Thoughts on Early Age Opening

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Pavement/Patch Opening Strength

- For many reasons we can make the argument that we want pavements with lower cement contents and more supplementary materials
- However many times contractors will prefer mixtures that do not embrace this due to other specifications – Opening strength
- Many SHA are dealing with patching in concrete pavements in busy streets and intersections
- Many use overnight closures to remove the damaged concrete, reinstitute the base, install dowels, place the concrete and then reopen to traffic before morning traffic

Opening Criteria

- Many states have aggressive strength requirements before a patch can be opened
- The focus on high early strength leads to mixtures that:
  - Increase cement content
  - Use only OPC (not SCM)
  - Use lower w/cm
  - Use accelerators
  - Not sufficiently cured
  - Strength requirement

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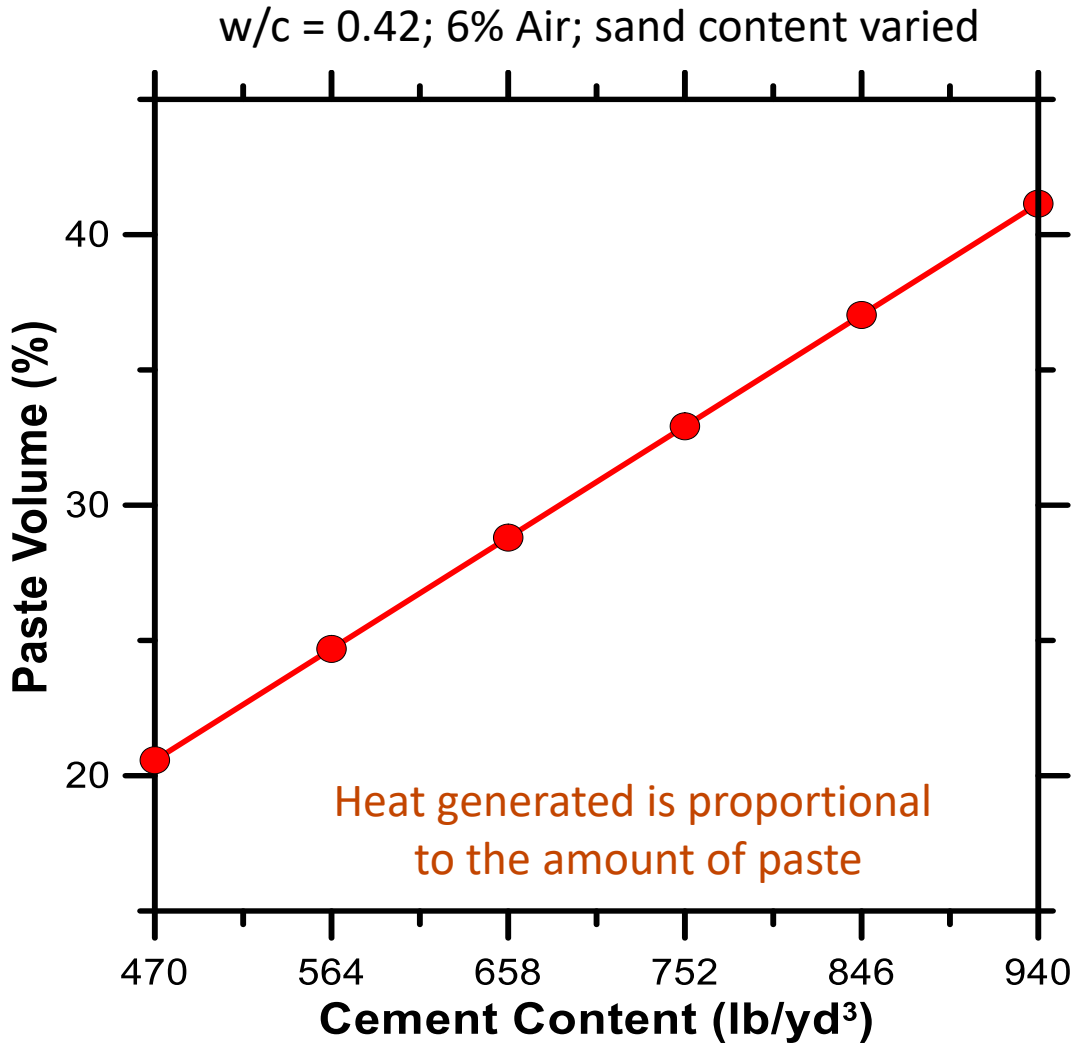
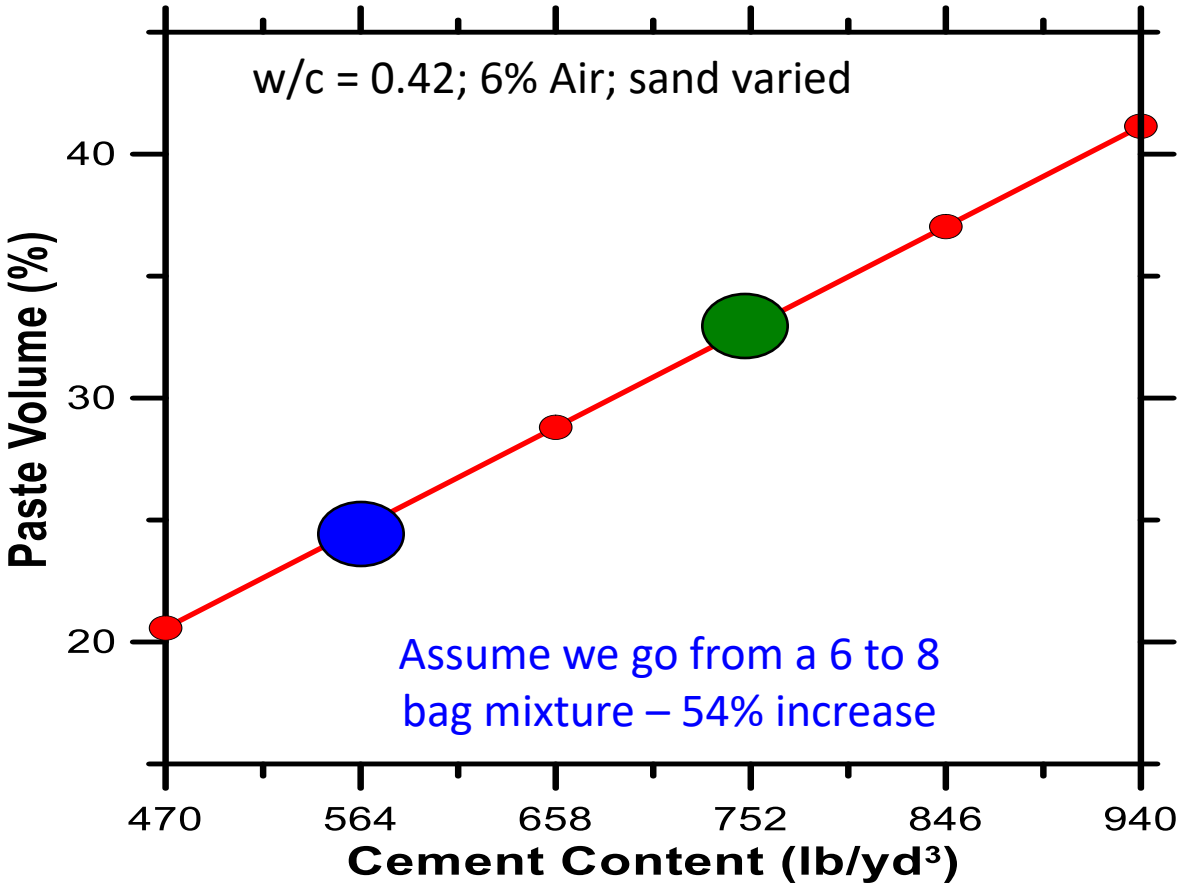
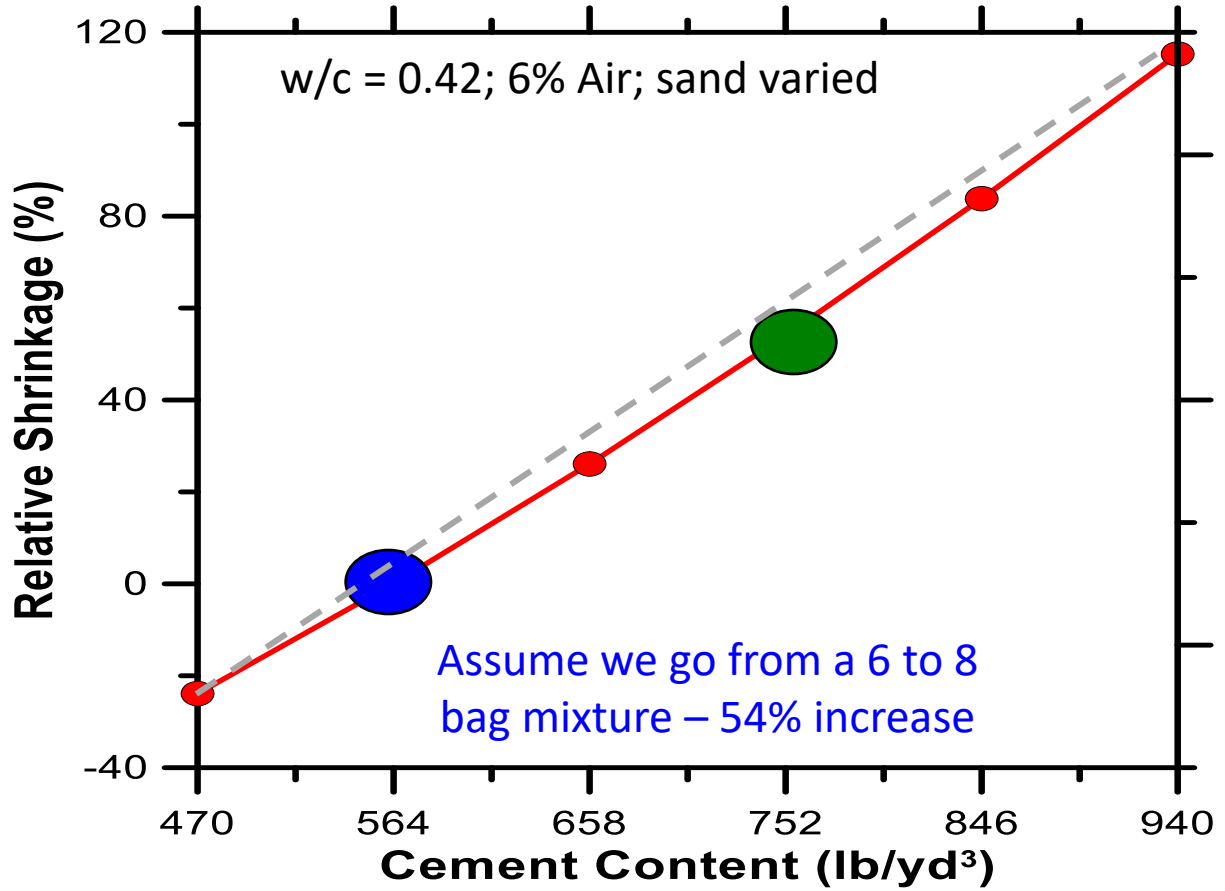
What Happens with High Cement Contents

- As we increase the content of the cement in a mixture three main things happen
- Temperature rises
- Shrinkage cracking potential increases
- Calcium hydroxide volume increases



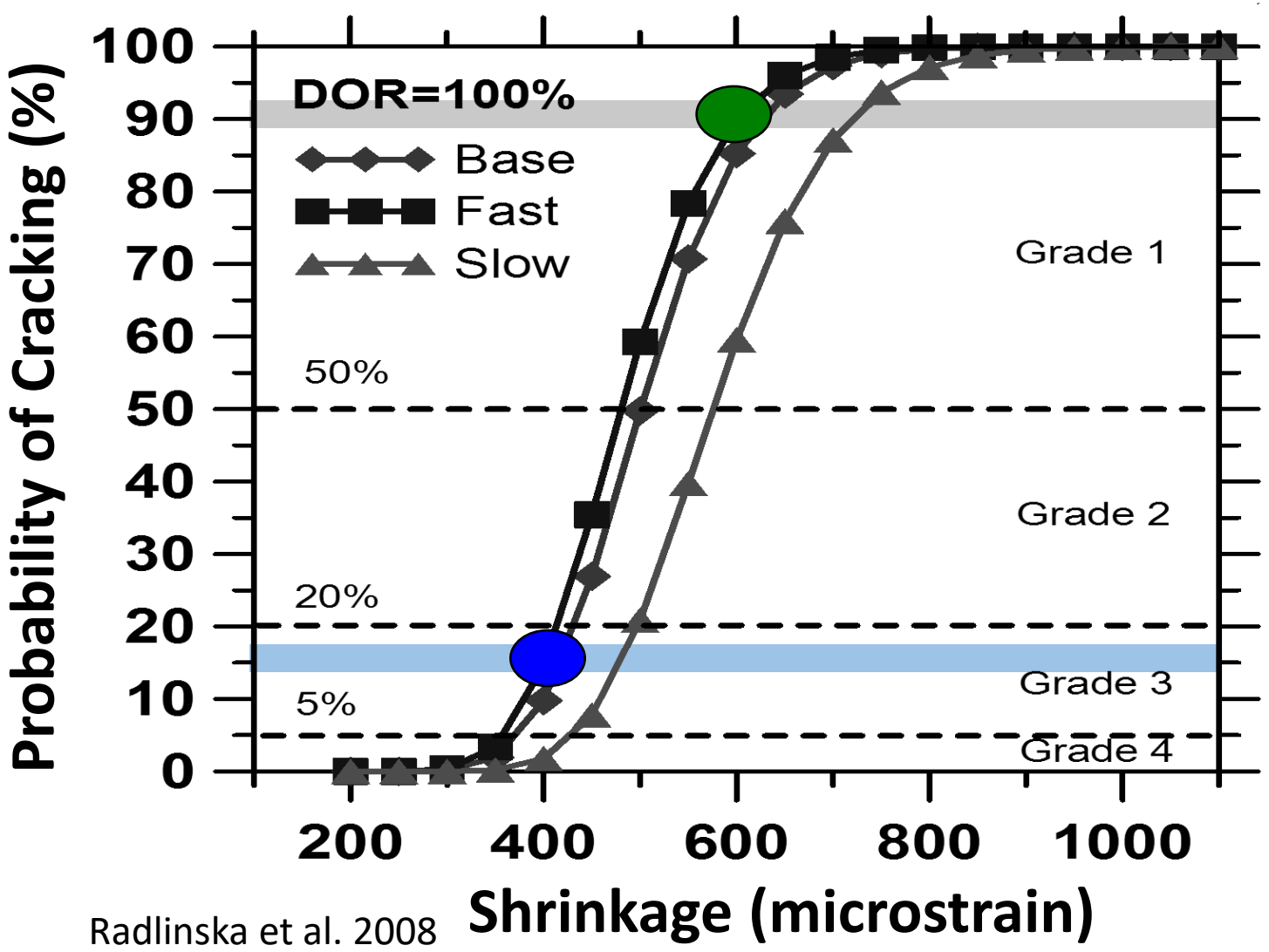
High Cement Contents and Shrinkage/Cracking





How Does a 54% Increase in Shrinkage Relate to an Increase in Cracking

- Assume the 5 bag mixture has a uniaxial shrinkage of 400 με as measured in ASTM C150
- This would have a 15% probability of cracking
- 54% higher would be a shrinkage of 616 με
- The probability of cracking increase to approximately 90%



Radlinska et al. 2008

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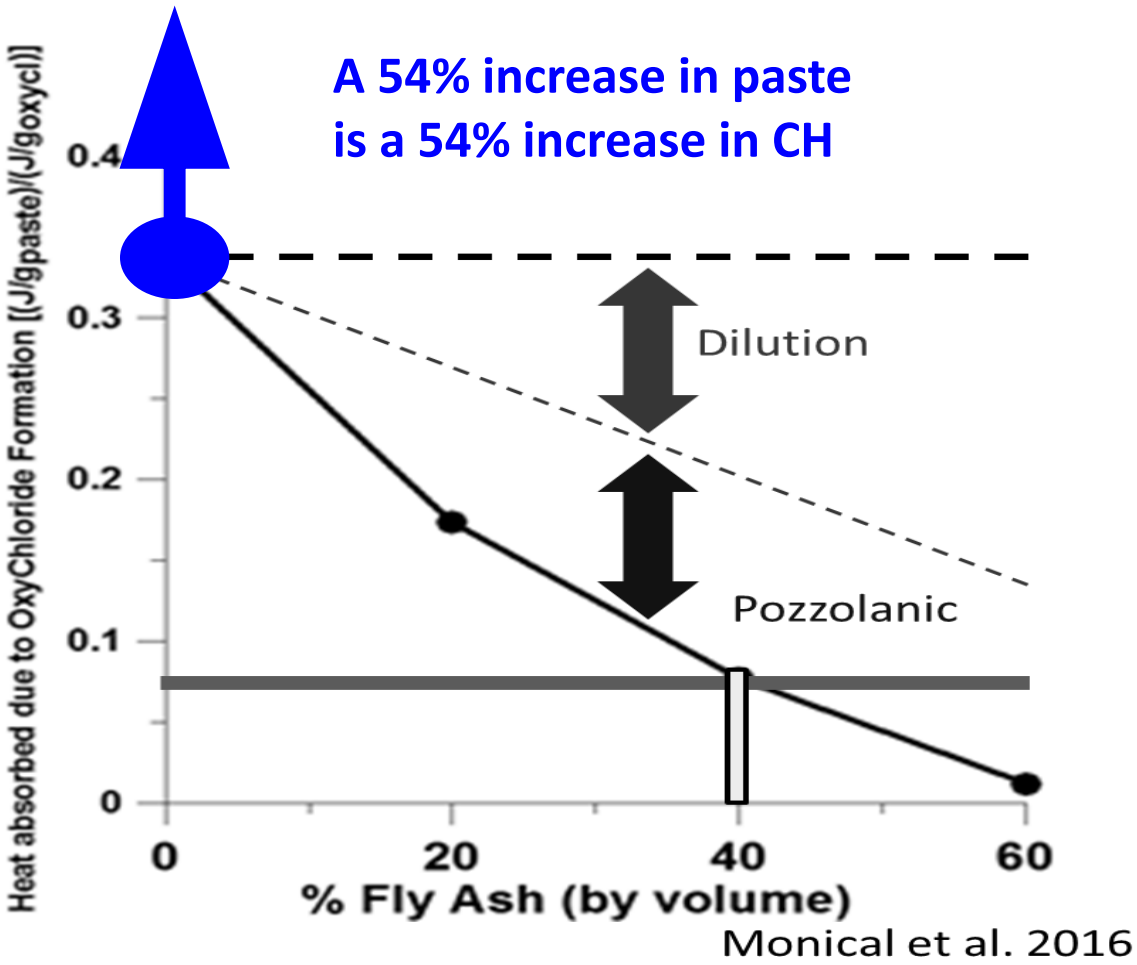
  - Are not sufficiently water cured (or compound cured)

OPC Mixtures with High Cement Contents and Salt Deterioration Issues

- $2C_3S + 7H > C_3S_2H_4 + 3CH$
- As the amount of cement increases so does the amount of calcium hydroxide (CH)
- This would result in a greater potential for calcium oxychloride



Monical et al. 2016

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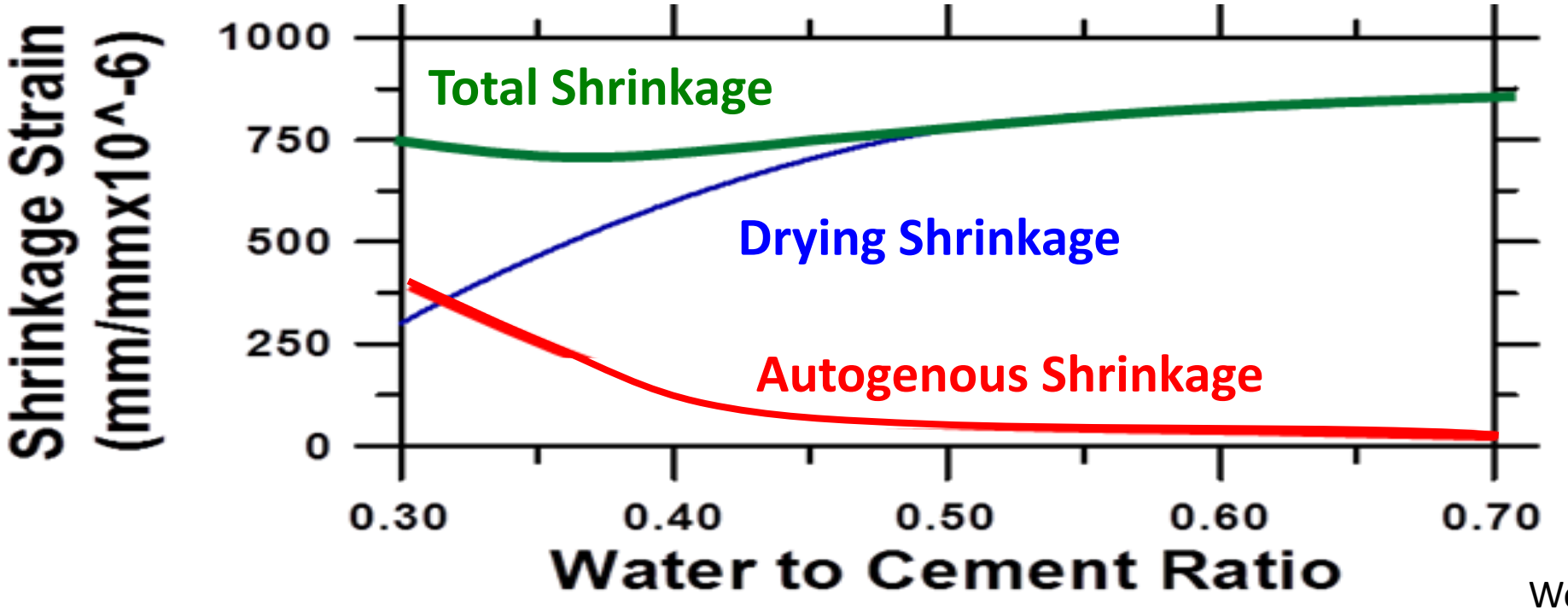
Autogenous Shrinkage Increases

- Autogenous shrinkage occurs without loss of water to the environment and at early ages



Weiss et al. 2006

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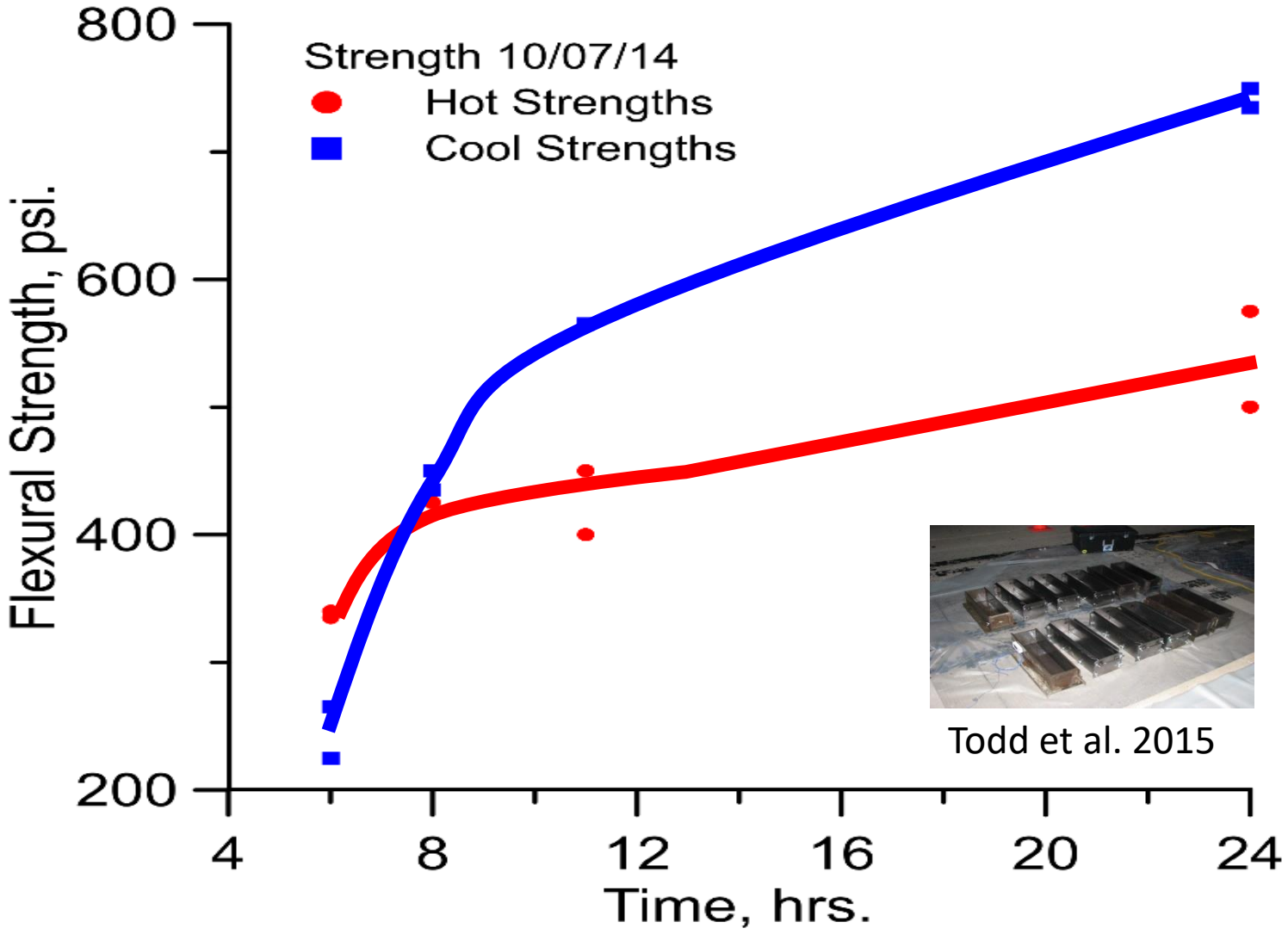
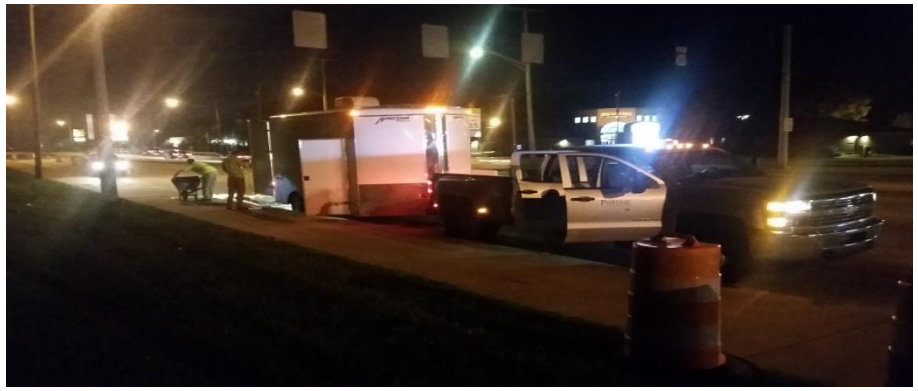
Measured Issues with Strength Gain



Todd et al. 2015

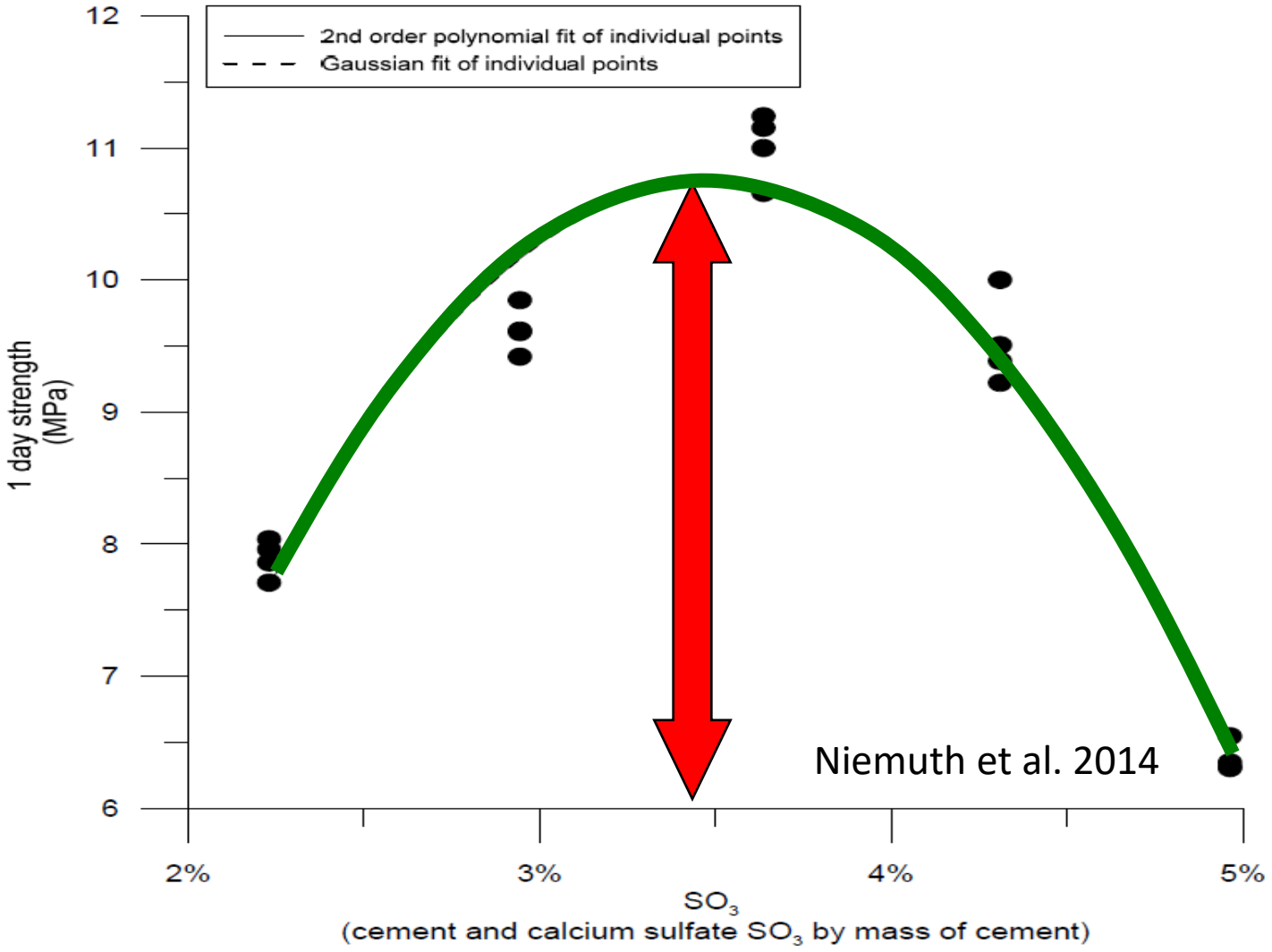


Accelerators and Cement Chemistry

- Calcium Silicates – Main Strength Parameter
- Calcium Aluminates – Fast Reactors
- Accelerators work on either silicate or aluminate reaction
- Sulfate Source – Helps to Control the Reaction of the Aluminates Allowing Transport

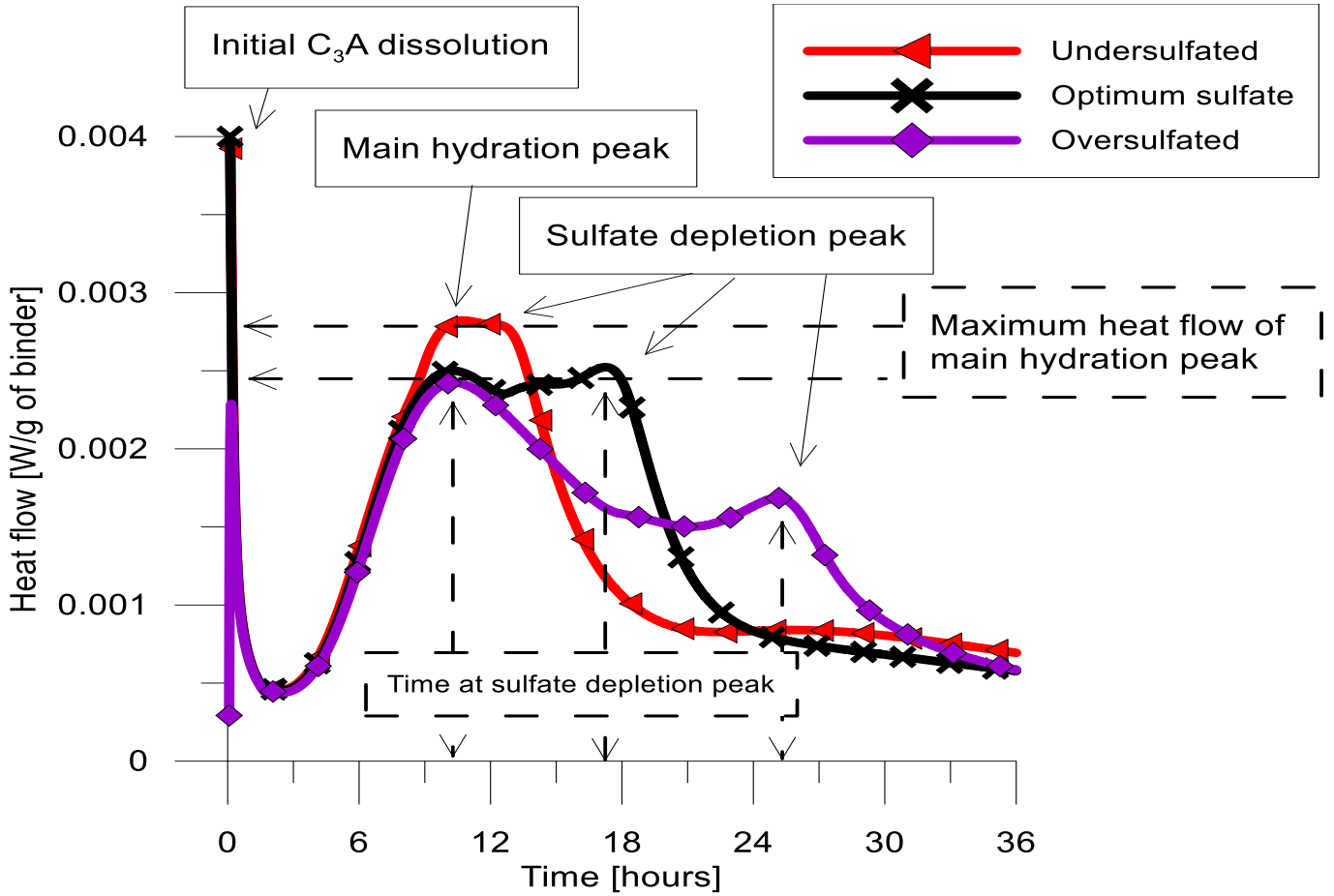
Using 1 Day Compressive Strength

- Peak gives the 'optimal SO_3'
- This however is done at 1 day in terms of compressive strength
- It assumes, no admixtures, only cement, 23C



Optimum from Isothermal Calorimetry

- Optimum is the minimum amount of sulfate needed to have the sulfate depletion peak and the main alite peak clearly distinguishable



Niemuth et al. 2014

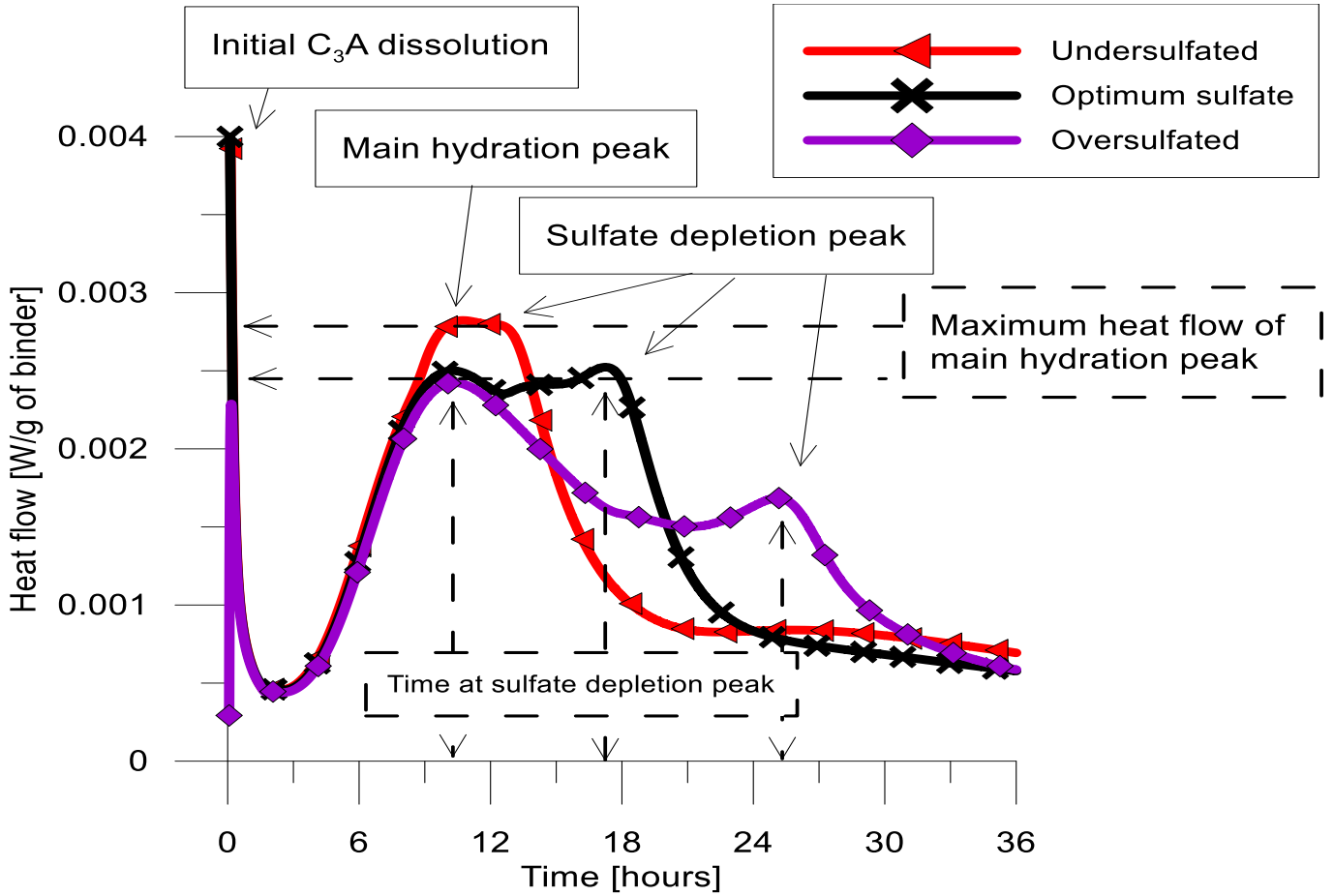
In Patches Things Get Complex

- First, we tend to use accelerators that alter the sulfate balance
- Second, we tend to have temperatures that alter the sulfate balance
- Possible that we ‘poison’ the hydration process

Optimum from Isothermal Calorimetry

- Optimum is the minimum amount of sulfate needed to have the sulfate depletion peak and the main alite peak clearly distinguishable

- The balance can be altered by
  - additions of admixtures
  - high temperature



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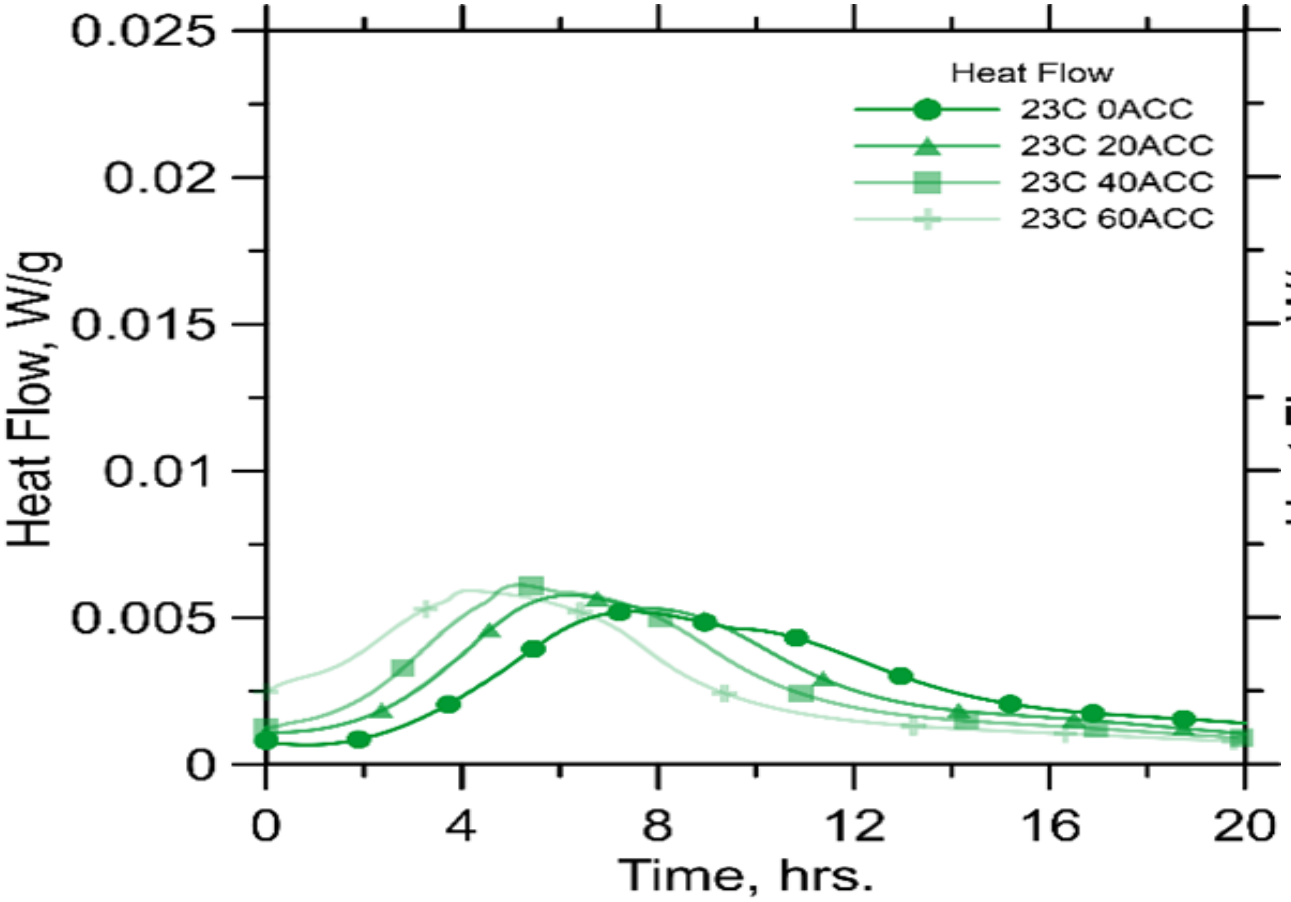
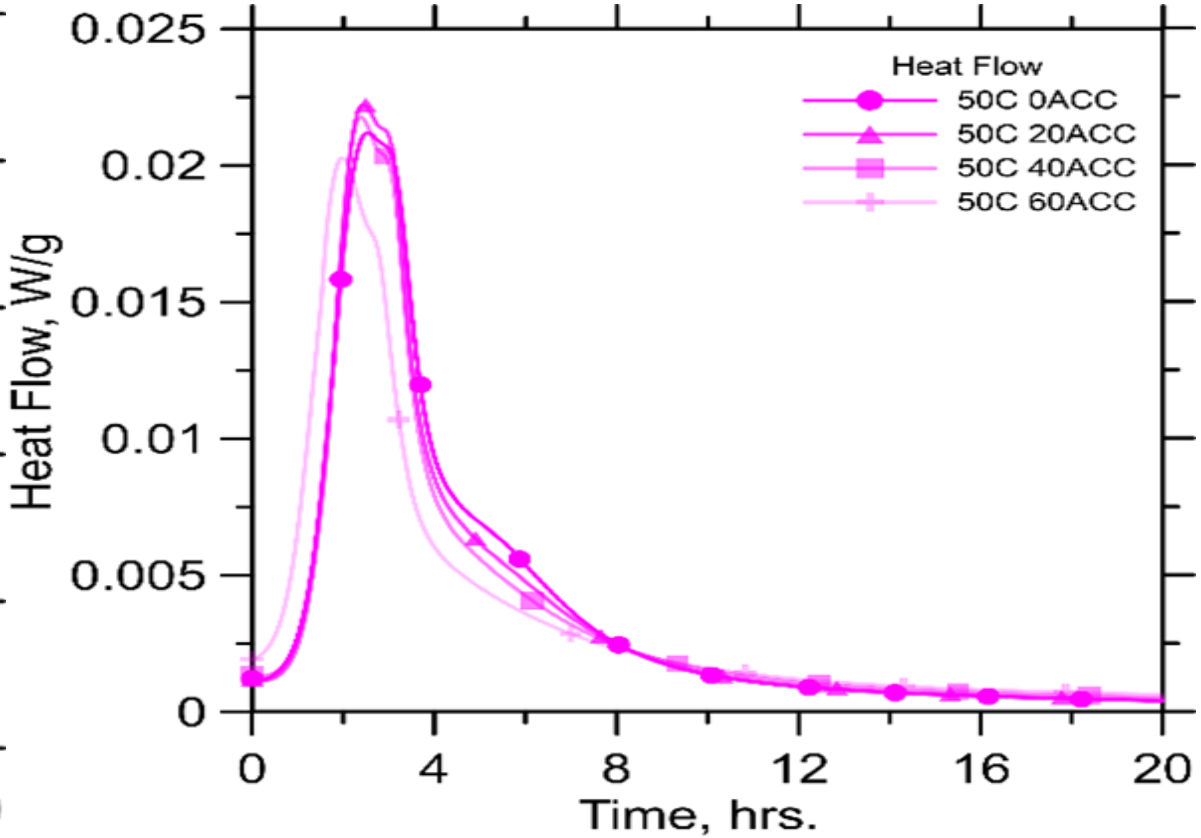
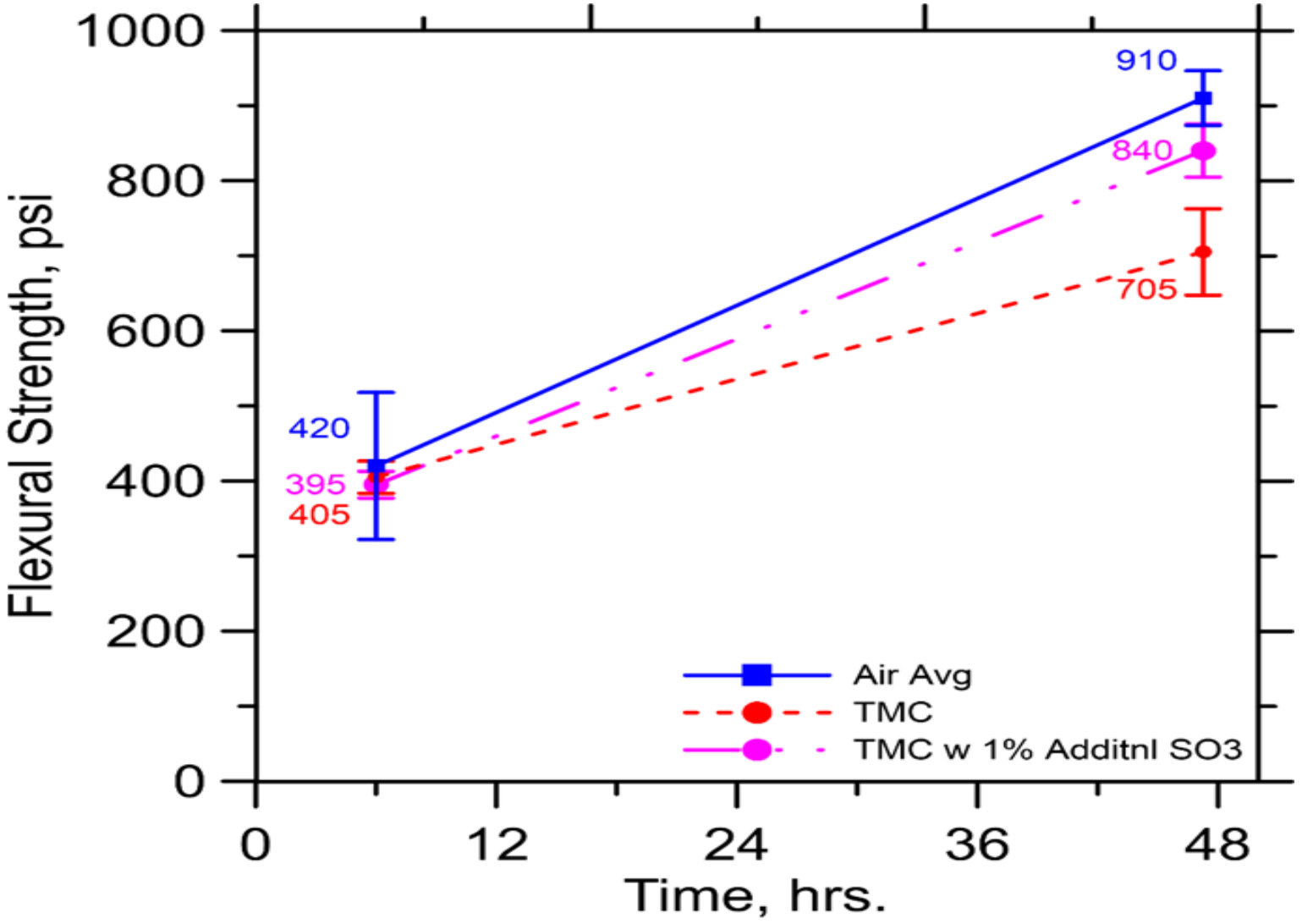
Potential Challenges





Todd et al. 2015

Sulfate Balance



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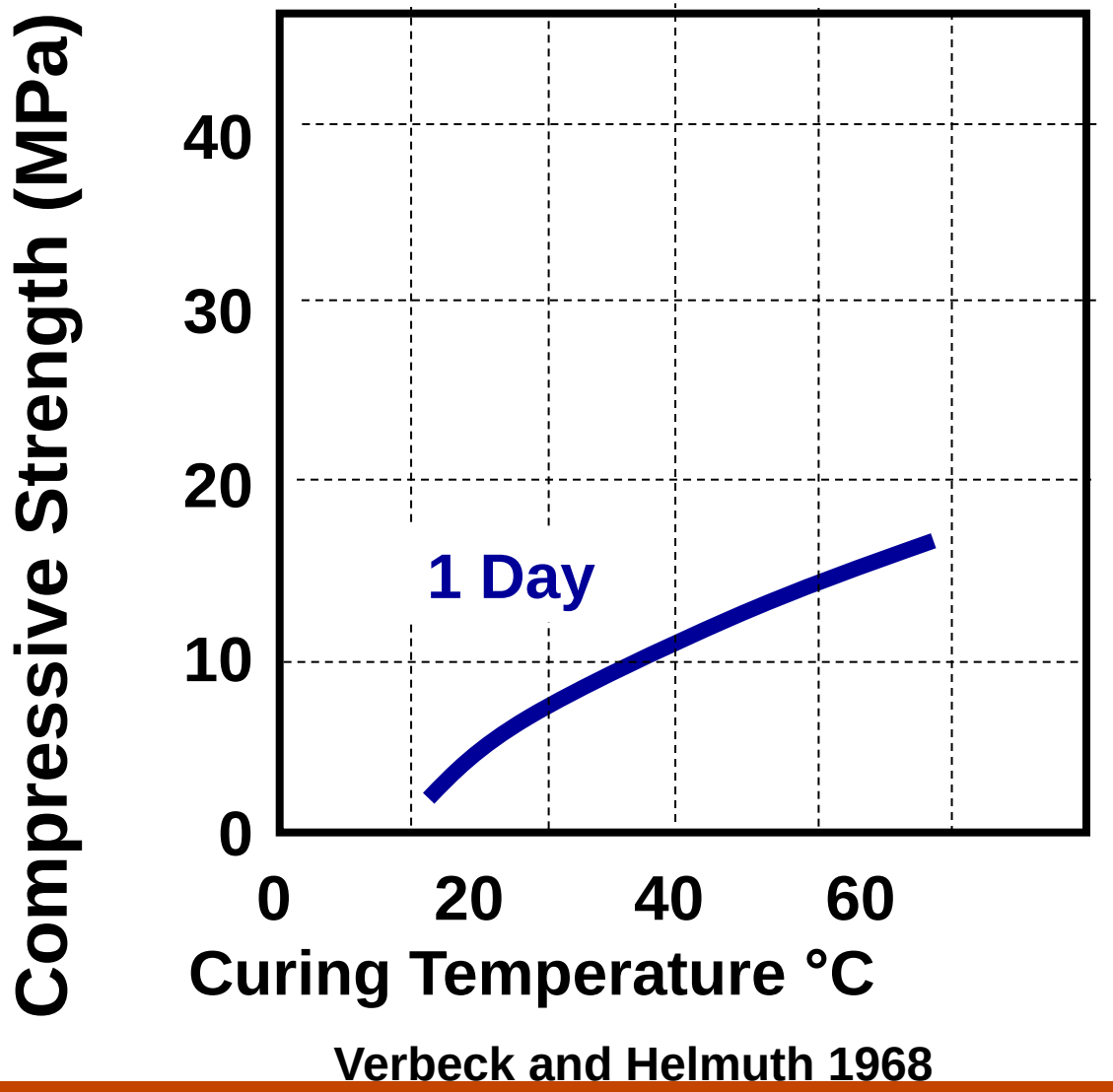
Early Strength Gain

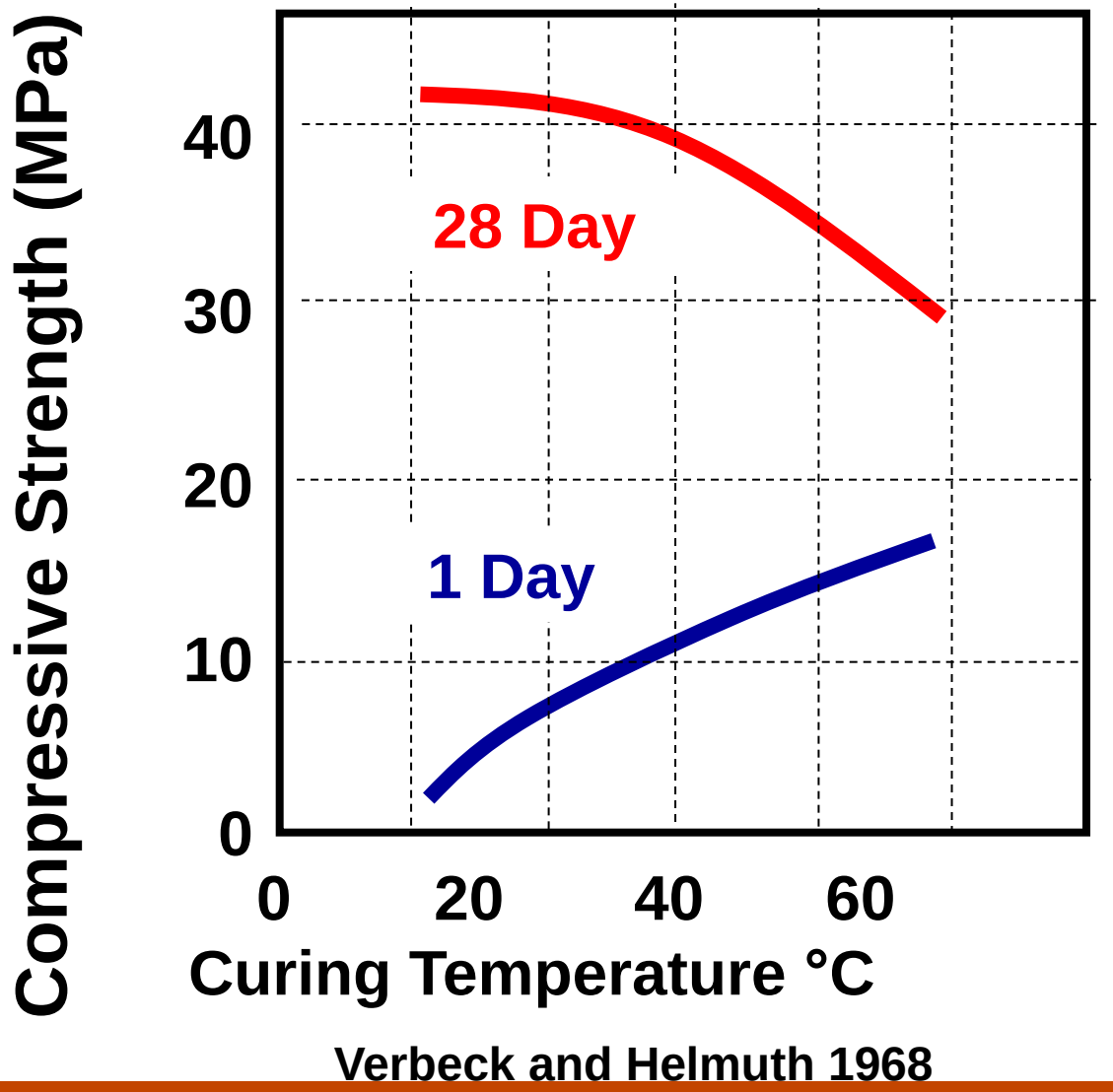
- Here we see the effect of curing temperature at 2 arbitrary ages
- Increase in strength at early ages can be explained by chemical reactions (Arrhenius)
- Eventually all materials gain strength to reach a certain limit (if they do not freeze) (-10°C)



Verbeck and Helmuth 1968

Long-Term Strength Gain

- Reduction in long-term strength is harder to describe



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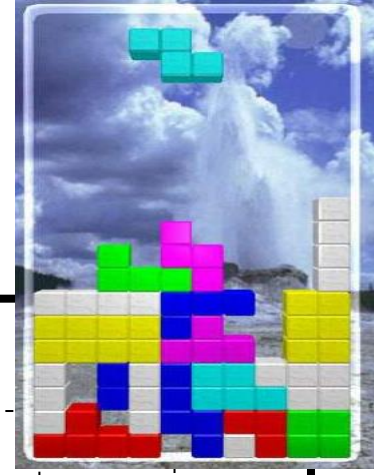
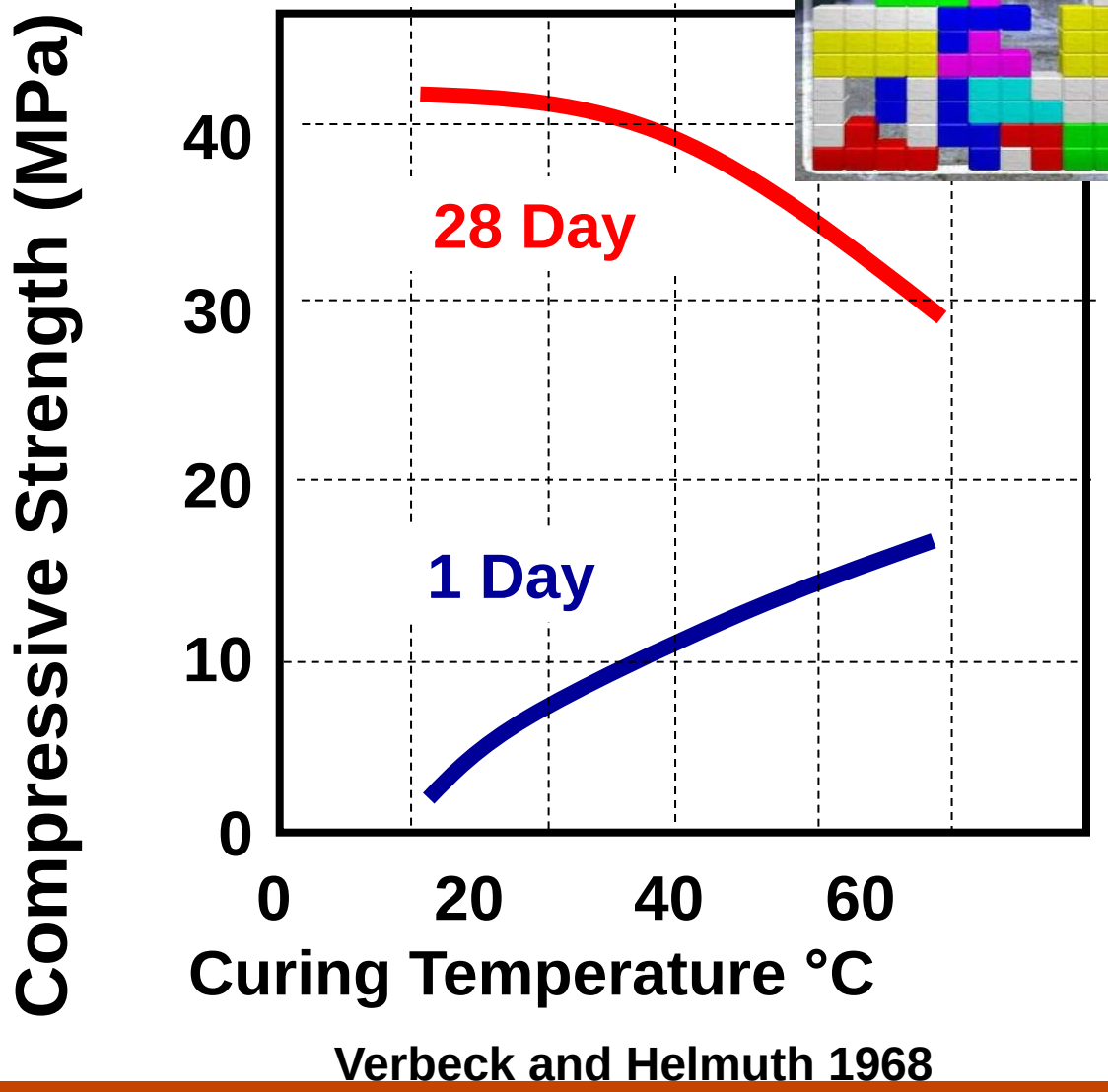


- Reduction in long-term strength is harder to describe
- Likely due to a less uniform distribution in hydrated products
- General rule of thumb the higher the temperature the lower the long-term strength



Verbeck and Helmuth 1968

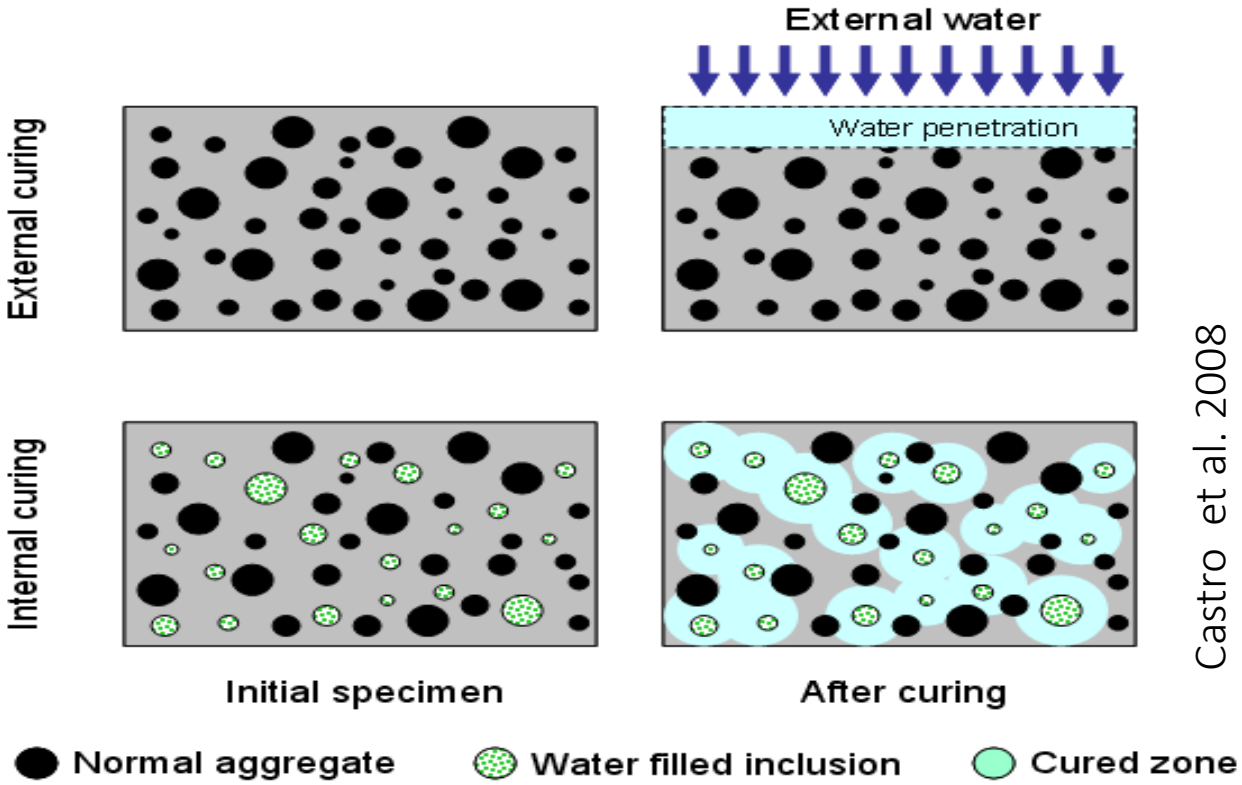
Repairs and Patching (with LWA)

- Here we can see IC patching in West Lafayette
- Premature cracking was observed in many (all) cases for plain concrete, no cracking observed in IC concrete
- 60 minutes, mixture converted, and in truck
- Benefit is reduced cracking and curling & increased hydration of the cement/opening

Barrett et al. 2014

What is Internal Curing?

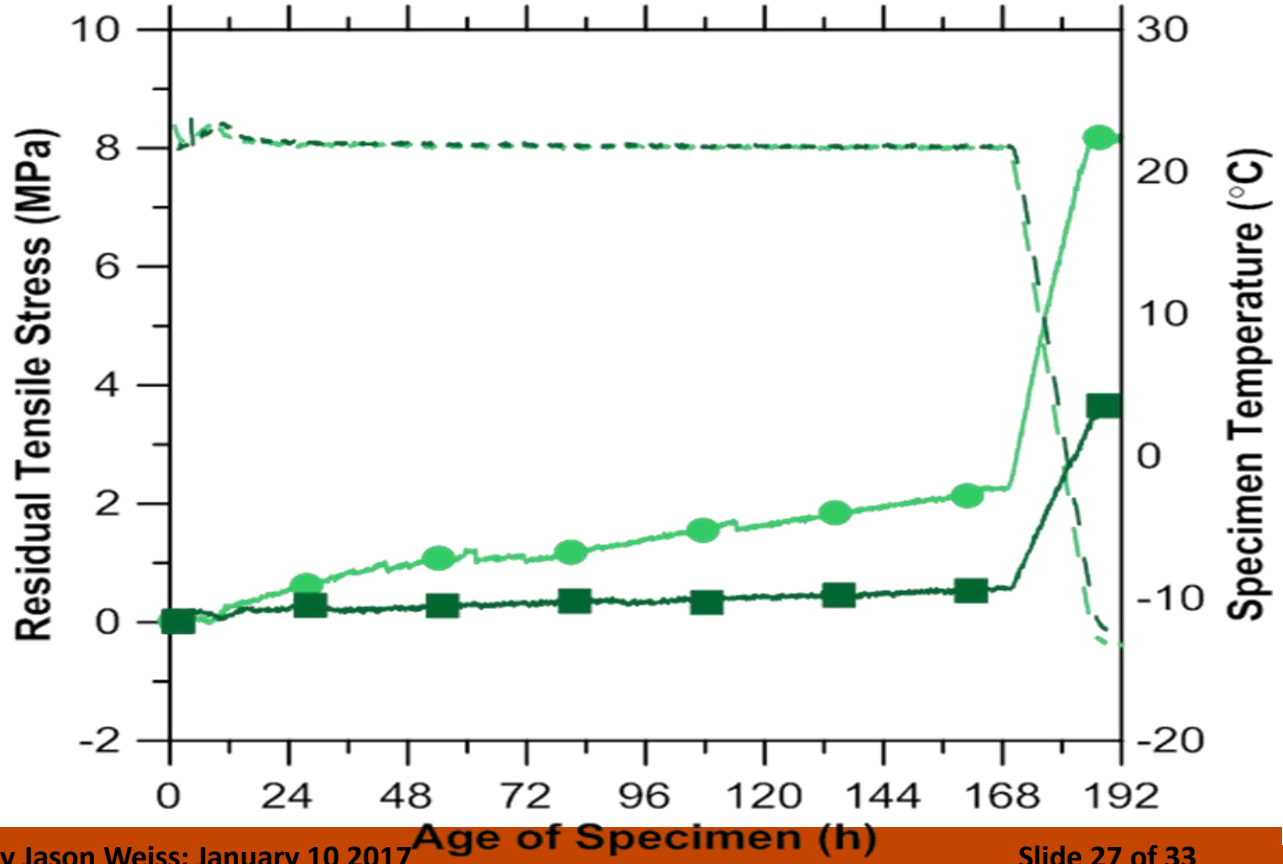
- Its Concrete 101 with a twist
- Add water to cure concrete properly
- The twist… the water comes from inside the concrete
- Water held in LWA or SAP
- Magically released



Castro et al. 2008

Tests to Run (If Needed)

- Dual Ring – Assesses Cracking Potential – In a well designed Mixture = 0 stress
- ASTM C1698 on the mortar fraction



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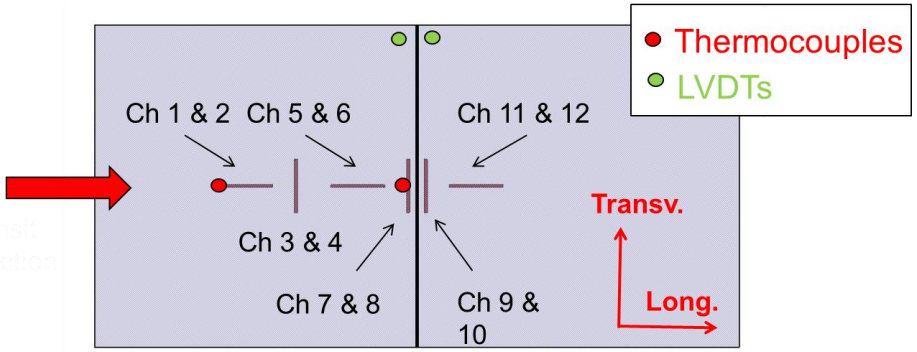
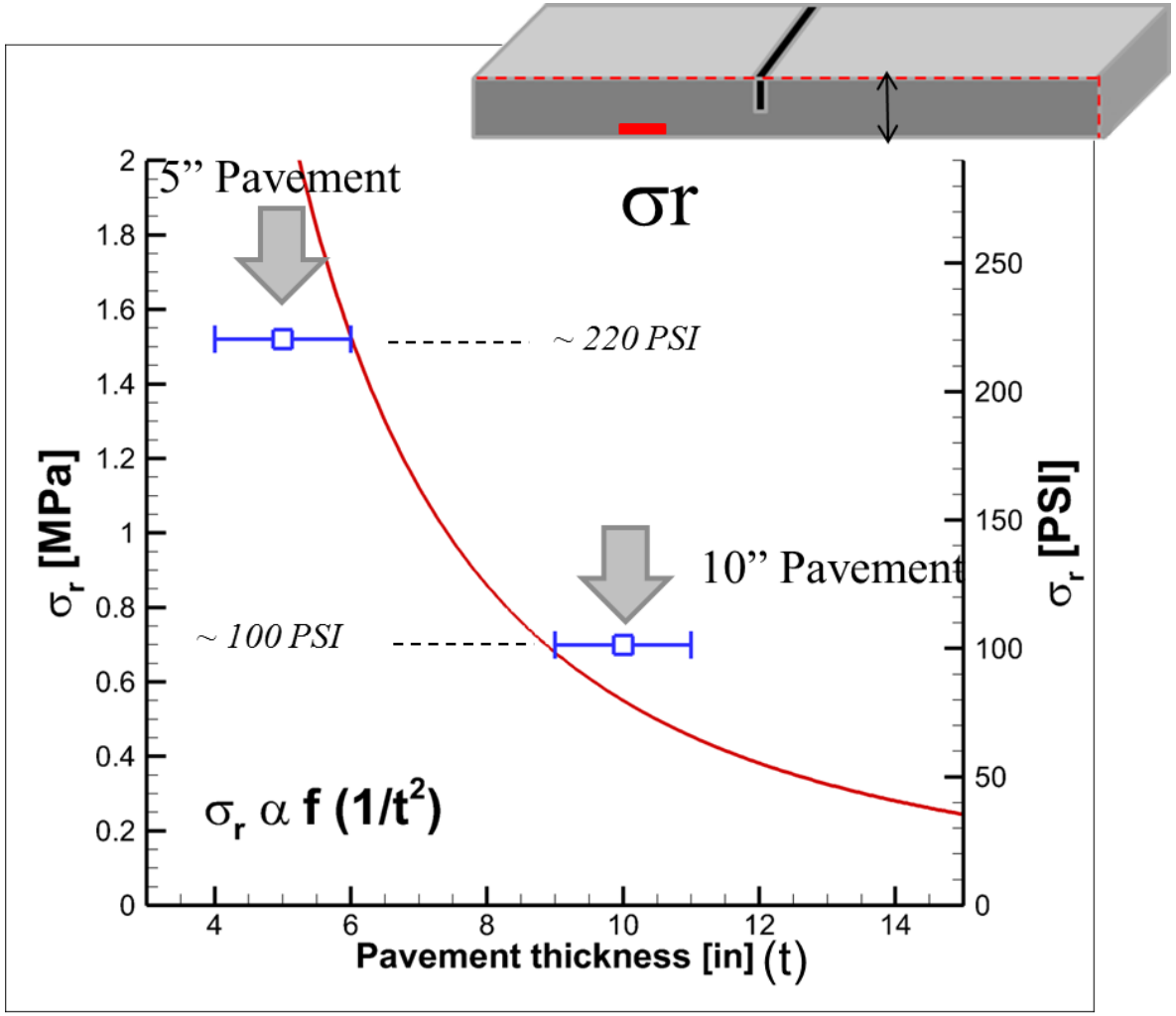
Stress Level Due to Traffic Loading

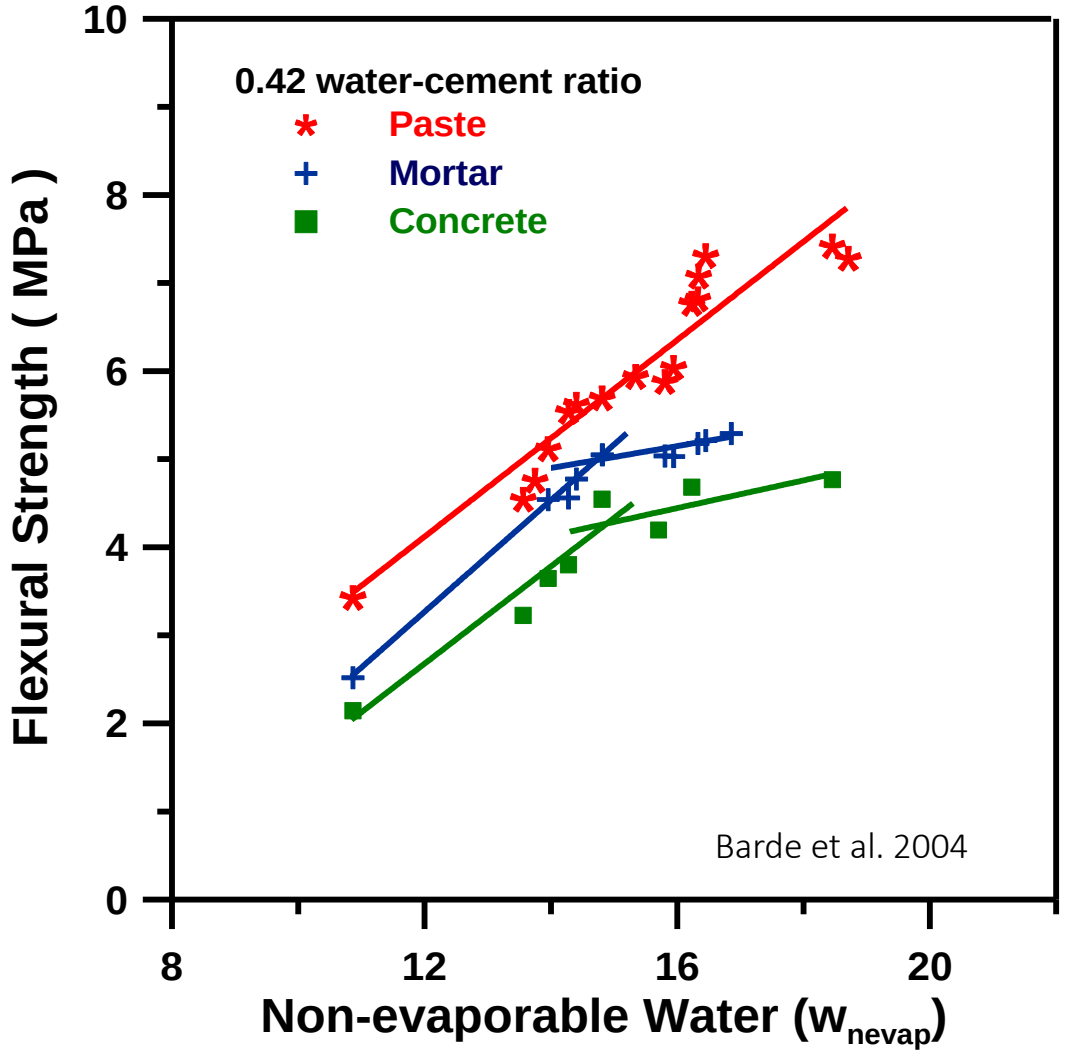


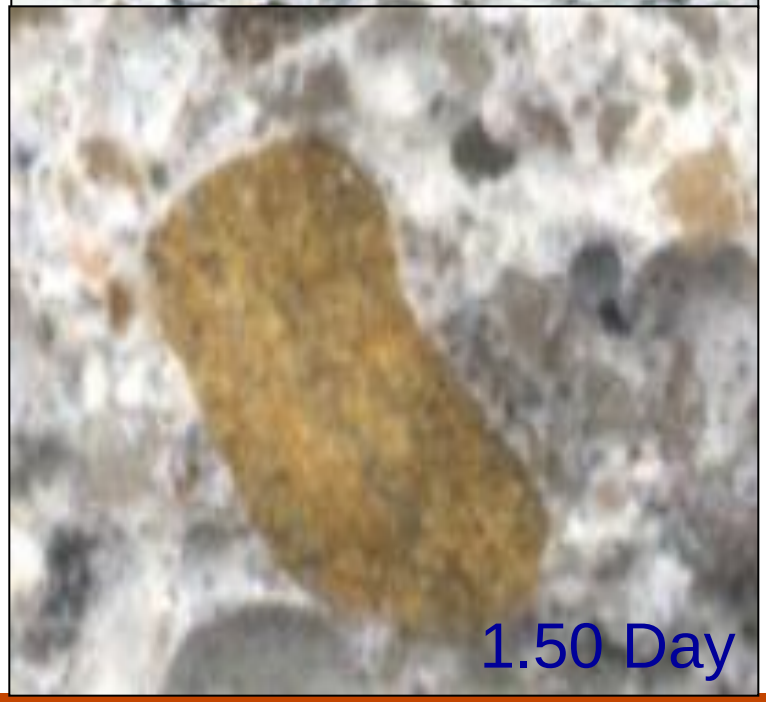
Gages oriented in the longitudinal axis and placed at the bottom and closed the joint will be studied. These are Ch. 6 and 12.



Aggregate Fracture

- Pushing for high early strength can result in mixtures that begin to fracture the rocks limiting long-term strength





Summary

- Patching is very complex, especially with early opening requirements
  - Increase cement content – higher thermal and shrinkage vol. change
  - Use only OPC (not SCM) – leads to potential salt damage
  - Use lower w/cm – can limit reaction and increase autogenous shrinkage and cracking; internal curing is a great approach
  - Use accelerators – when coupled with high temperature can result in a sulfate imbalance that limits strength
  - Not sufficiently cured – can limit strength, increase transport, can be overcome with the use of internal curing
  - Strength requirement – The stress from traffic is dependent on depth squared and HES requirements can lead to ‘brittle mixtures’

Thank you
Are There Any Questions

http://cce.oregonstate.edu/deicing-salt

http://cce.oregonstate.edu/internalcuring

http://cce.oregonstate.edu/resistivity

Jason Weiss , Edwards Distinguished Professor

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