

Changes in Cement – Implications for Performance and How We Move Ahead

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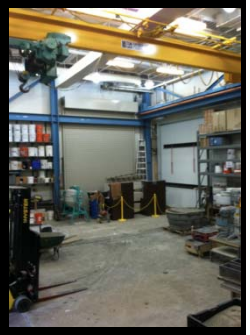


Cement Fineness Over Time

Perspective on Fineness

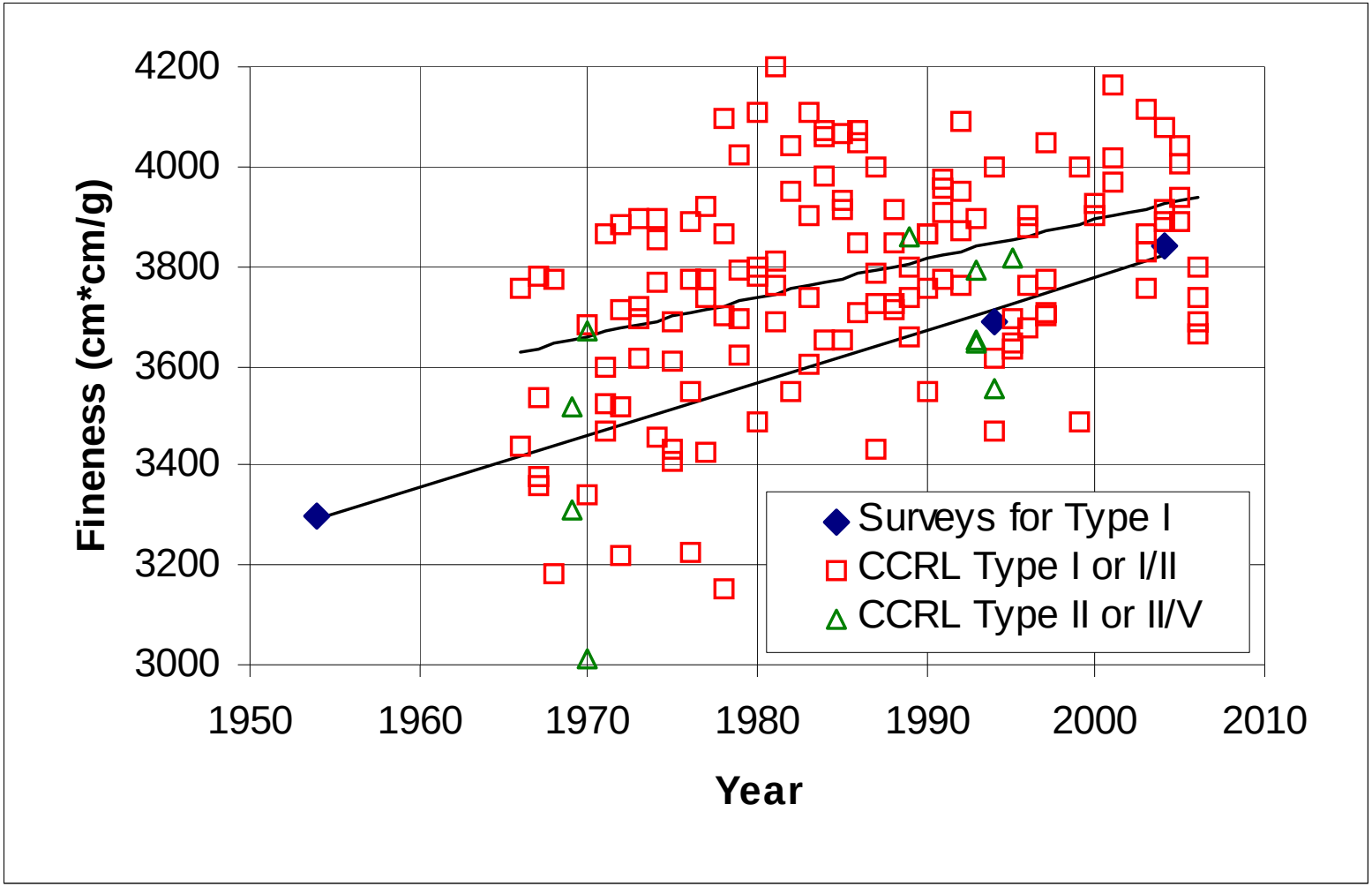
Review of an Early Paper

Shrinkage Paste Volume

Joint Damage Amount of C_3S

New Cements Optimize

Discuss and Conclude



Bentz et al. 2008

A Bit of Perspective

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Discuss and Conclude

- Over the last 20 years I have been involved in several discussions on cement fineness
- Today I will expand to include an aspect of chemistry as well
- Many seem to take on the approach that was used to find Frankestein's Monster
- Grab a pitchfork and torch and lets start our discussion on cement fineness

Increasing Fineness
1970 E. C. Higginson, Conc Const

1. Bleeding is reduced (more [illegible] EA)
2. Increases the wa[illegible]
3. Workabil[illegible]
4. AEA air-voi[illegible] fected
5. 28-day f'c increases, at 1 year little dif.
6. Slight decrease in the static modulus
7. Influences the drying shrinkage
8. Resistance to FT decreases
9. Accelerates ASR if a 100% reactive aggregate is used

All Explained by Surface Area and First Principles

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Discuss and Conclude

1. Bleeding is reduced (more in non AEA)
2. Increases the water requirement
3. Workability in AEA less pronounced.
4. AEA air-void system not sig. affected
5. 28-day f'c increases, at 1 year little dif.
6. Slight decrease in the static modulus
7. Increases the drying shrinkage
8. Resistance to FT decreases
9. Accelerates ASR if a 100% reactive aggregate is used

Effect of Fineness
1970 E. C. Higginson, ASTM

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- ‘Fineness has a considerable effect on the drying shrinkage of concrete’ in summary from concrete construction; however when one looks at the ASTM article something new emerges

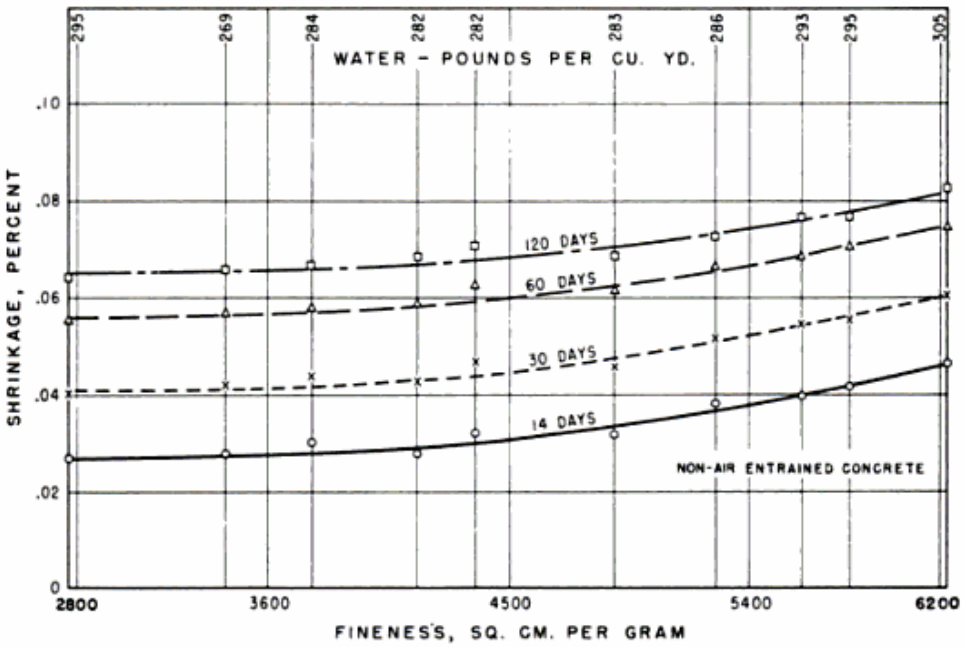

FIG. 6—*Effect of fineness of cement on drying shrinkage of 3 by 3 by 15-in. bars after 14-day fog curing, followed by drying in 50 percent relative humidity.*

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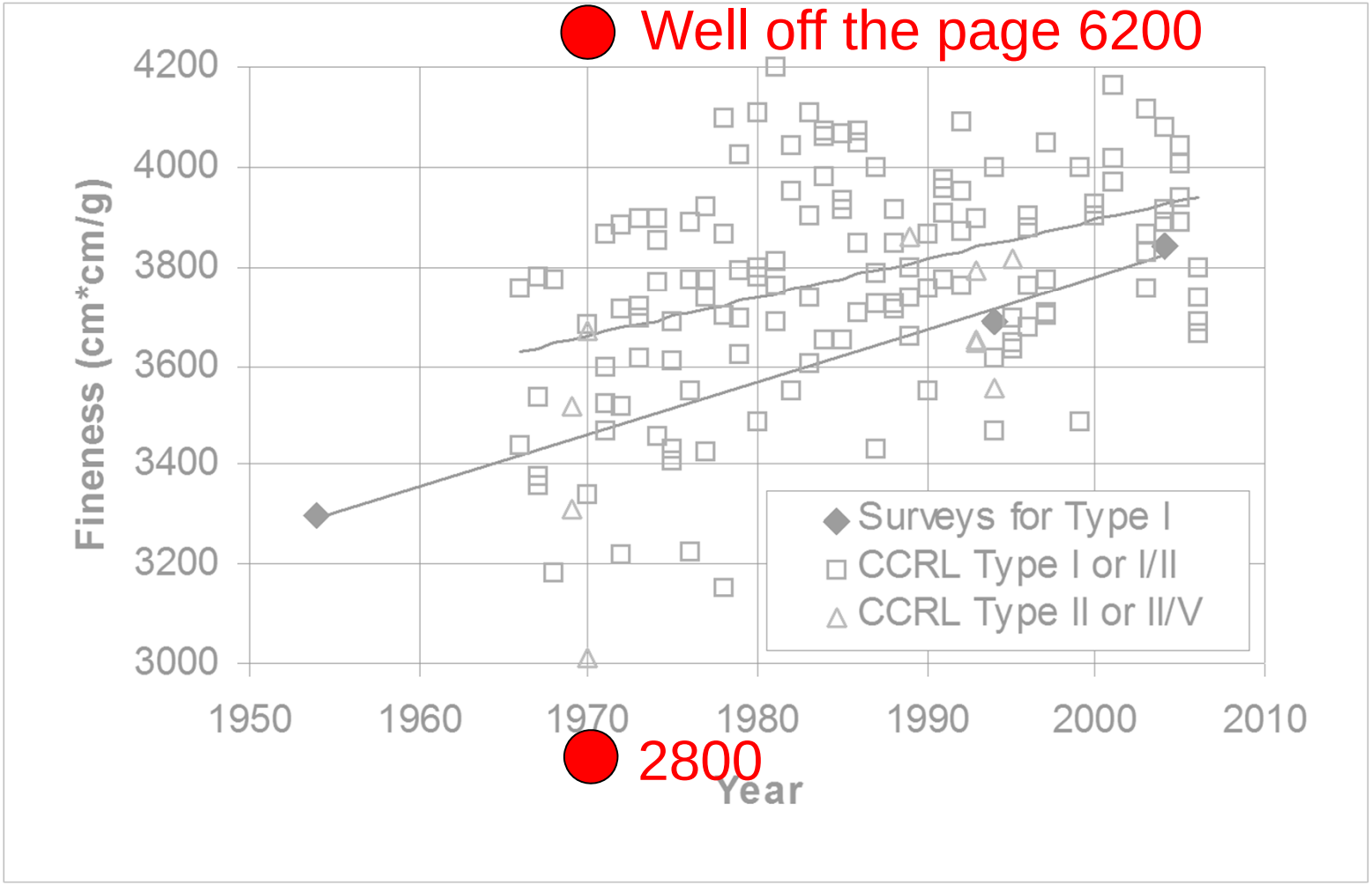

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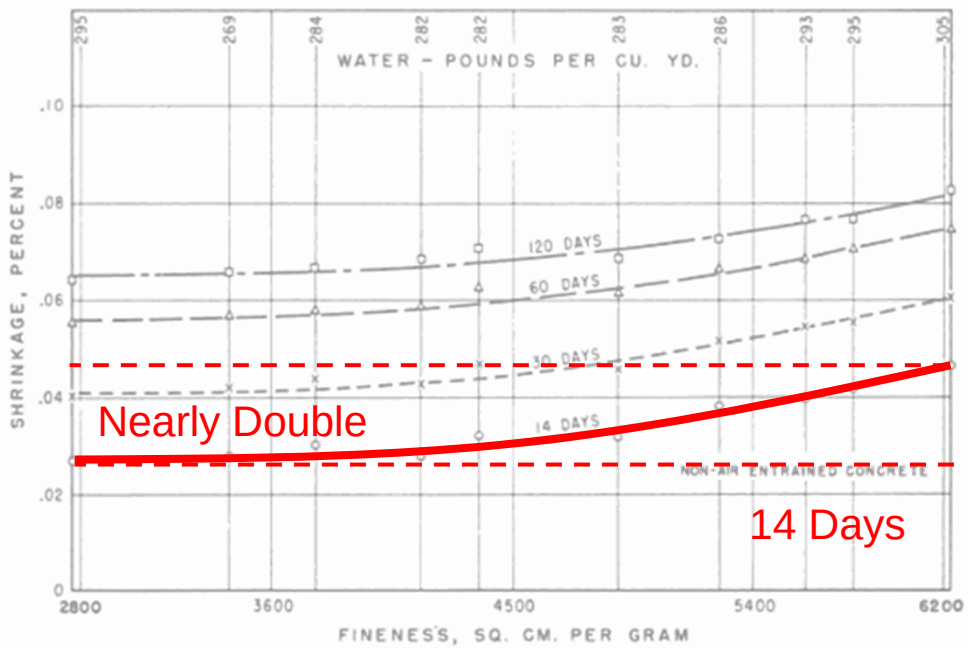
Discuss and Conclude

- ‘Fineness has a considerable effect on the drying shrinkage of concrete’



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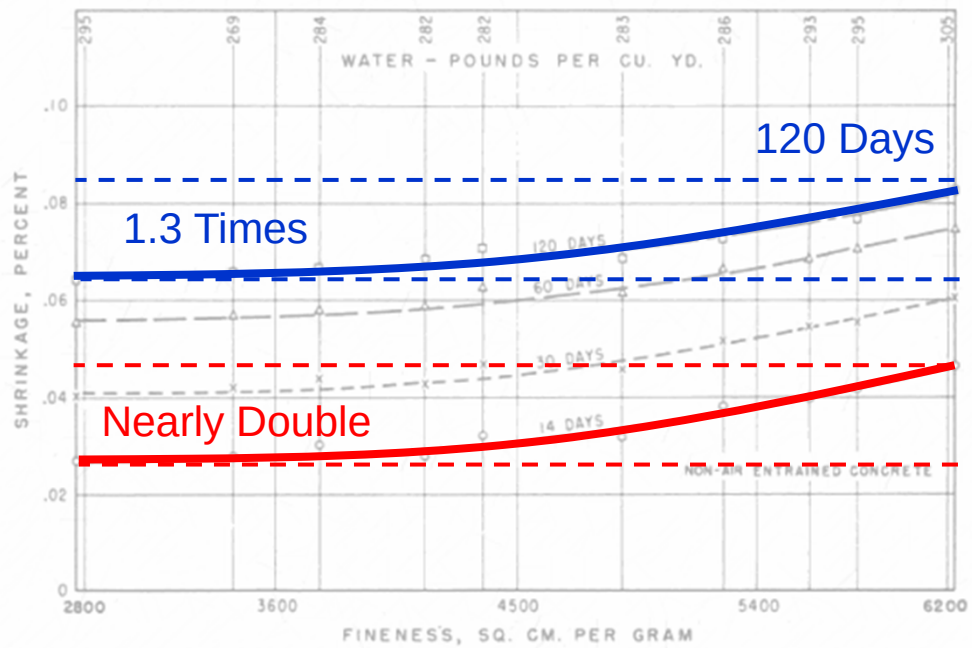

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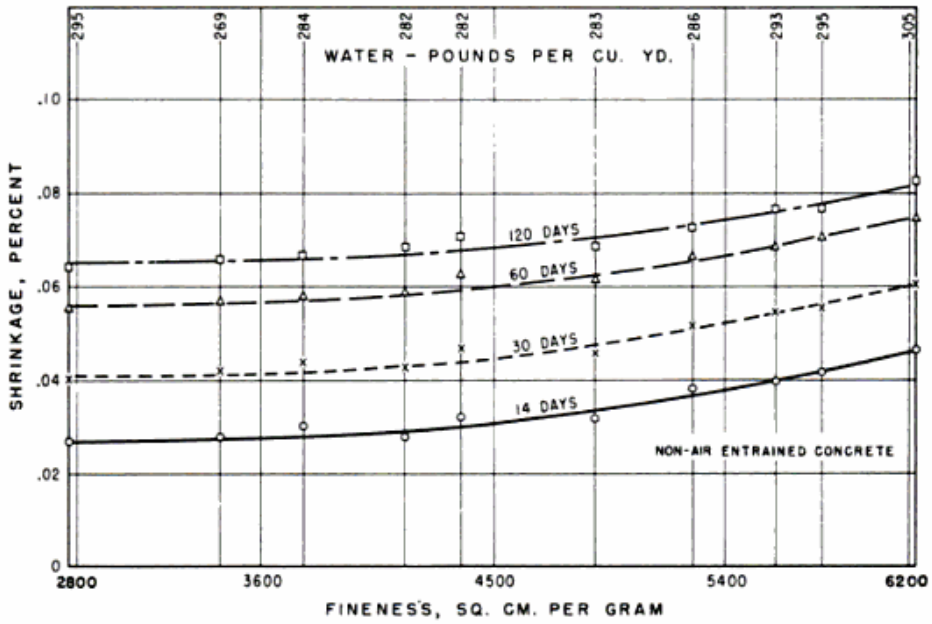
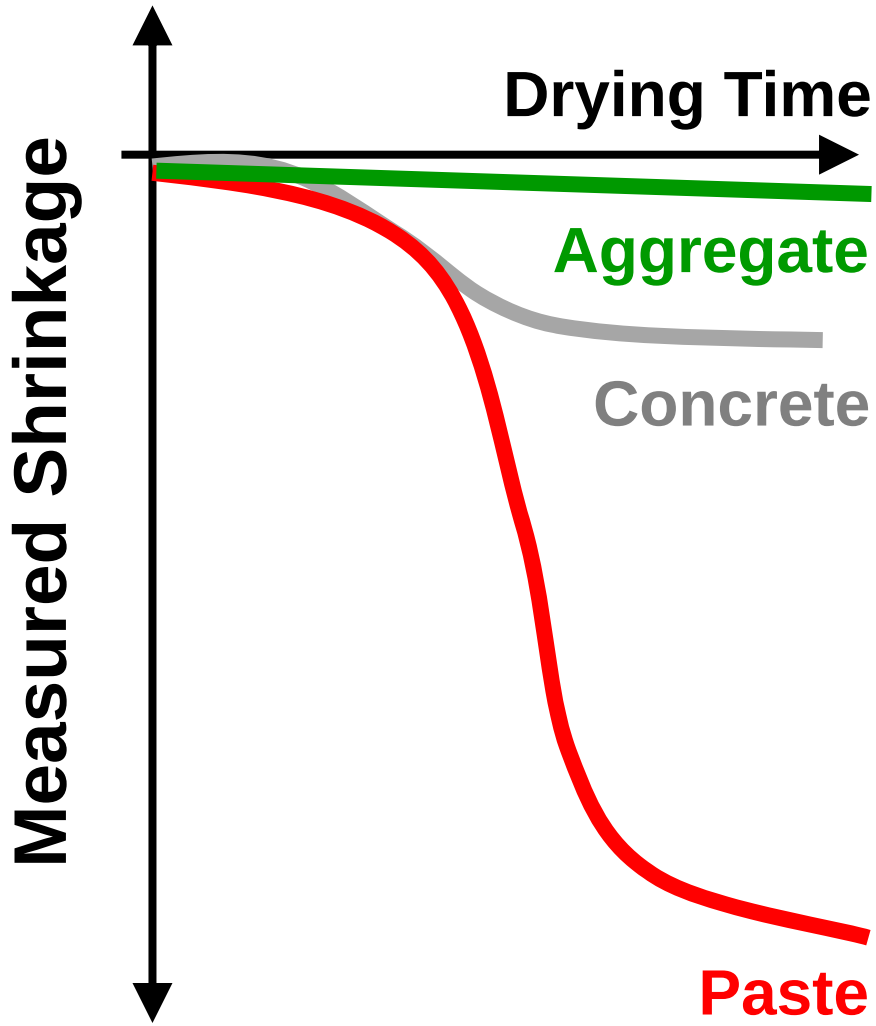


FIG. 6—*Effect of fineness of cement on drying shrinkage of 3 by 3 by 15-in. bars after 14-day fog curing, followed by drying in 50 percent relative humidity.*

- Often missed …‘Careful study of the water content of the mixes …. shrinkage may be attributed to higher water requirements’ 1-2% paste increase

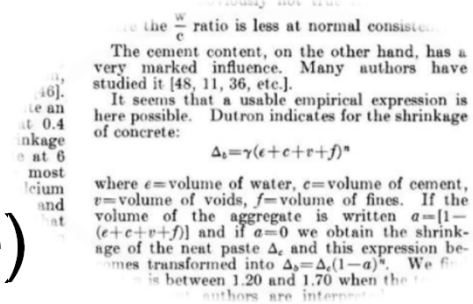
Shrinkage of Components (L' Hermite, Review 1960's)

- Looking at shrinkage of the components
- Aggregate generally does not shrink
- Paste is the portion that shrinks
- Shrinkage is a paste property



This Work Required Battling Many Widely Held Thoughts – V_{Paste}

- Dutron (1956) shares data, followed by L'Hermite (1960 stating little influence)



... the $\frac{w}{c}$ ratio is less at normal consiste...

The cement content, on the other hand, has a very marked influence. Many authors have studied it [48, 11, 36, etc.].

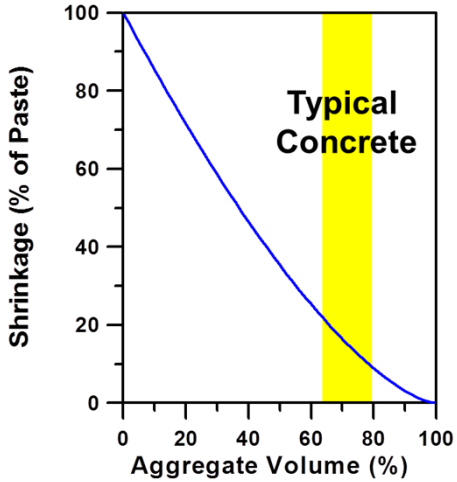
It seems that a usable empirical expression is here possible. Dutron indicates for the shrinkage of concrete:

$$\Delta_b = \gamma(e+c+v+f)^n$$

where e = volume of water, c = volume of cement, v = volume of voids, f = volume of fines. If the volume of the aggregate is written $a = [1-(e+c+v+f)]$ and if $a=0$ we obtain the shrinkage of the neat paste Δ_c and this expression becomes transformed into $\Delta_b = \Delta_c(1-a)^n$. We f... is between 1.20 and 1.70 when the ...

- Point to discussion on volume of paste which has been ongoing since the 1920s
- 1950's see this come to many meetings (int'l cement, TRB etc)
- Pickett ('65) and others

$$\varepsilon_{Concrete} = \varepsilon_{Paste}\left(1 - V_{Agg}\right)^n$$



A Look at Shrinkage and Paste Volume

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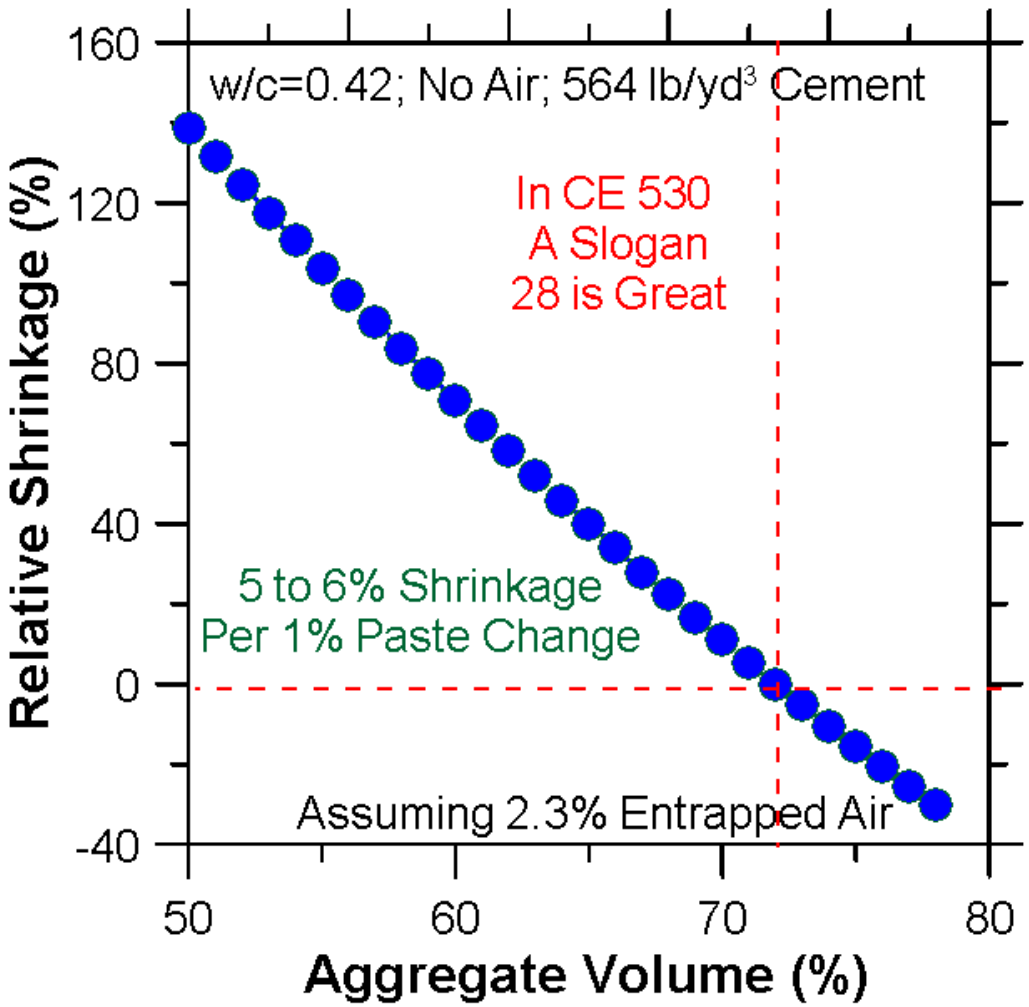
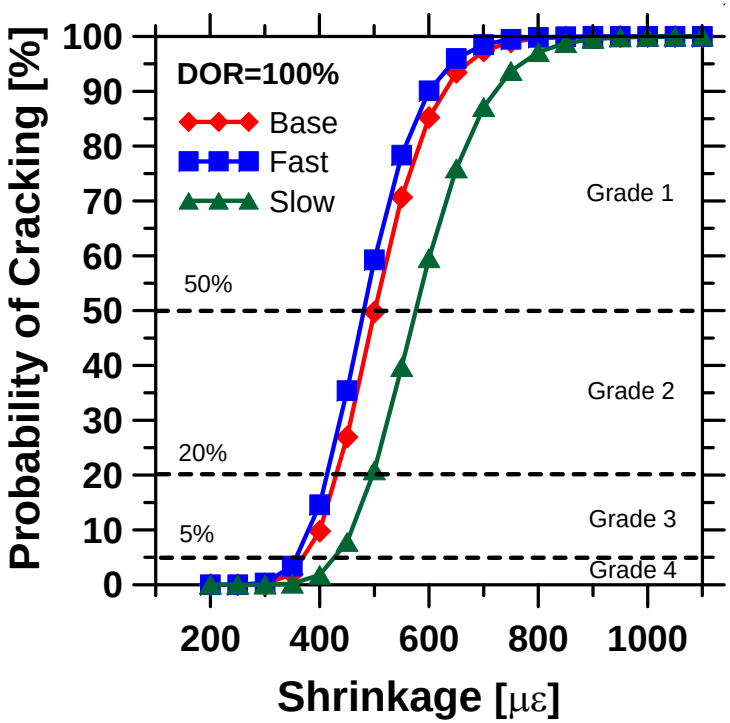
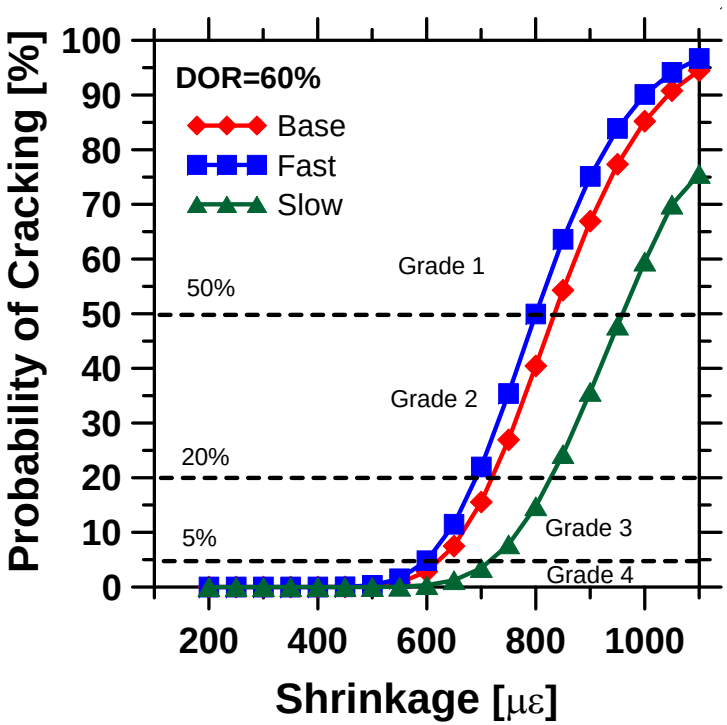


Models for Shrinkage and Cracking

- Shrinkage can be related to cracking
- Restrained shrinkage cracking and free shrinkage are non-linearly related





Radlinska et al. 2008

First Main Conclusion

- Simply said shrinkage is related to the volume of the paste.
- If we want to reduce shrinkage and restrained shrinkage cracking we want to minimize the paste.
- Sometimes this is done easily (in mixtures with too much cement) in other mixtures this will require optimizing the aggregate gradation
- If one goes too low … transport properties can increase substantially ….

Topic Two – Preferred Chemistry

Perspective on Fineness

Review of an Early Paper

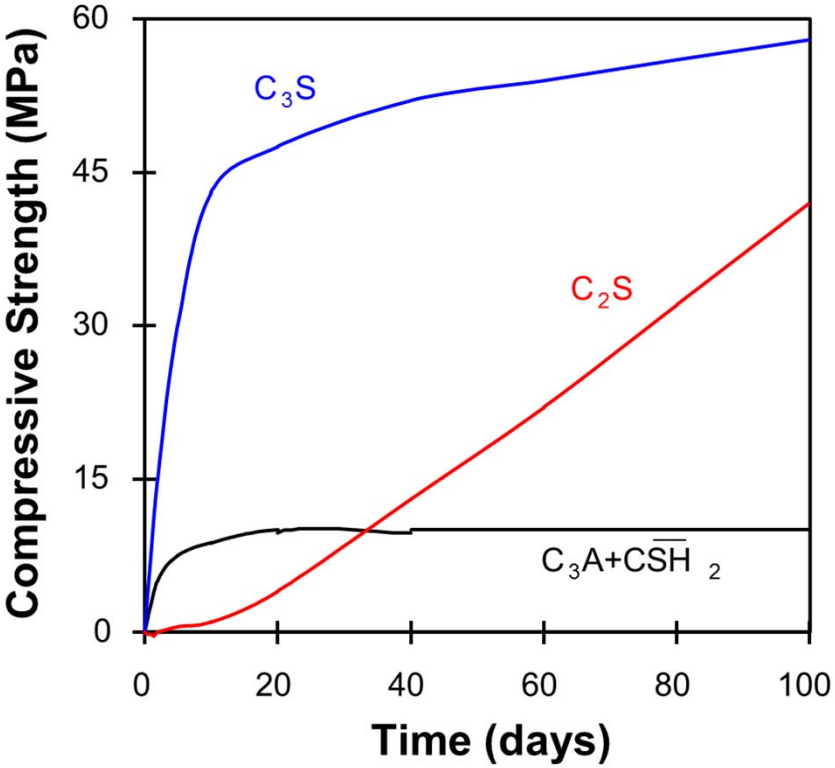
Shrinkage Paste Volume

Joint Damage Amount of C_3S

New Cements Optimize

Discuss and Conclude

- While fineness gets a lot of coverage, others will talk about the role of chemistry – Calcium silicates, calcium aluminates, etc
- Many times ‘people’ prefer high C_3S materials due to the need for early opening or formwork removal



Examine Hydration Reactions and the Role of Cement Chemistry

- Tricalcium Silicate (C_3S)

$$C_3S + 3H \rightarrow C_2SH_2 + CH$$

$$C_3S + 3H \rightarrow C_{1.5}SH_{1.5} + 1.5CH$$

- Dicalcium Silicate (C_2S)

$$C_2S + 2H \rightarrow C_2SH_2$$

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Variations can occur I have shown like equations (Bouge)

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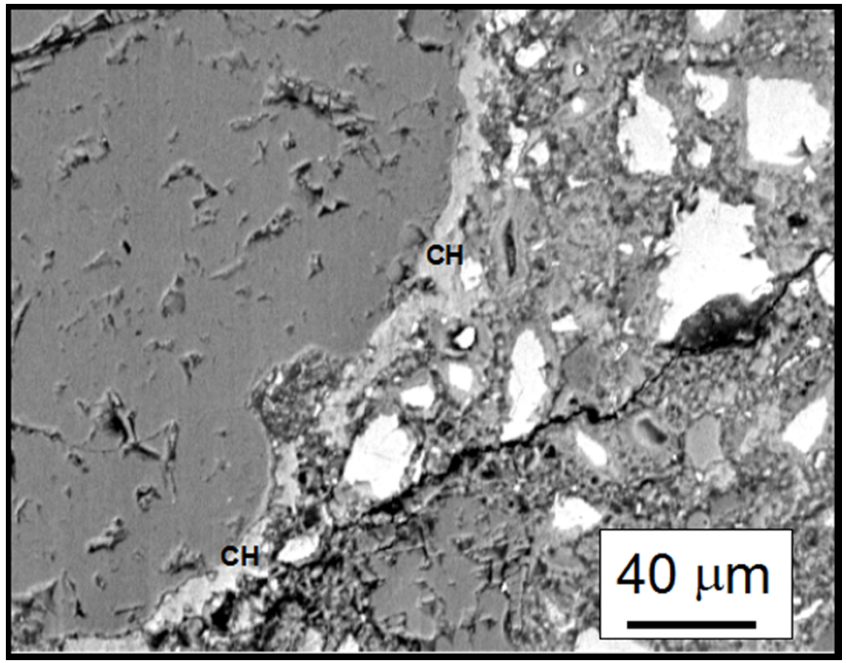
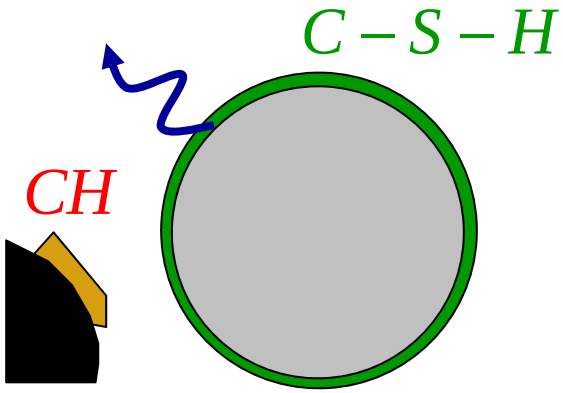
- C_3S requires more water and produces more calcium hydroxide

Variations can occur I have shown simple, like eqns (Bouge)

Some Comments About Calcium Hydroxide ($CaOH_2$; CH)

- CH forms in solution and deposits (in/on)
- CH deposits on aggregate surfaces (few to 20 μm) as stage III begins (before set)
- Important in discussing ITZ (exists or no)





CH on Surfaces

$CaOH_2$ and Durability

- Calcium Hydroxide (Portlandite, CH, $CaOH_2$) is related to many aspects of concrete durability
- 15 – 25% of the system
- CH contributes (slightly) to strength
- CH is soluble
- CH leaches (dissolve), increasing porosity which is important for low w/c concrete
  - Marchand et al. w/c 0.6 – 3x; w/c 0.4 – 15+ x
- CH carbonates reducing pH (depassivates reinforcing steel)

Joint Deterioration and CH

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Shrinkage Paste Volume

Joint Damage Amount of C_3S

New Cements Optimize

Discuss and Conclude

- CH plays a role in salt/joint durability (Ca-oxychloride)
- Recent research from Peterson et al. and Farnam et al. That CH reacts with the $CaCl_2$

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

- Phase change that results in a massive volume change (~ 30%)

Calcium Oxychloride (from LTDSC)

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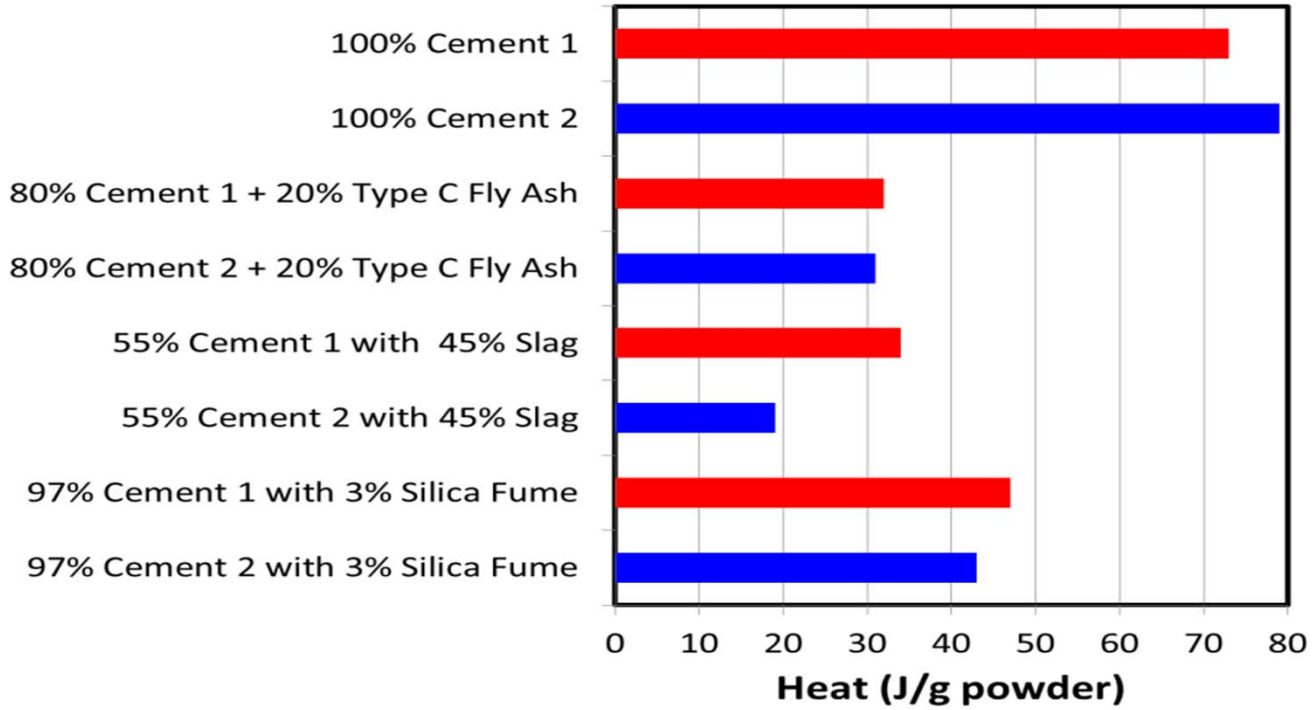
Discuss and Conclude

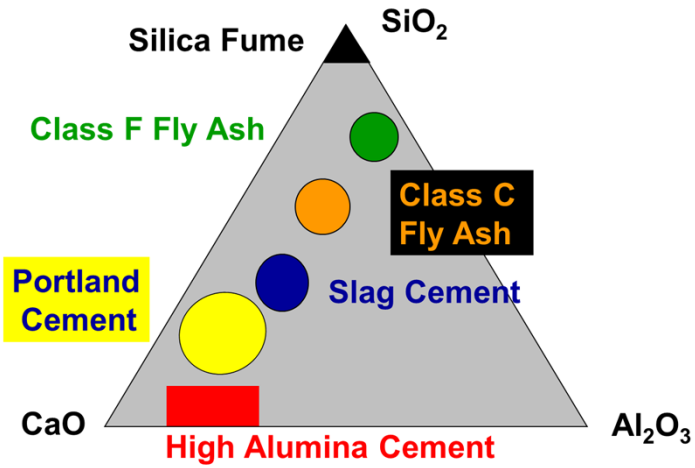
- Preliminary results examining how SCM can reduce joint damage
- Material sources vary and this is limited



Villani et al. in preparation

Role of Supplementary Cementitious Materials

- Silica Fume, Slag, Fly Ash Class C, Fly Ash Class F



- Pozzolanic Reaction
  - CH reacts with water and silica/alumina
  - This results in less CH to react
- Dilution Effect – When we replace a volume of cement with a SCM we
  - Reduce the CH that is formed
  - Reduce the permeability

Calcium Oxychloride (from LTDSC)

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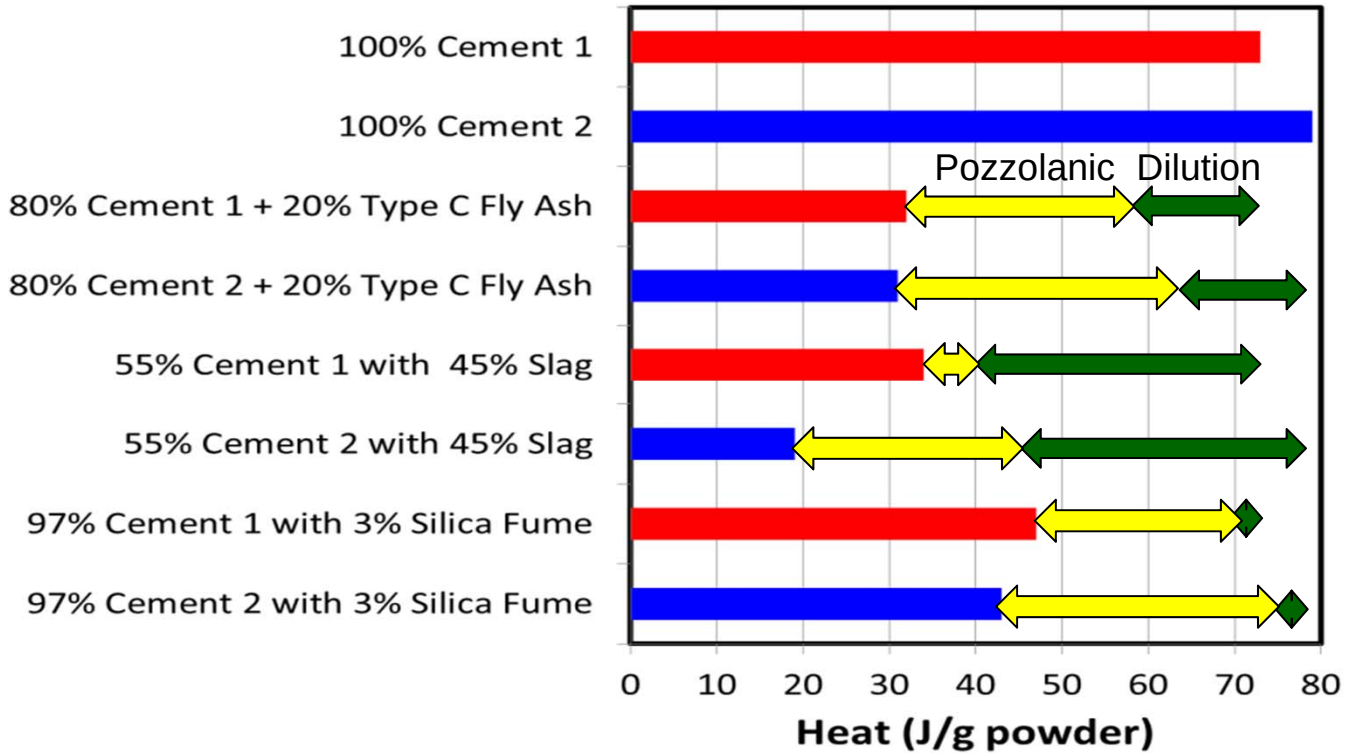

Proposed Calcium Oxychloride Research Moving Forward

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Discuss and Conclude

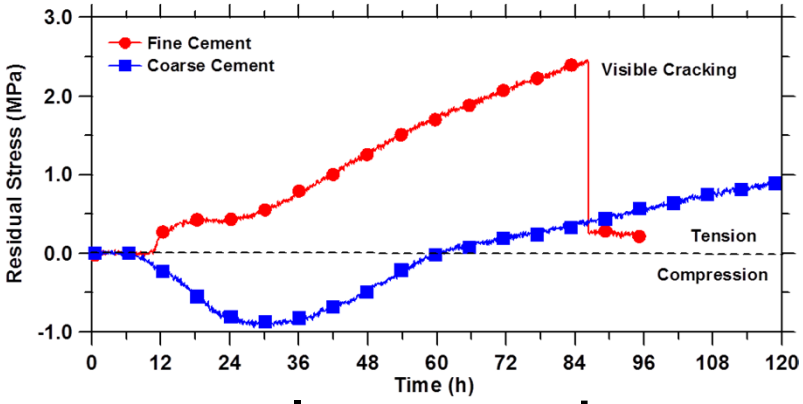
- I am starting to work on the next phase of this research (fundamental/database)
- I believe we need to better understand Ca-Oxy formation as it relates to chemistry and to relate this to field performance
- I would like to collect binders as people are building this year and in coming years and to relate the performance of this new rapid test, to lab tests and ultimately to field performance
- I am hoping that as we do this there could be support for this important problem
- Happy to discuss with those interested

Topic 3 - Effect of Fineness
1970 E. C. Higginson, ASTM

- "It might then be possible to specify and obtain cement with an optimum grading for a specific use"
- Some discussion revolves around 'performance'

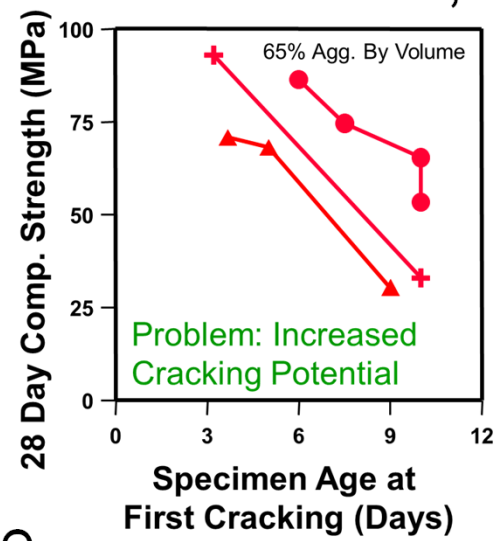
Studies of Fineness and Cracking

- Chariton and Weiss (2002) – Compared a Type I and III with the same chemistry but different fineness. III cracked earlier
- Bentz et al. 2008 – Compared two cements (310, 380) and noticed lower heat release, less autogenous shrinkage and lower cracking in coarse cement
- Coarse (50C), Fine (65C)
- Performance was not equal, strength etc



Main Observations

- Findings are similar to HSC, faster reaction, higher E, lower Ψ, increased heat, and more CSH (cap stress)
- Cracking increases for HSC Reason:
  - Creep (less relaxation)
  - Stiffness increases (α f'c)
  - Cement contents, heat increase

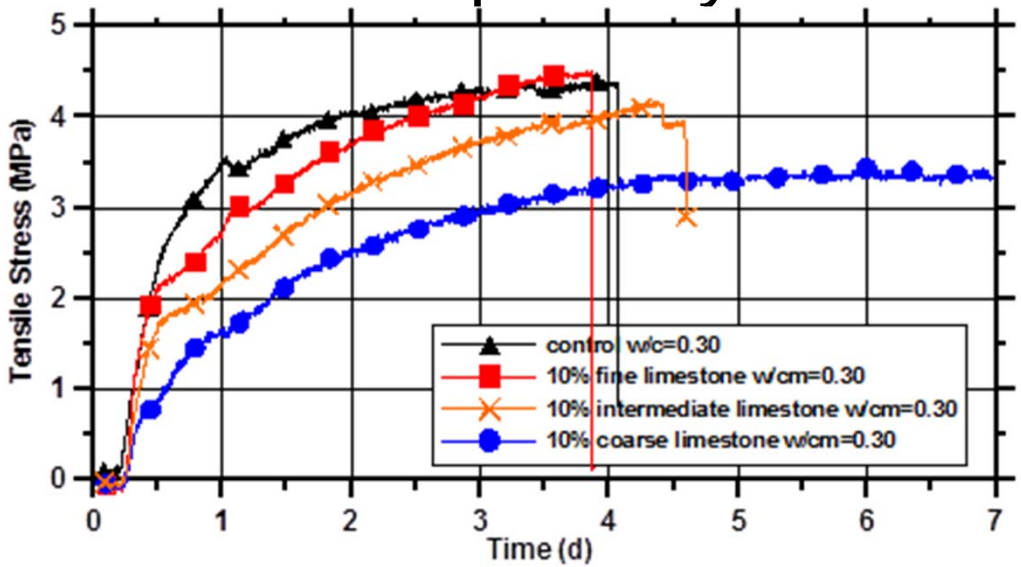


$$d\varepsilon(t,\xi) = \frac{d\sigma(\xi)}{E_\sigma(\xi)} + d\varepsilon_{SHR}(\xi) + d\sigma(\xi)\left[\frac{\phi(t,\xi)}{E_{28}}\right]$$

Weiss 1999

We Also Looked a Lot at this Issue When Looking at PLC Cements

- Bucher et al. (2009) limestone powders were added to a cement separately
- Again, we need to note that these are not equivalent performance



- We then started testing some of the PLC systems which I think really start to shine light on this discussion in a new way

Bucher et al. 2009

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1970 E. C. Higginson, ASTM

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Joint Damage
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New Cements
Optimize

Discuss and Conclude

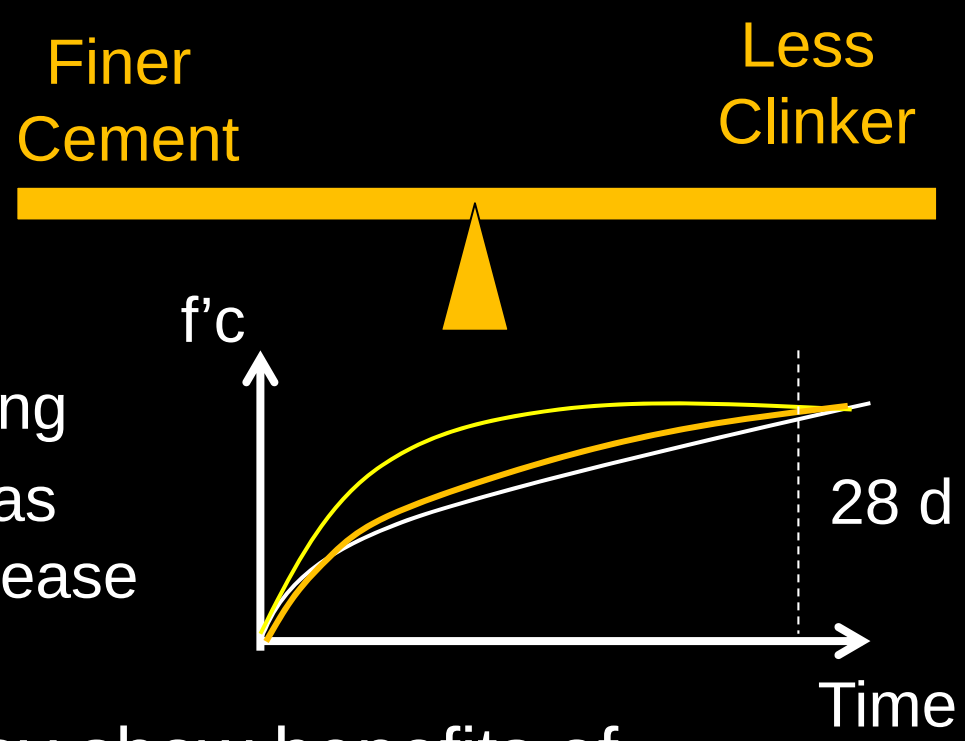
- "It might then be possible to specify and obtain cement with an optimum grading for a specific use"

- Some discussion revolves around 'performance'

- Maybe we need to step back and tell the chef what we want and not ingredients/how to assemble

Lets Look at a System

- Similar performance is targeted
- PLC is generally ground finer than OPC
  - PLC requires more grinding
  - Higher fineness may act as a nucleating agent to increase early age strengths
- Higher reaction rates may show benefits of blending with other supplementary materials



Examining Systems with Differing Blaine Fineness Numbers

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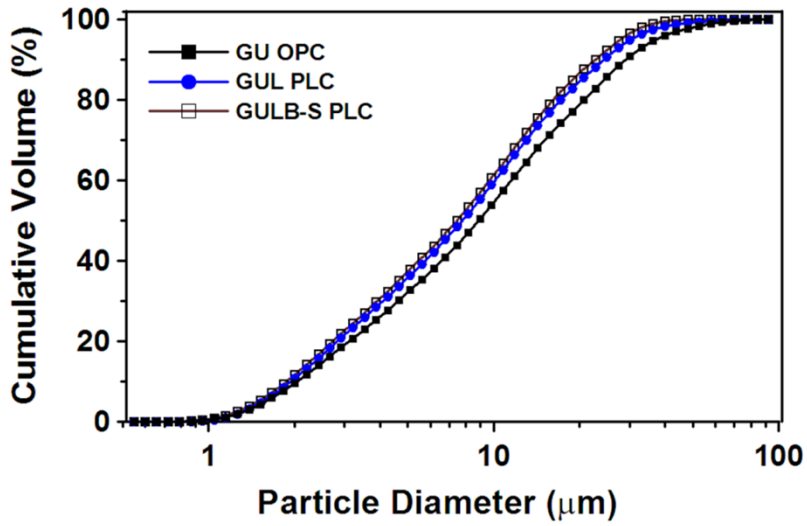

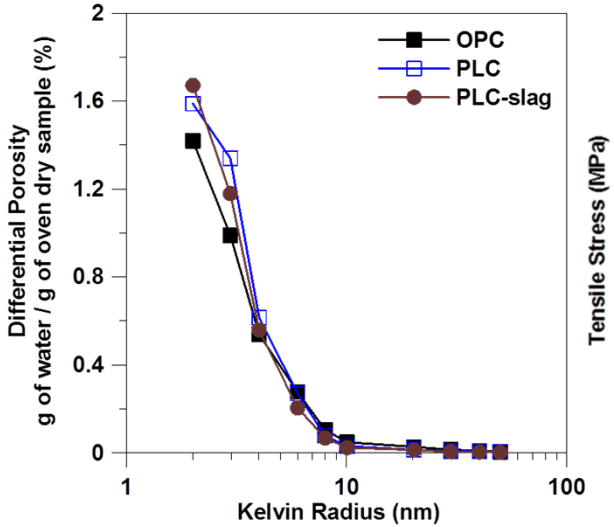

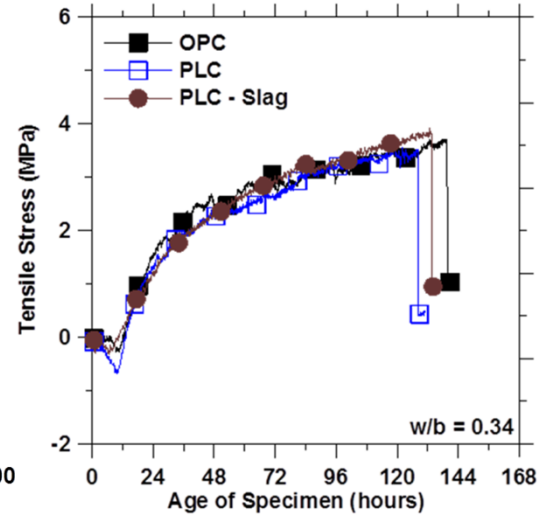

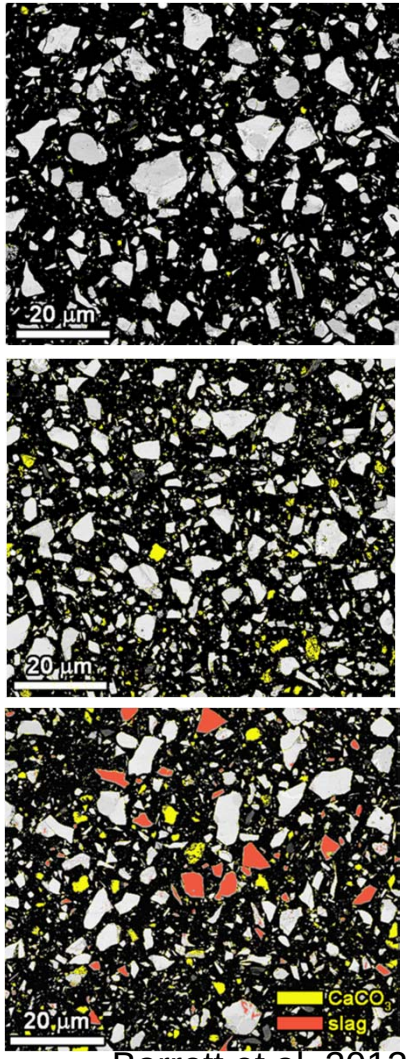

Barrett et al. 2012

Shrinkage and Cracking (Barrett et al. 2012)

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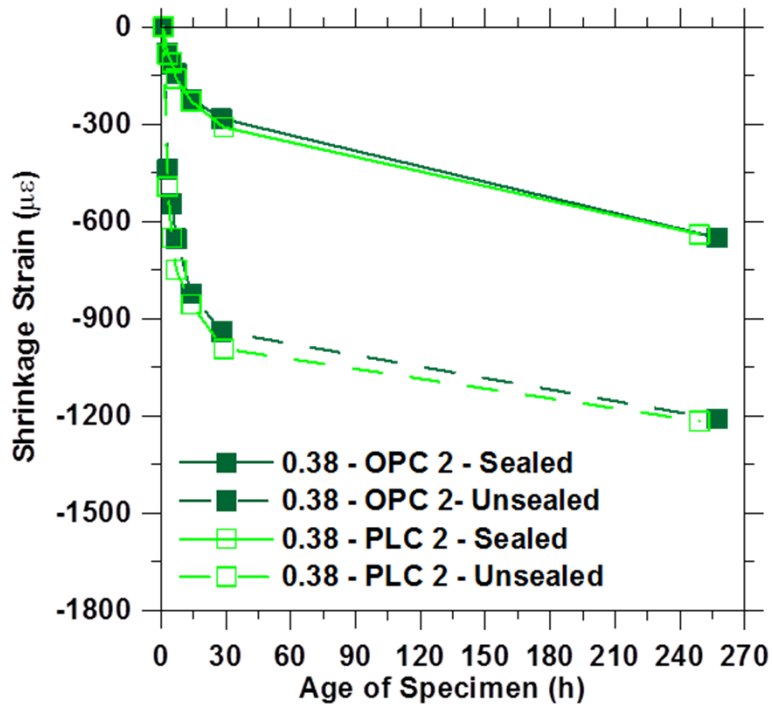

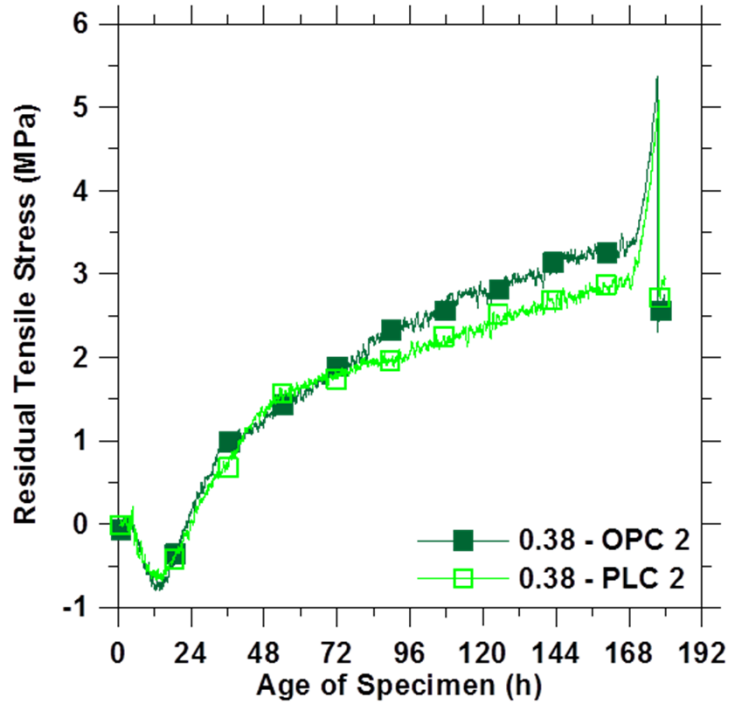

- Used a commercially interground cement
- No increase in cracking tendency despite a higher Blaine fineness (for PLC) due to changes in PSD

Barrett et al. 2013

A Bit of Perspective

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Discuss and Conclude

- Over the last 20 years I have been involved in several discussions on cement fineness
- Many seem to take on the approach that was used to find Frankestein's Monster
- Some things to consider
  - Who wants a lower/higher fineness and why
  - What levers do we have/think performance
  - What else may be changing

Open Discussion

Perspective on Fineness

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New Cements Optimize

Discuss and Conclude

- Some things to consider
  - Who wants lower/higher fineness; C_3S/C_2S
    - Contractors/Producers
    - Opening to traffic; use for construction
    - Meeting Specifications (f'r; RCPT; when linked to a time like 7, 28, 56 days…..)
  - What levers do we have/think performance
    - Should we be thinking about binder systems ….
    - Specifications can limit SCM; blends etc
    - Should we be thinking of using maturity for other properties with early tests to 'accept' based on TB that provide values at 91 or 120 days
    - Could do this already for formation factors for example…

Conclusions

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Discuss and Conclude

- Shrinkage is primarily driven by the volume of paste in a system
- CH increases with C_3S making concrete more susceptible for Ca-Oxy at joints
- There are blended systems that can balance size and chemistry but these will need to be optimized and need new rules of thumb – Cant simply say fine is bad
- We have prescriptive specifications … may we be ready to think performance
- Think about specs – What they drive

Questions and Request

Perspective on Fineness

Review of an Early Paper

Shrinkage Paste Volume

Joint Damage Amount of C_3S

New Cements Optimize

Discuss and Conclude

- Again, for those interested in joining into a program where you can send me cementitious materials and mixture designs being used for pavements, I would be glad to determine the amount of oxychloride and work to provide links between the fast test, the longer test and field performance…. Lets discuss

- Think we can have a test by years end and can develop the needed database of performance