Premature Joint Deterioration in Concrete Pavements
And Methods to Prevent It

Jason Weiss, Edwards Distinguished Professor, Oregon State University
Abstract

• 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

- 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

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

Weiss 2008

Weiss 2005

Taylor 2013

Weiss 2005

Weiss 2005
Ideal Pavement Joint

Weiss and Nantung 2005
Pavement Joint Issue

Weiss and Nantung 2005
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

• Increase in Water Ingress
  – Increases saturation

• Increase in Salt Damage
  – Increase in potential reactions
Critical Saturation Based Approach

• 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

Increasing Air

Decreasing Air

Mass of Water Absorbed

Square Root of Time
Two Primary Factors Contributing to Premature Damage

• 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

- 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

- Concentration (Mass %)
- RH (%)
- Volume of Pores
- Relative Humidity

- NaCl
- CaCl$_2$
- MgCl$_2$ (c)

With Salt Solution
With Water

Fixed RH Atmosphere

Water
Salt Solution

RHeq
‘Drying’ with Salts

- Drying doesn’t occur to RH_{EQ} is reached
Reducing Joint damage

- Identify Possible Reaction
- Develop Test to Quantify Reaction
- Field Lab Test
- Develop Specification Language Levels
- Fully Predictive Thermodynamic Models

- Develop Phase Diagrams/Isopleths
- Examine Solutions SCM, Sealers, Carbonation
- Develop Concrete Proportioning Procedures
- Transport Models Enhanced Exposure Models

Final Model Step
Reducing Joint Damage

- Identify Possible Reaction
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Pavement Joints

- 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

\[
3\text{Ca(OH)}_2 + \text{CaCl}_2 + 12\text{H}_2\text{O} \rightarrow 3\text{Ca(OH)}_2 \cdot \text{CaCl}_2 \cdot 12\text{H}_2\text{O}
\]

Calcium Oxychloride
Classic CaCl$_2$ – H$_2$O Phase Diagram

- 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
\[ \text{CaCl}_2 - \text{H}_2\text{O} - \text{Ca(OH)}_2 \]

Phase Isopleth

- Unfortunately however when we are working with cementitious systems we need to also consider the calcium hydroxide.

- CaOxy is traced out and exhibits a 303% vol change.

\[ 3\text{Ca(OH)}_2 + \text{CaCl}_2 + 12\text{H}_2\text{O} \rightarrow \text{CaCl}_2 \cdot 3\text{Ca(OH)}_2 \cdot 12\text{H}_2\text{O} \]
Reducing Joint Damage

- Develop Test to Quantify Reaction
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  - SCM, Sealers, Carbonation
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  - Enhanced Exposure Models
- SCM, Sealers, Carbonation
Test - AASHTO T365

- 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

![Diagram](image_url)

- I: Eutectic
- II: Ice
- III: Calcium oxychloride

Villani et al., 2014
Overall Timeline

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Designing Mixtures

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

Monical et al. 2016
Mixtures Considered

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

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Results from Tests

Normalizing by the CH in the Plain System

Suraneni et al., 2016
Overall Timeline

1. Identify Possible Reaction
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9. Develop Solutions SCM, Sealers, Carbonation
10. Develop Phase Diagrams/Isoleths
Thermodynamic Model

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

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

• 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 Calorimetry
  – 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

Heat release (J/g SCM)

Calcium hydroxide consumed (g/100 g SCM)

More hydraulic

Highly pozzolanic

Inert

Fly ash
Slag
Calcined clay
Densified silica fume
Undensified silica fume
Quartz
Limestone

Suraneni et al. 2018
Extending the Model to Other US Cements

Suraneni et al., 2016
We are currently working hard to relate the damage from the paste test to field observations.

Suraneni et al. 2016
How About Carbonation

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.