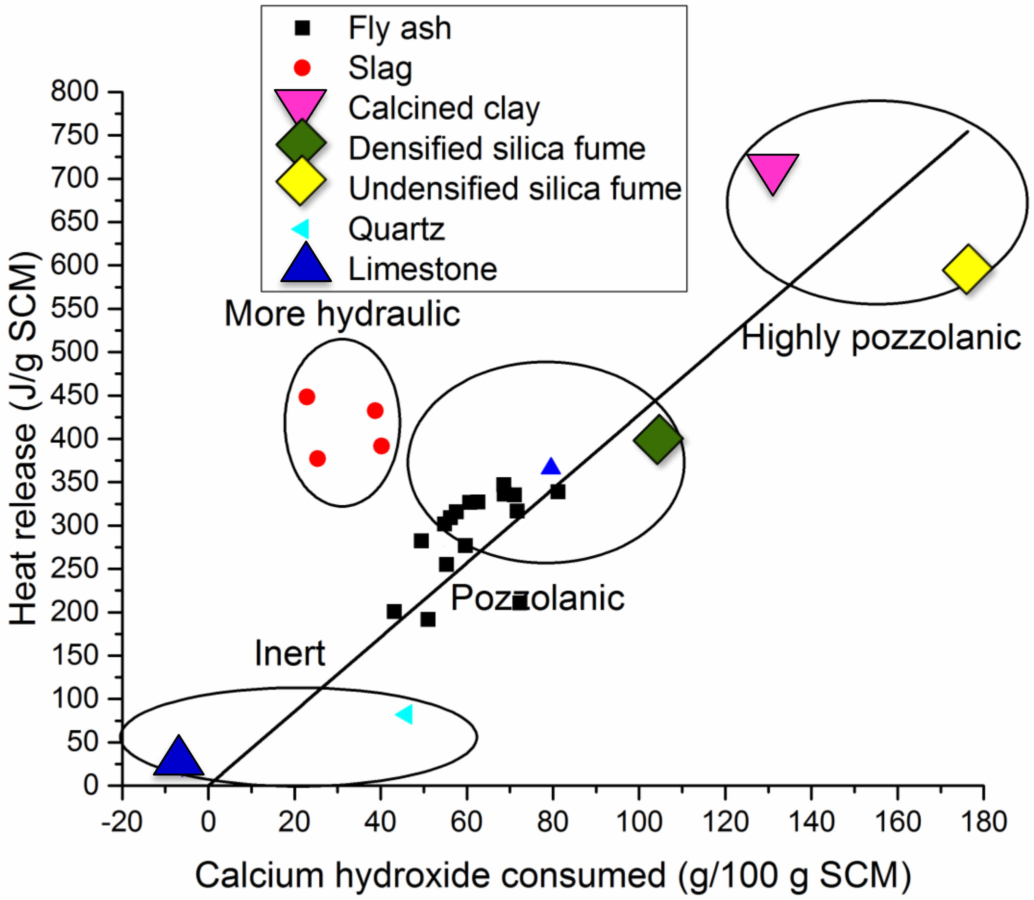

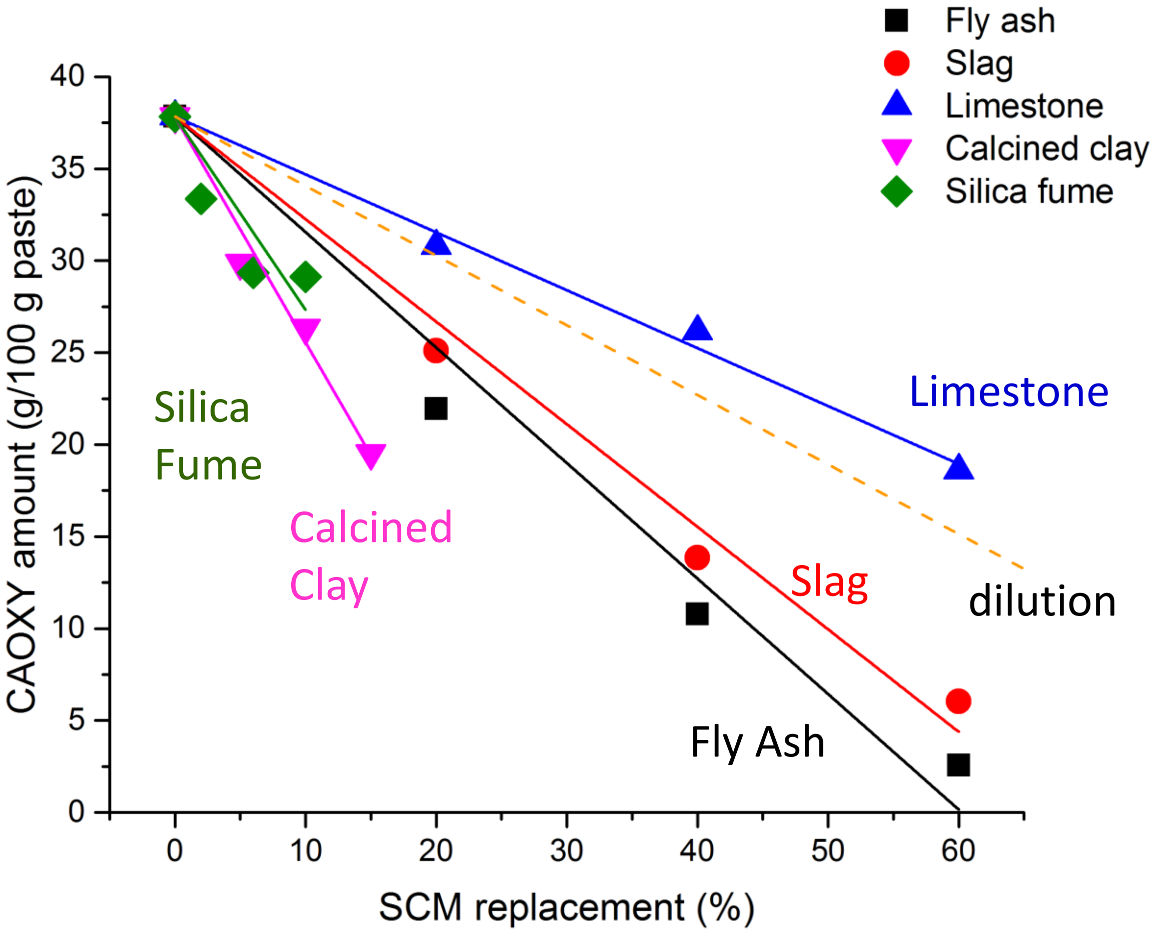

Suraneni et al. 2018

Extending the Model to Other US Cements

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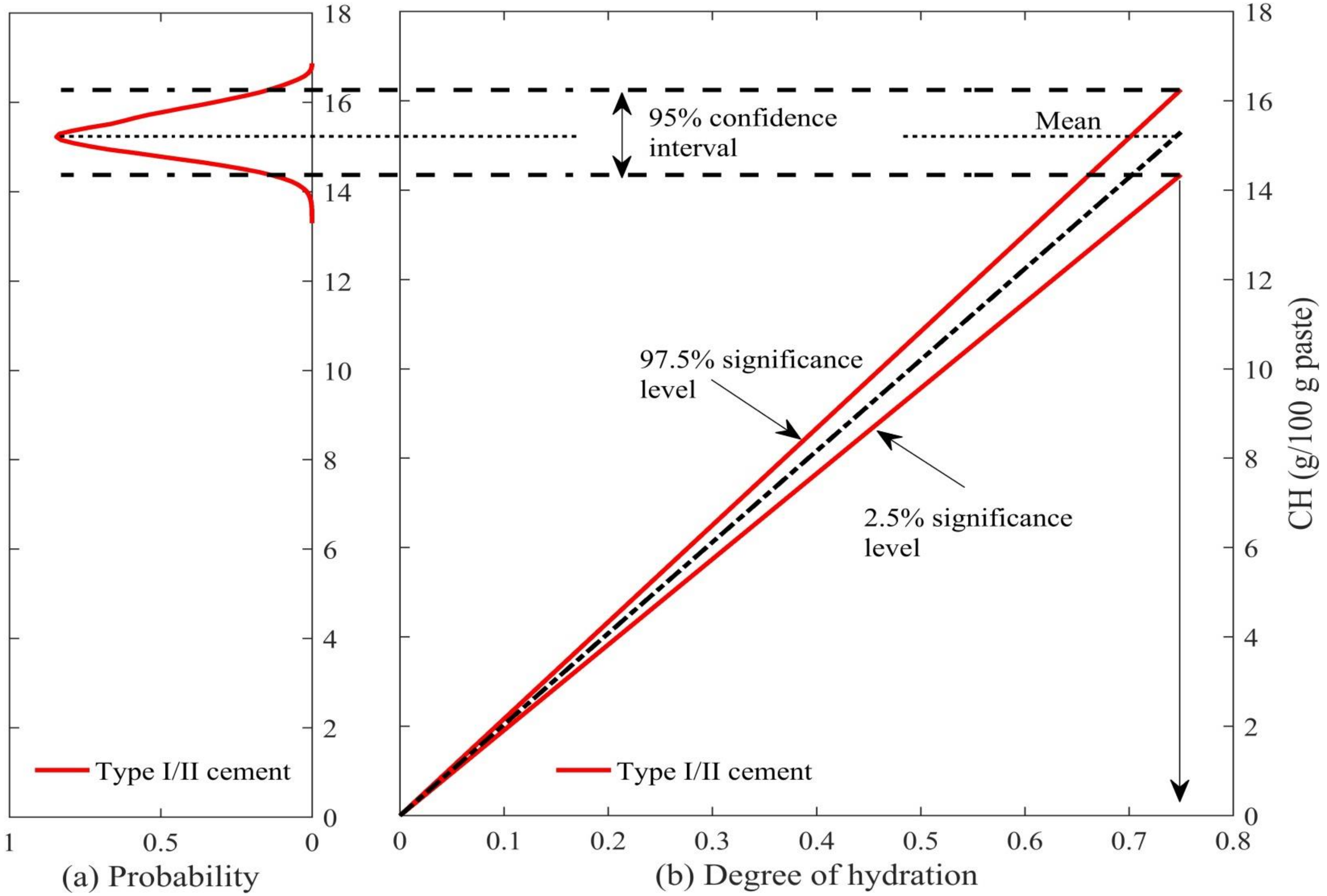

Suraneni et al., 2016

CH from the US Database

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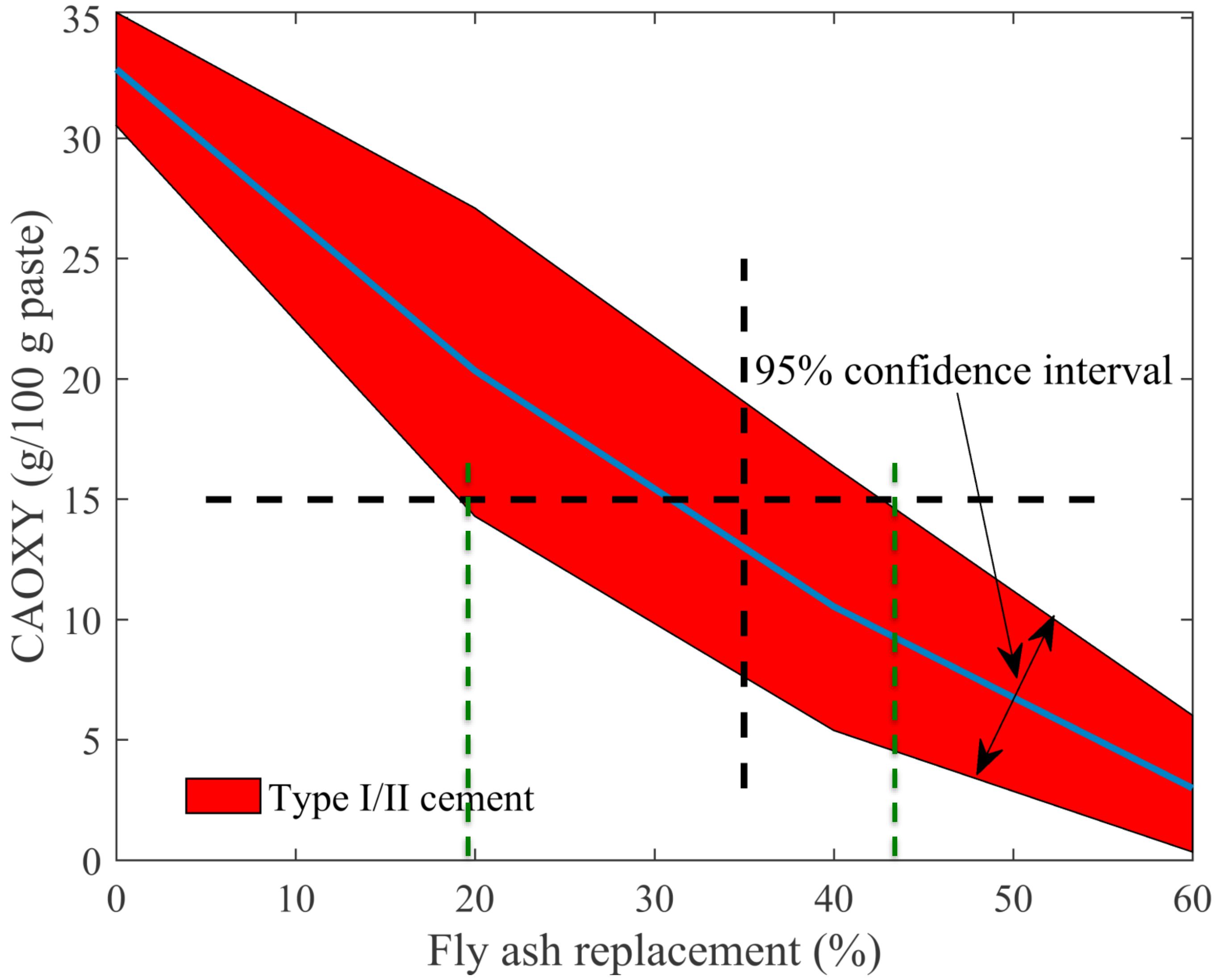

We are currently working hard to relate the damage from the paste test to field observations

Suraneni et al. 2016


Alternative
Approach

How About Carbonation

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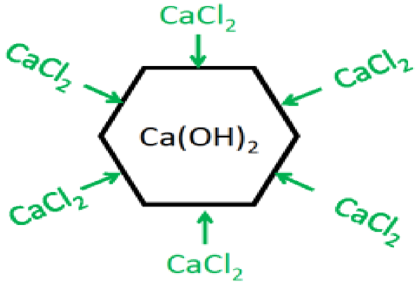
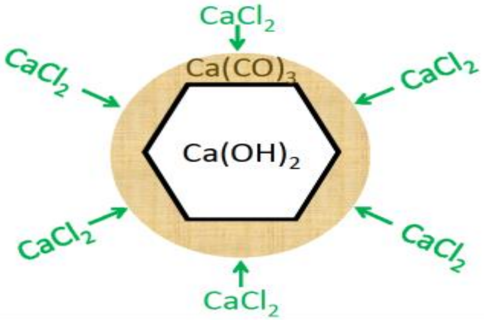
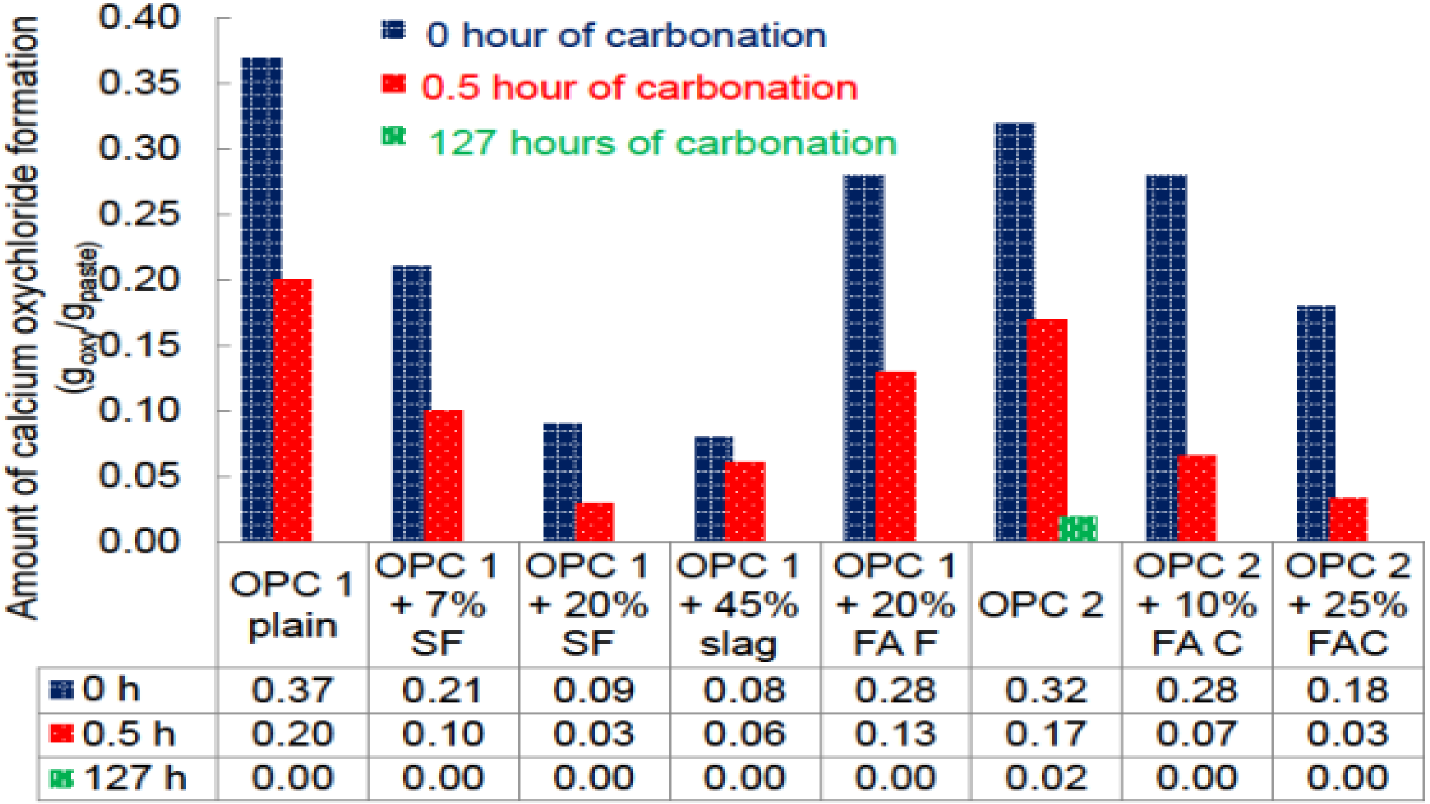


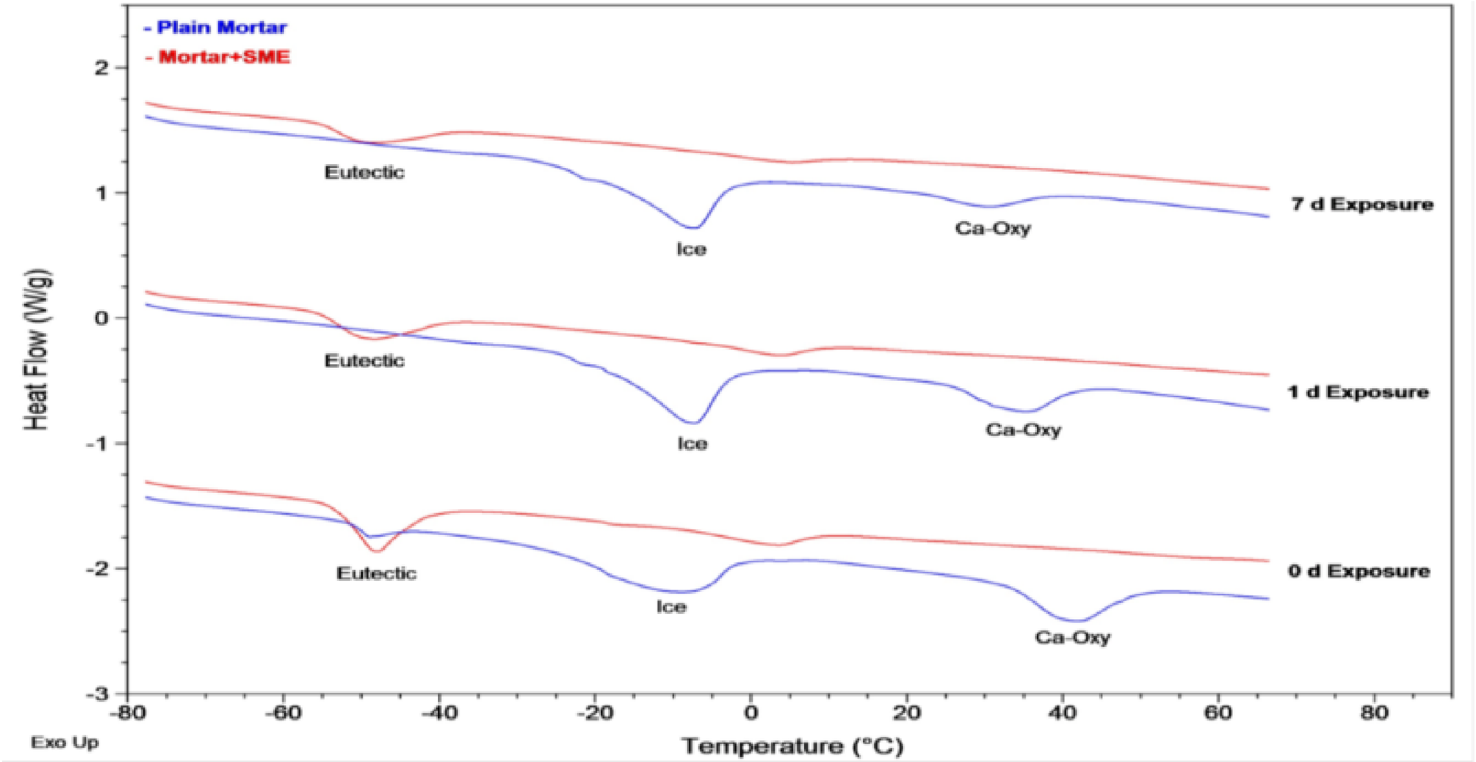




	OPC 1 plain	OPC 1 + 7% SF	OPC 1 + 20% SF	OPC 1 + 45% slag	OPC 1 + 20% FA F	OPC 2	OPC 2 + 10% FA C	OPC 2 + 25% FAC
0 h	0.37	0.21	0.09	0.08	0.28	0.32	0.28	0.18
0.5 h	0.20	0.10	0.03	0.06	0.13	0.17	0.07	0.03
127 h	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00

Ghantous et al. 2016

Topical Treatments



(Wiese 2015)

Summary

- We know a lot more about what is responsible for joint damage and we can design to prevent damage
- Mixture designs should consider the use of SCM for paving mixtures and flatwork exposed to salts (topical, CO_2)
- The reactivity test method has the potential to be utilized as a surrogate for AASHTO T365 as a way to determine the volume of SCM that could be utilized
- We need to provide more guidance in ACI 318 on the SCM limits as this may not apply for low slump/scale mixtures