Shrinkage and Internal Curing

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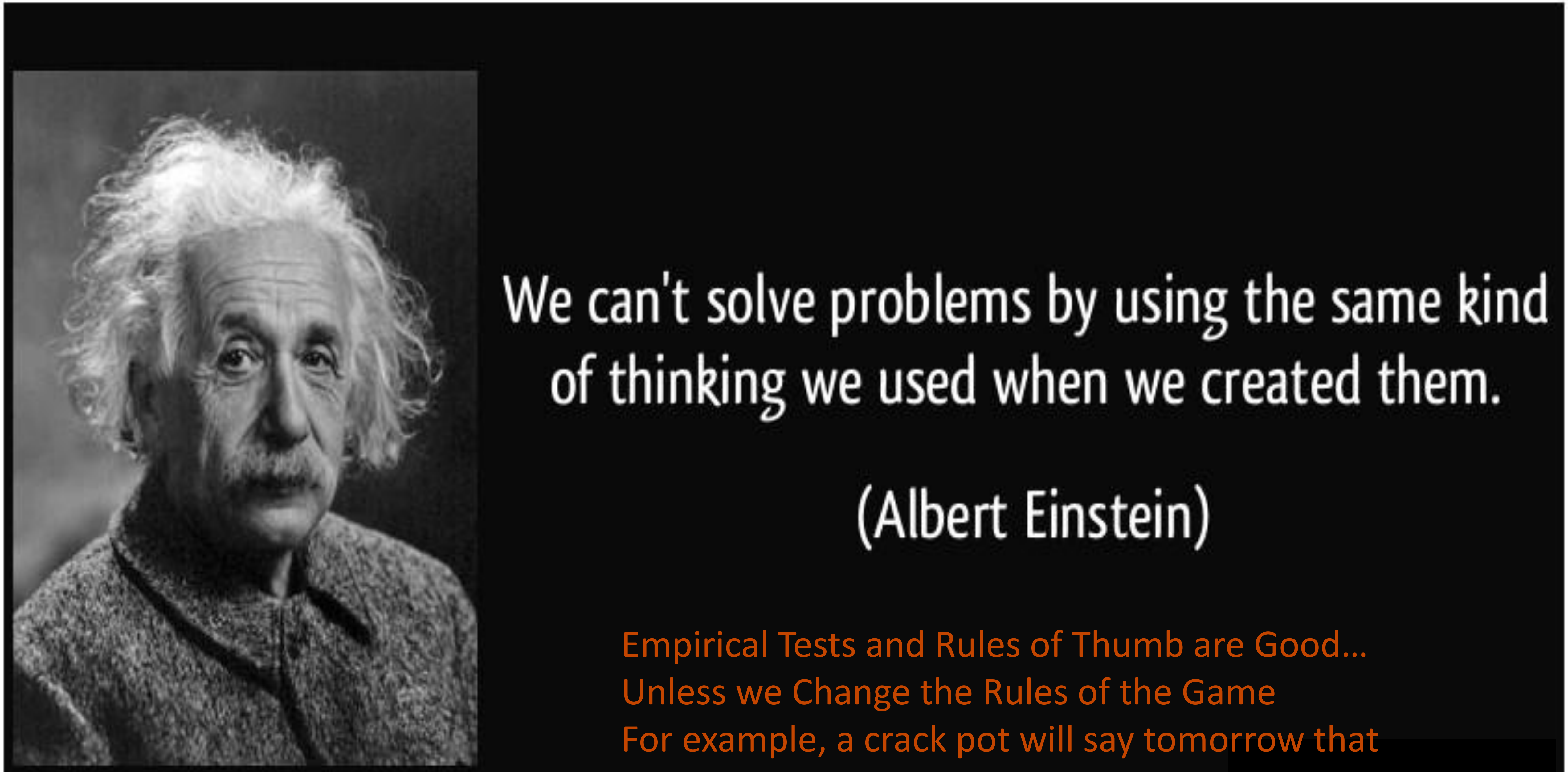
12 Years Later - Internal Curing Works

- Science has been demonstrated
- Constructability has been demonstrated
- Increased service life has been shown (IN 24 to 70 years; without considering the benefits of reductions in cracking)
- New QC procedures implemented
- Cracking due to material related substantially reduced in IC decks

Any Questions

Despite the Success, Documentation and Information…. Frequently the same Questions

- But when I run a compressive strength test I do not see a difference in strength
- But when I run a ‘shrinkage test’ (ASTM C157) I see a similar long term shrinkage
- How do I know that this really works… we need to wait 3, 5 , 10, 30 years before we know if this is ‘really something that works in my state’
- What is the slump of internally cured concrete
- This sounds like lab crete … I doubt it will work in the field
- But has it been shown to work in  (Insert state name here)



Empirical Tests and Rules of Thumb are Good…
Unless we Change the Rules of the Game
For example, a crack pot will say tomorrow that controlling paste volume …. Except IC and SRA

Before We Play the 'Adjective' Game

- Many people start by wanting to place internal curing into their favorite shrinkage test and saying 'this is why it does not work'

<u>Fresh (Plastic) Shrinkage</u>

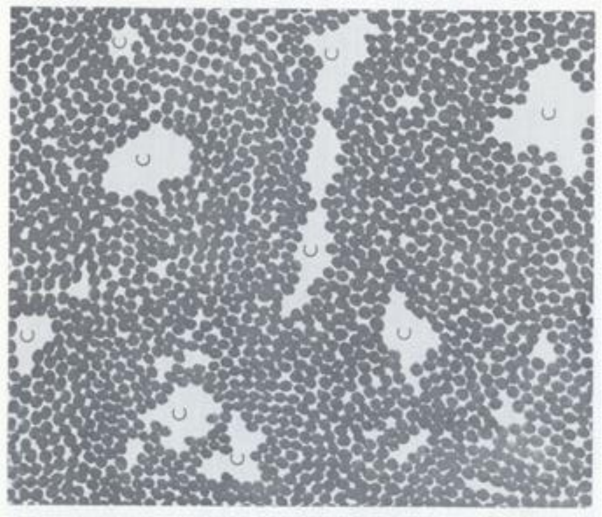
- Evaporation
- Settlement
- Autogenous

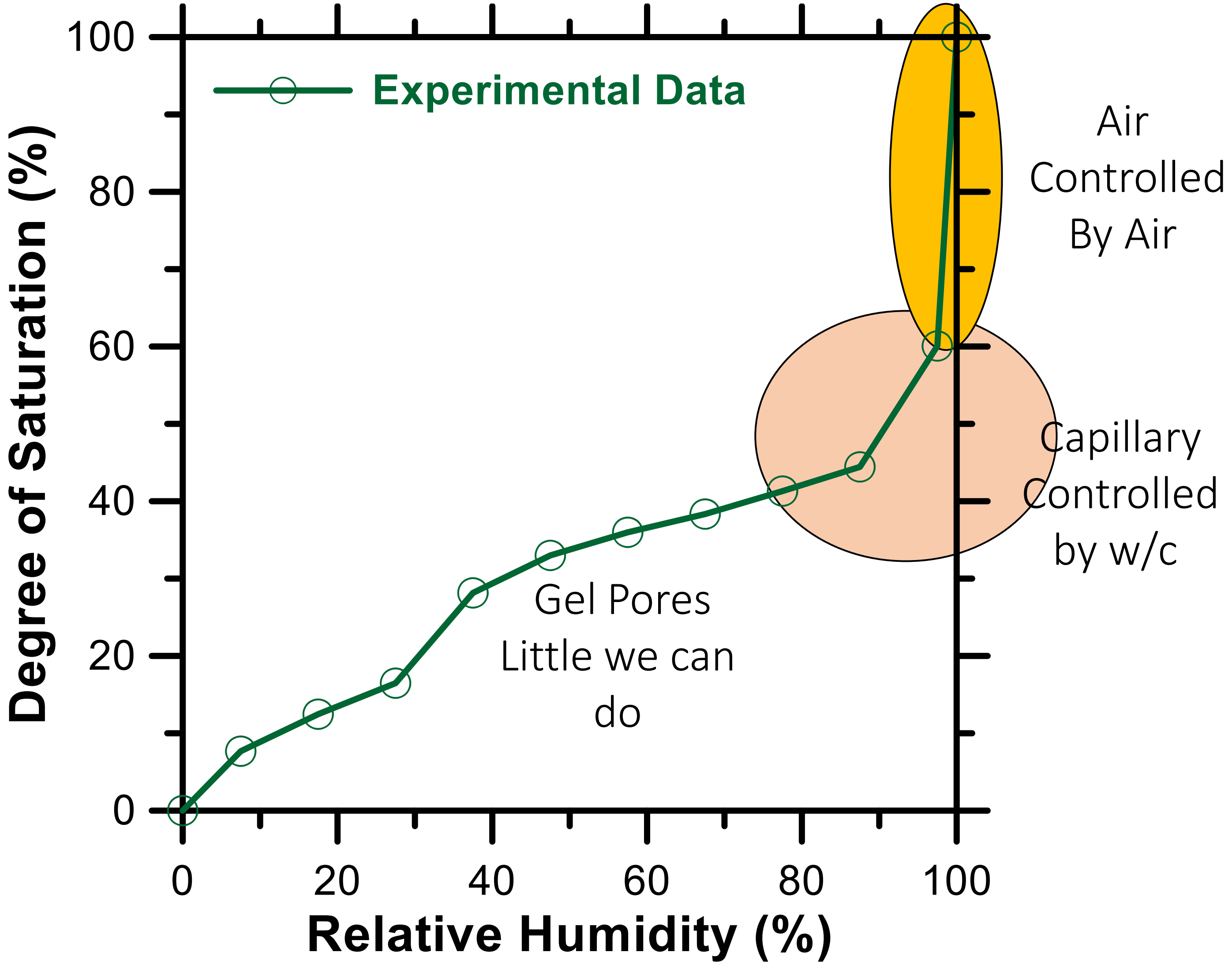
<u>Hardened (Hygral) Shrinkage</u>

- Autogeonous
- * Chemical
- Drying
- Carbonation
- Total

Lets Start to Talk about the Structure of Paste

- Gel Pores (2-5 nm)
  Important for Shrinkage
- Capillary Pores (5nm-10 μm)
  Important for Transport
- Entrained/Entrapped Air
  Important for Freeze Thaw



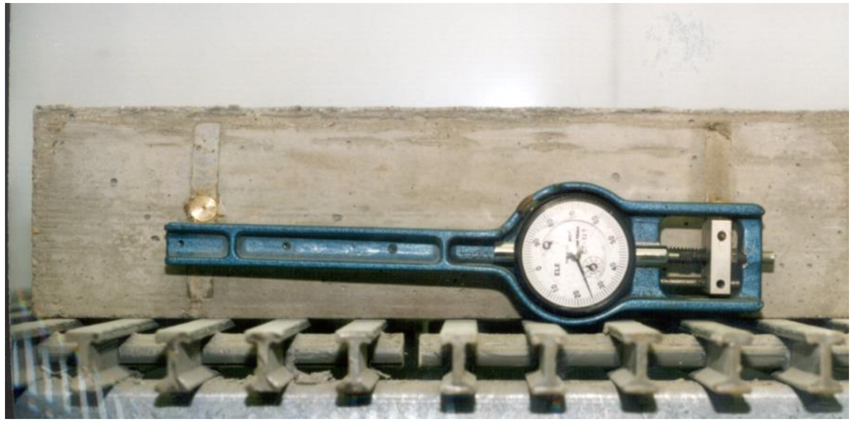


Family Feud the Adjective Edition

Adjectives that describe concrete volume change

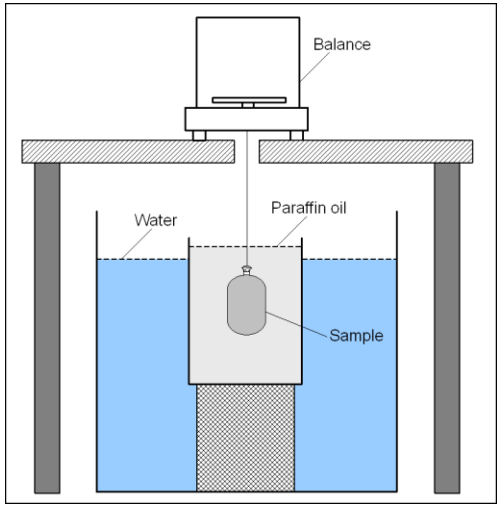
Drying Shrinkage

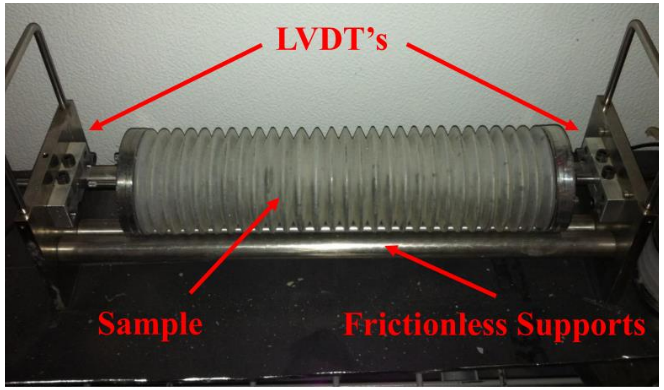
- By Far Everyone's favorite adjective
- Drying Shrinkage – Generally Reserved for Hardened Concrete (Strictly Speaking Just Due to Water Loss, Evaporation or Suction)
- Often used incorrectly to refer to the results of ASTM C 157/341 which is really more of a total shrinkage measure

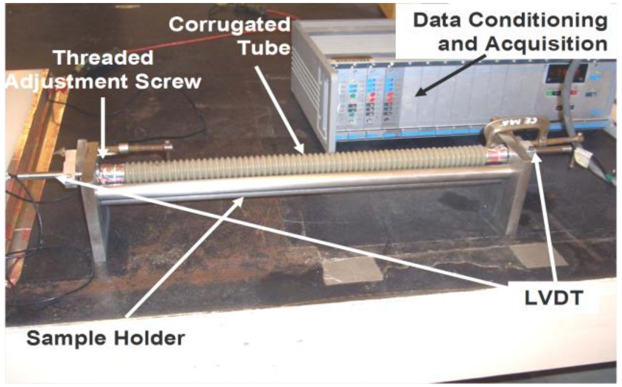


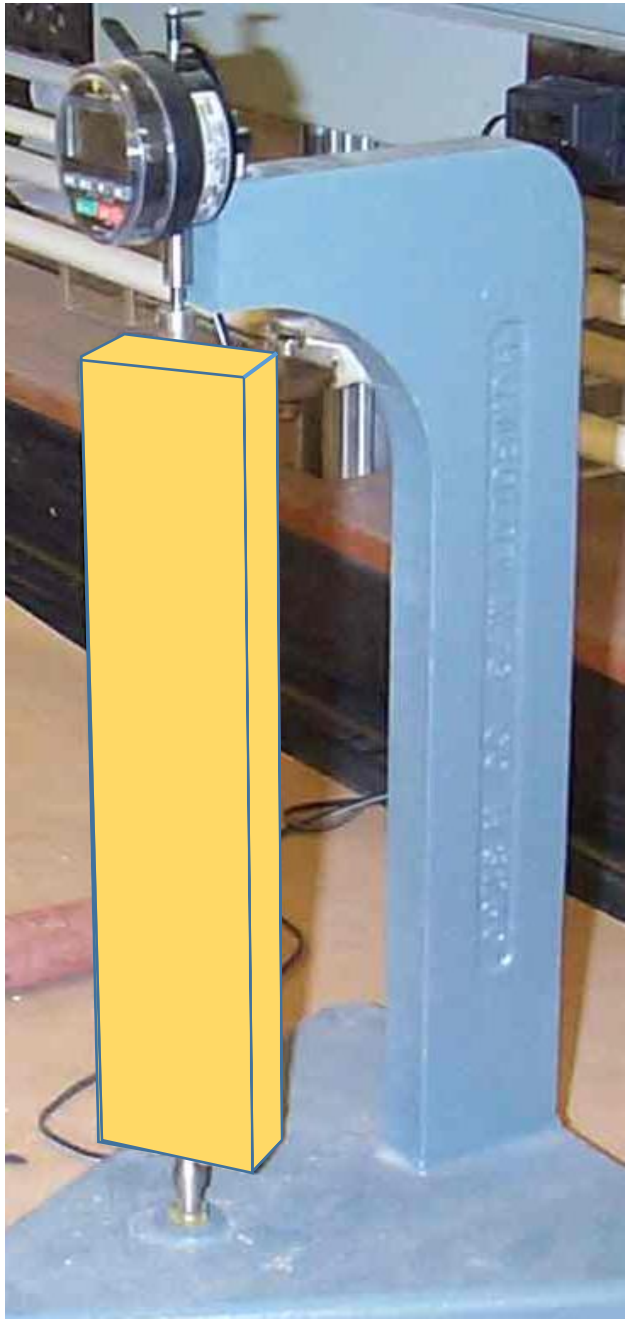
Autogenous (Sealed) Shrinkage

- The modern cool adjective
- Autogenous Shrinkage – the bulk shrinkage of a closed, isothermal, cementitious material system not subjected to external forces
- Measured using membrane, tube, or sealed



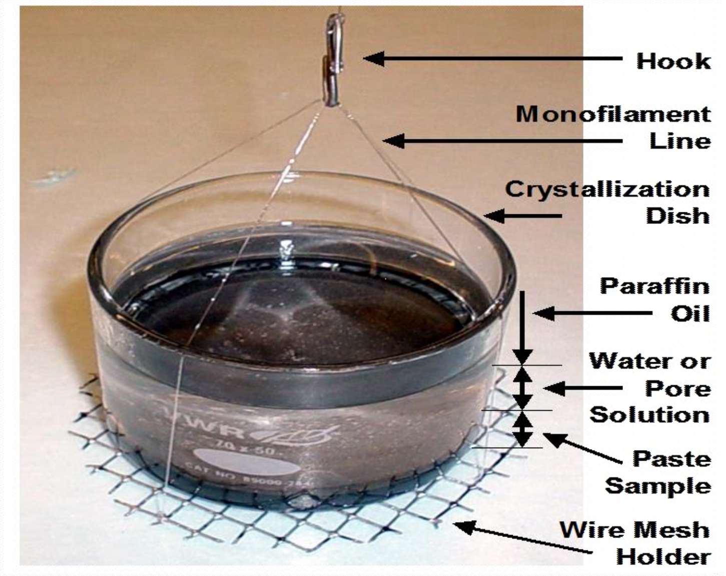


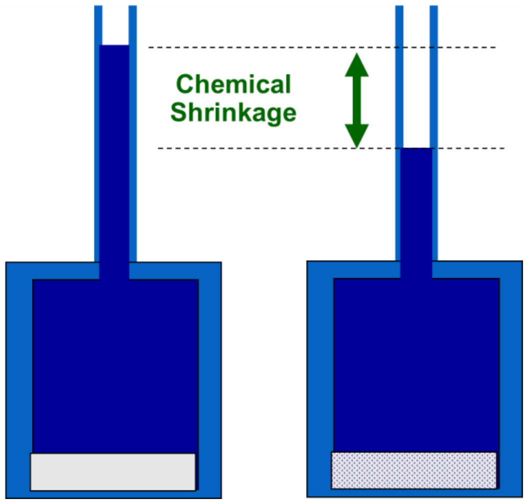


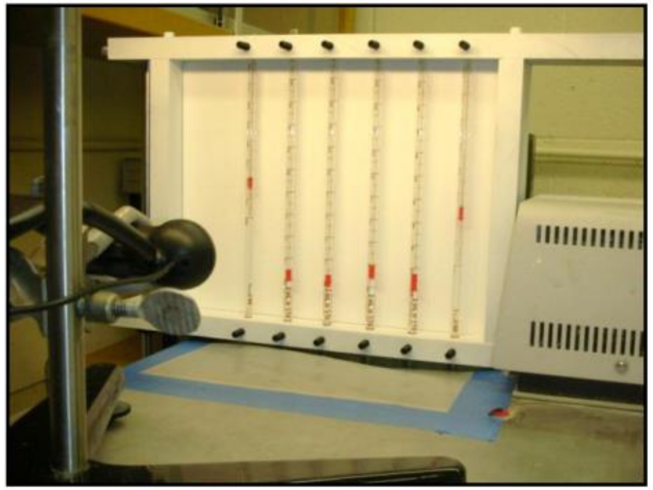


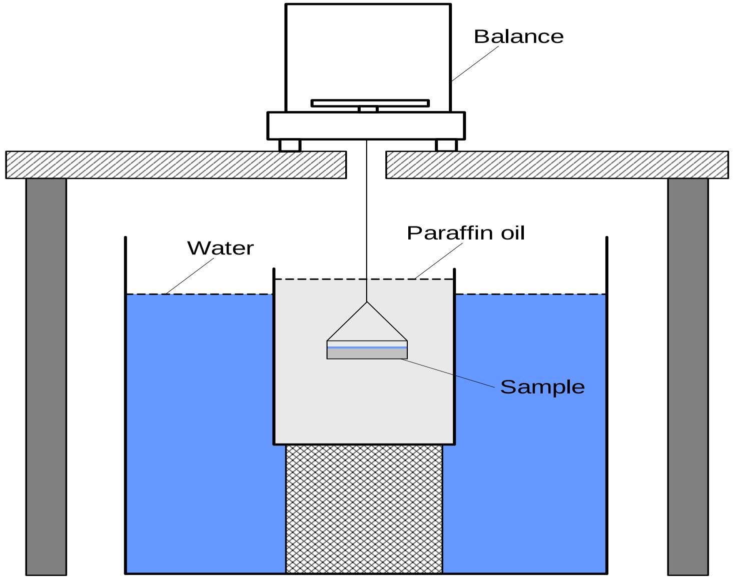
Chemical Shrinkage

- Fancy, Important, but not what we are after
- Chemical Shrinkage – the volume reduction associated with the hydration reactions in a cementitious material
- Measured using boyancy change or pipettes









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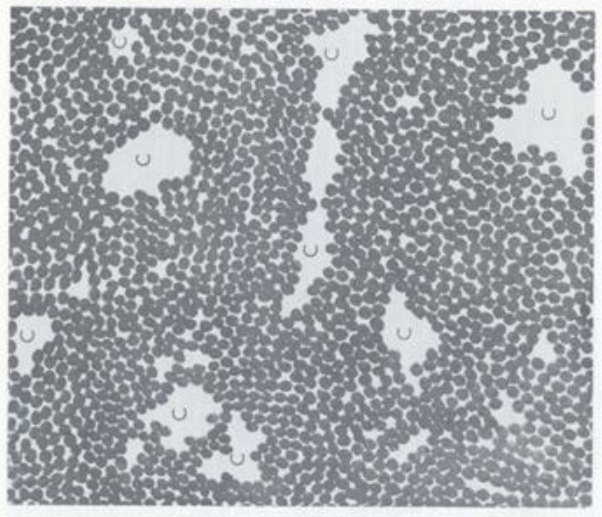
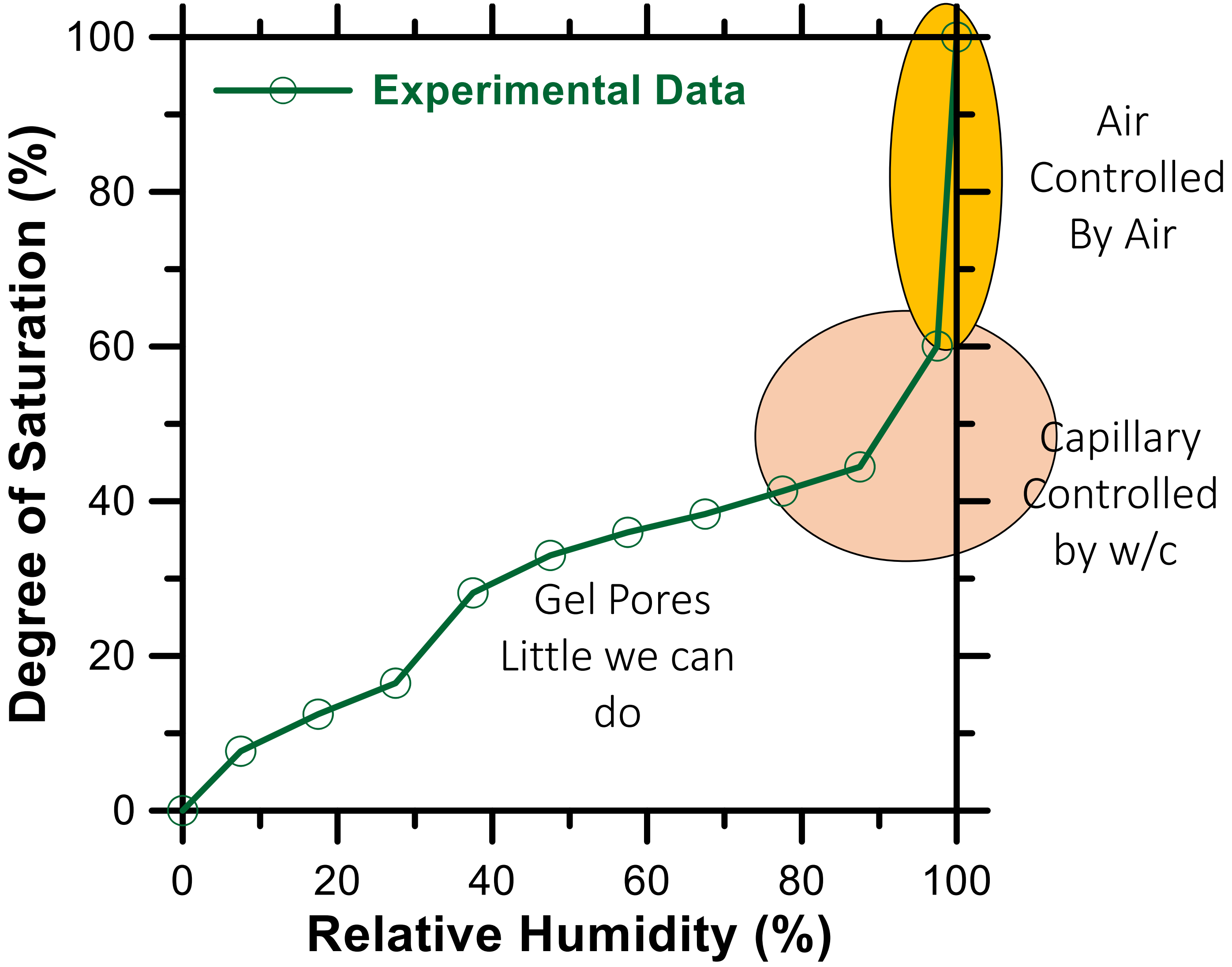
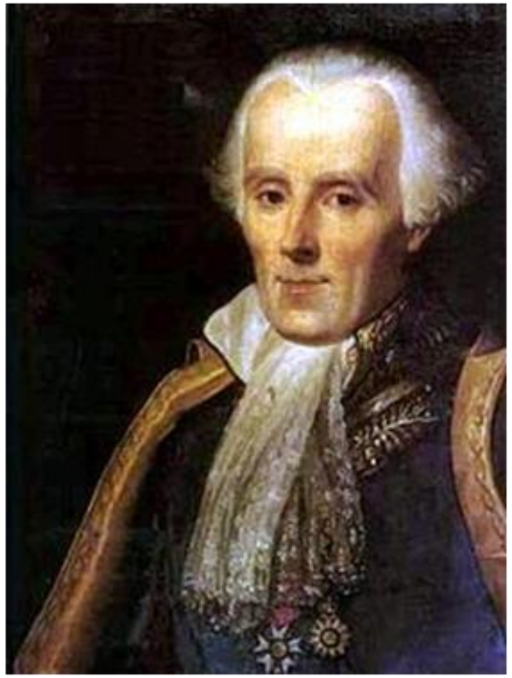




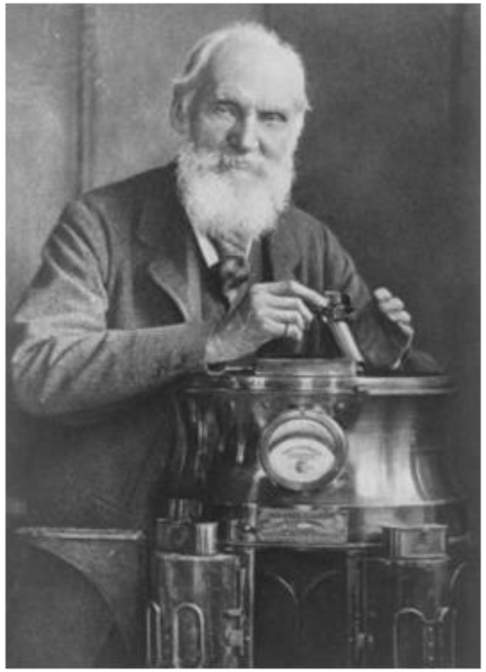
The Heros of Our Story

Thomas Young
(1773 – 1829)

Carl F. Gauss
(1777 - 1855)

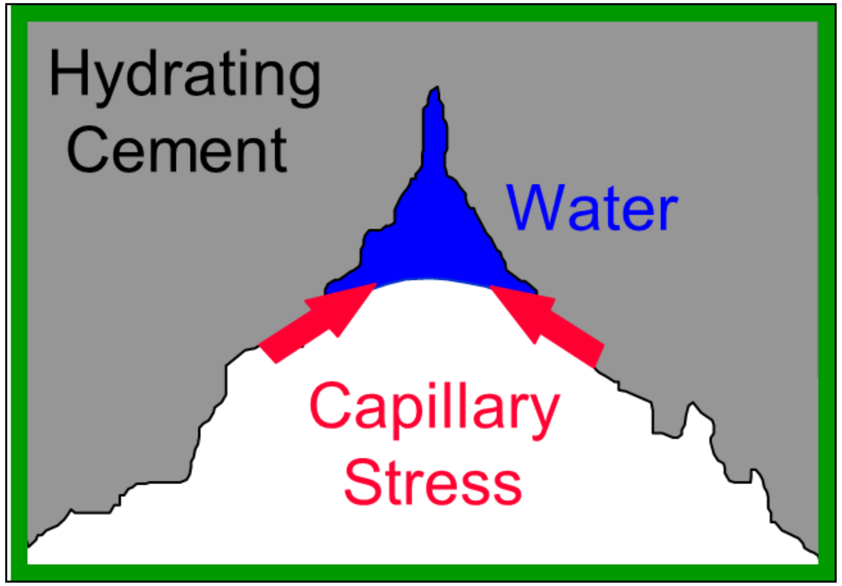


Marquis de Laplace
(1749 - 1827)

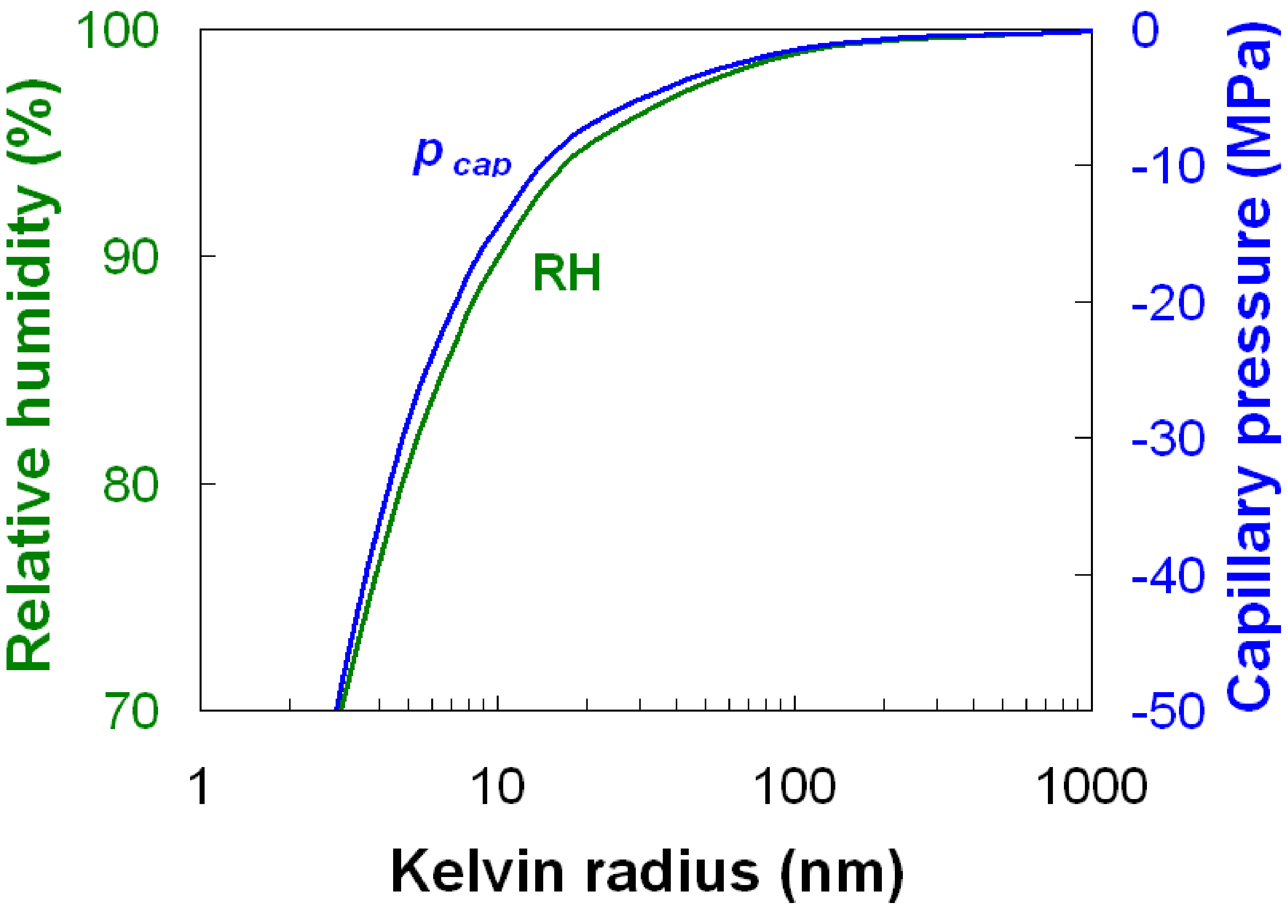


Lord Kelvin
(1824 - 1907)

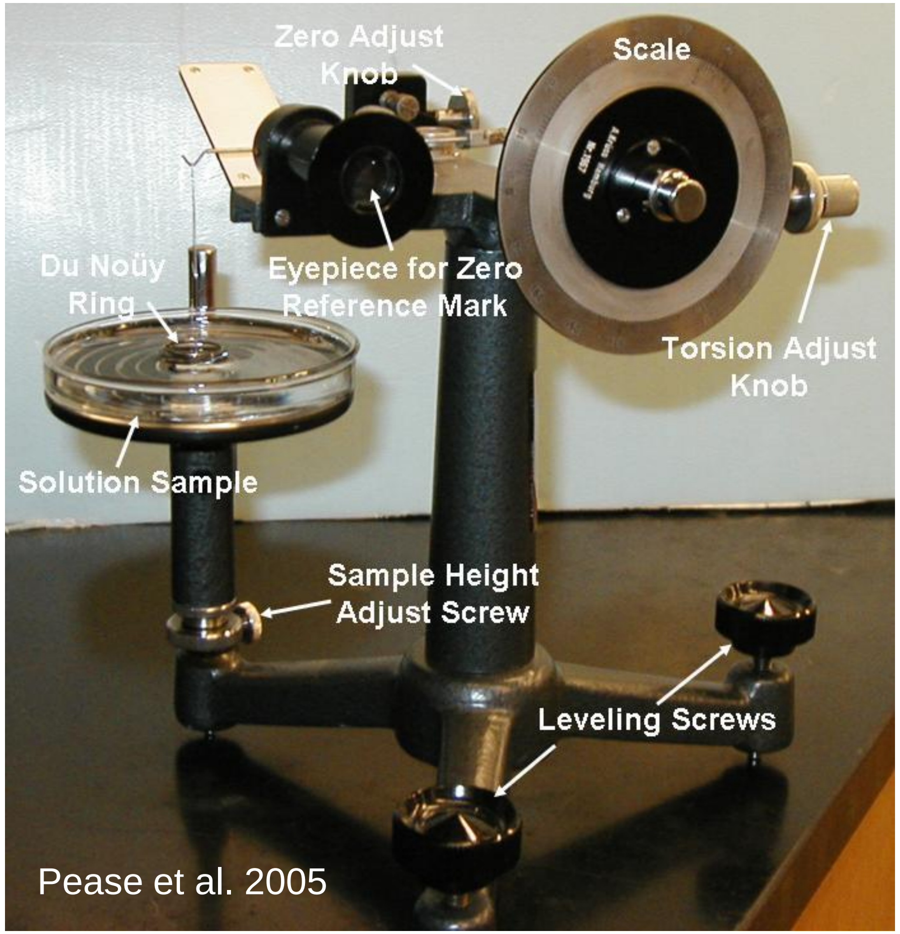
Capillary Pressure

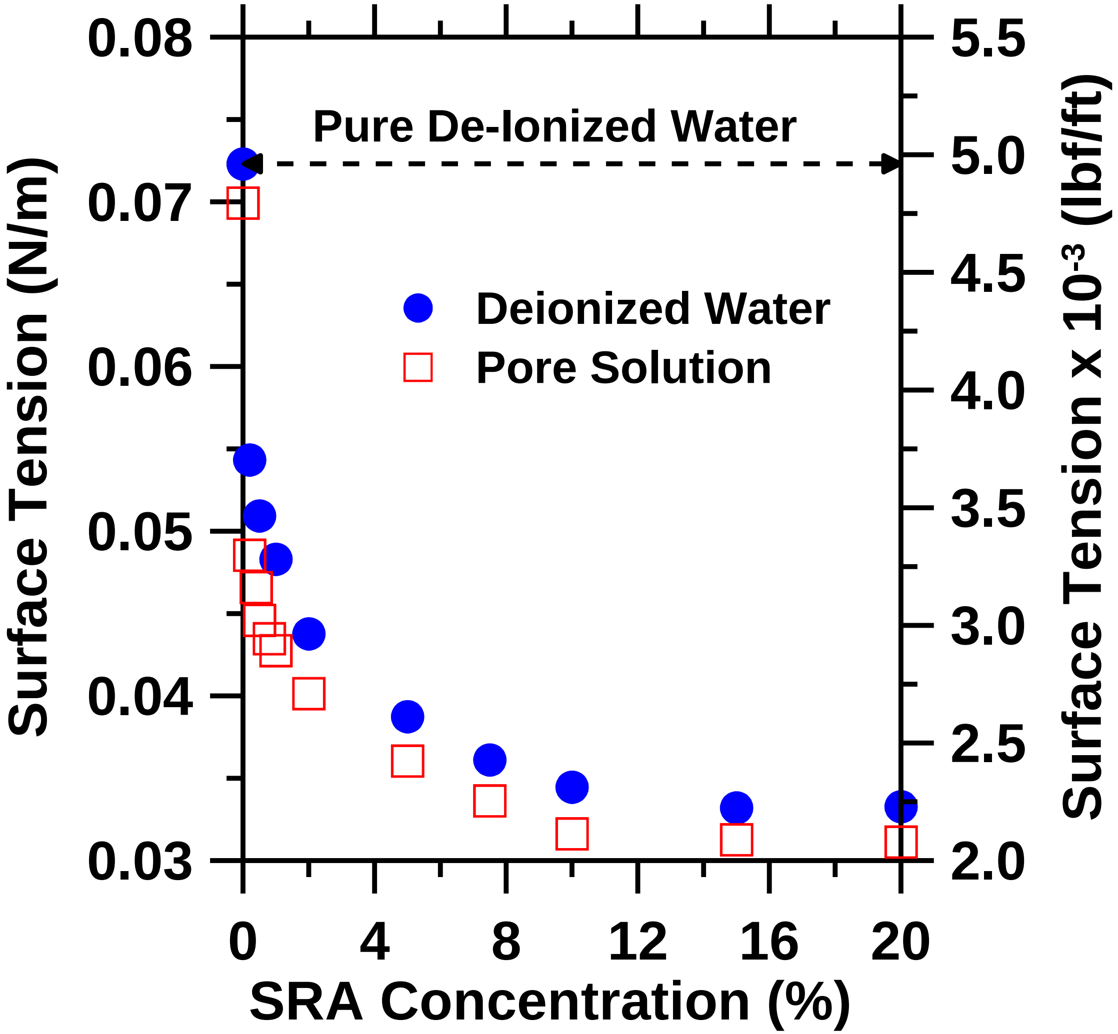


$$p_{cap} = -\frac{2\gamma \cdot \cos\theta}{r}$$



Shrinkage Reducing Admixtures



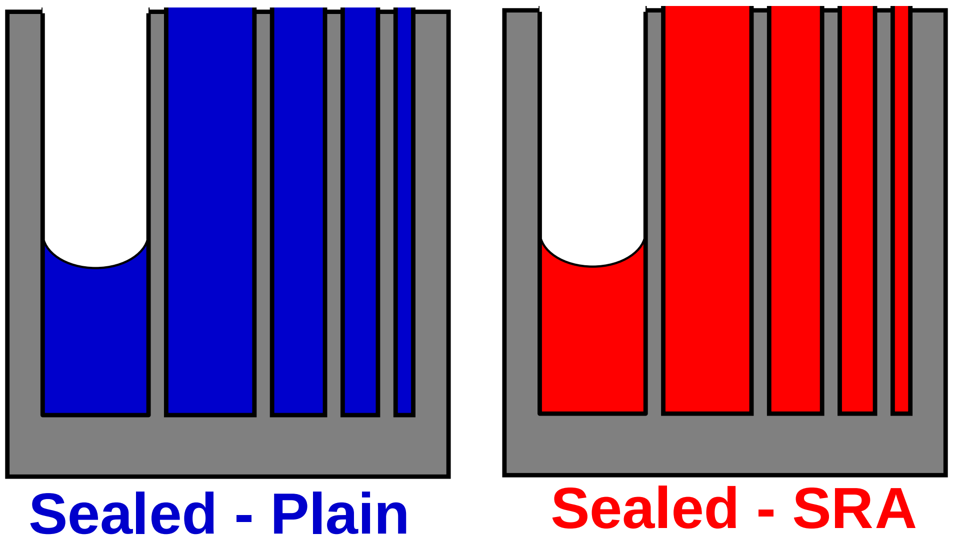


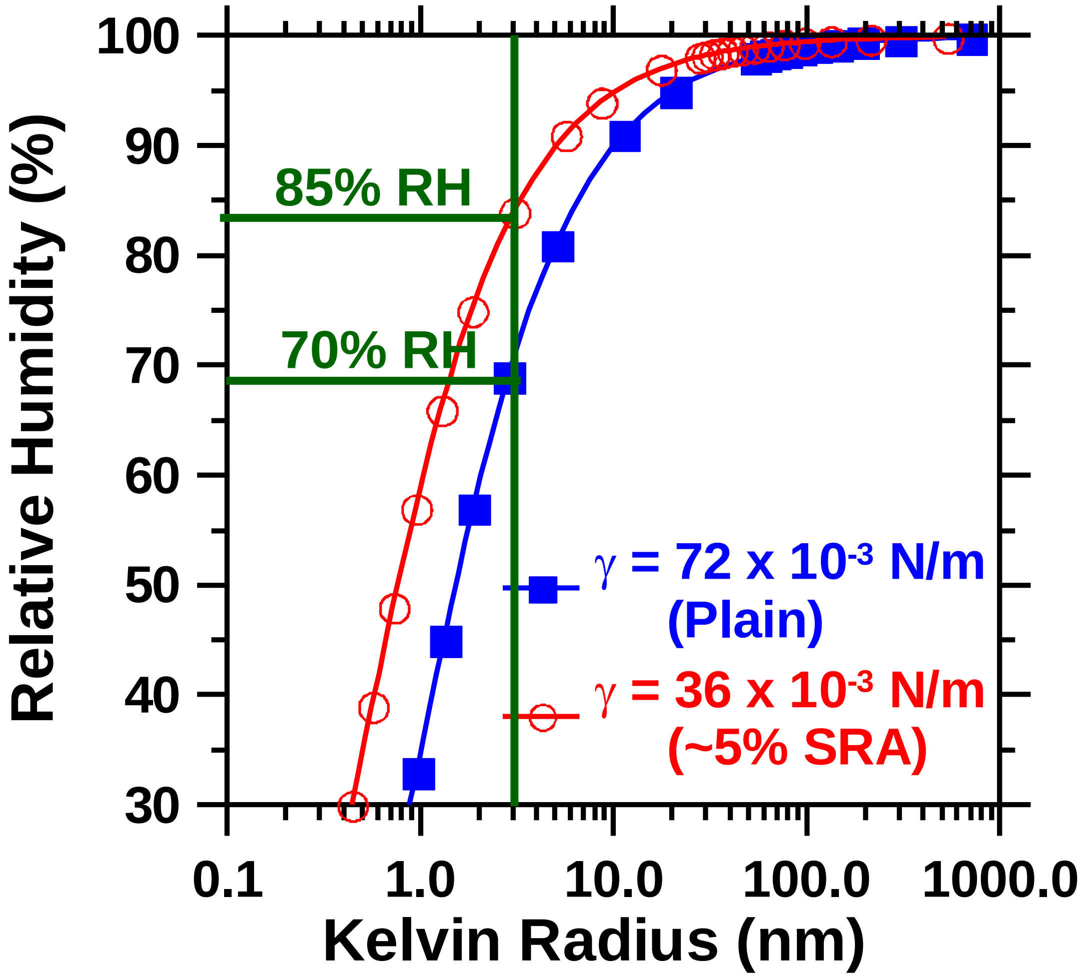
Rajabipour et al. 2008

Sealed Samples

$$\ln\left(\frac{p}{p_0}\right) = \ln(RH) = -\frac{2\gamma\cdot\cos\theta\cdot}{r}\frac{V_W}{RT} = p_{cap}\frac{V_W}{RT}$$

- Water is consumed equally
- The radius is fixed
- The internal RH (Stress) differs

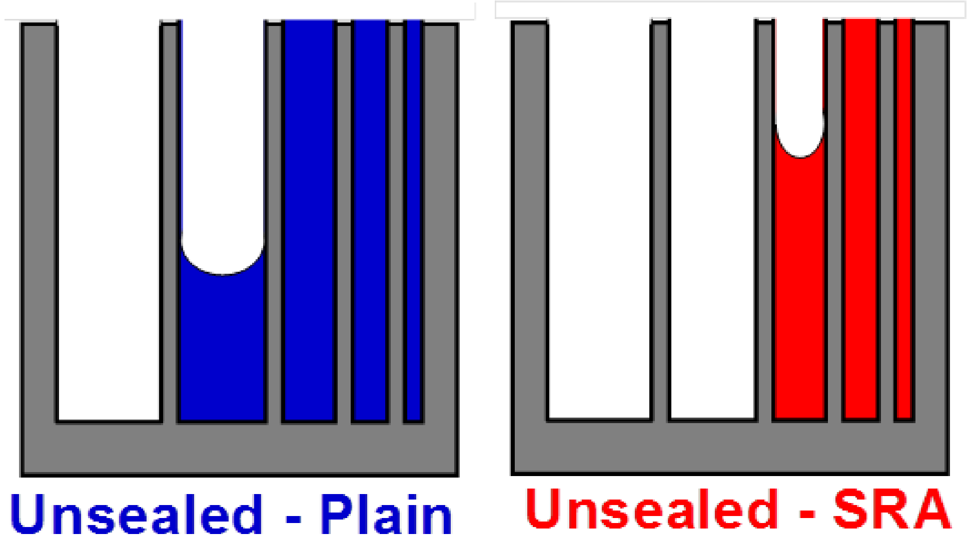


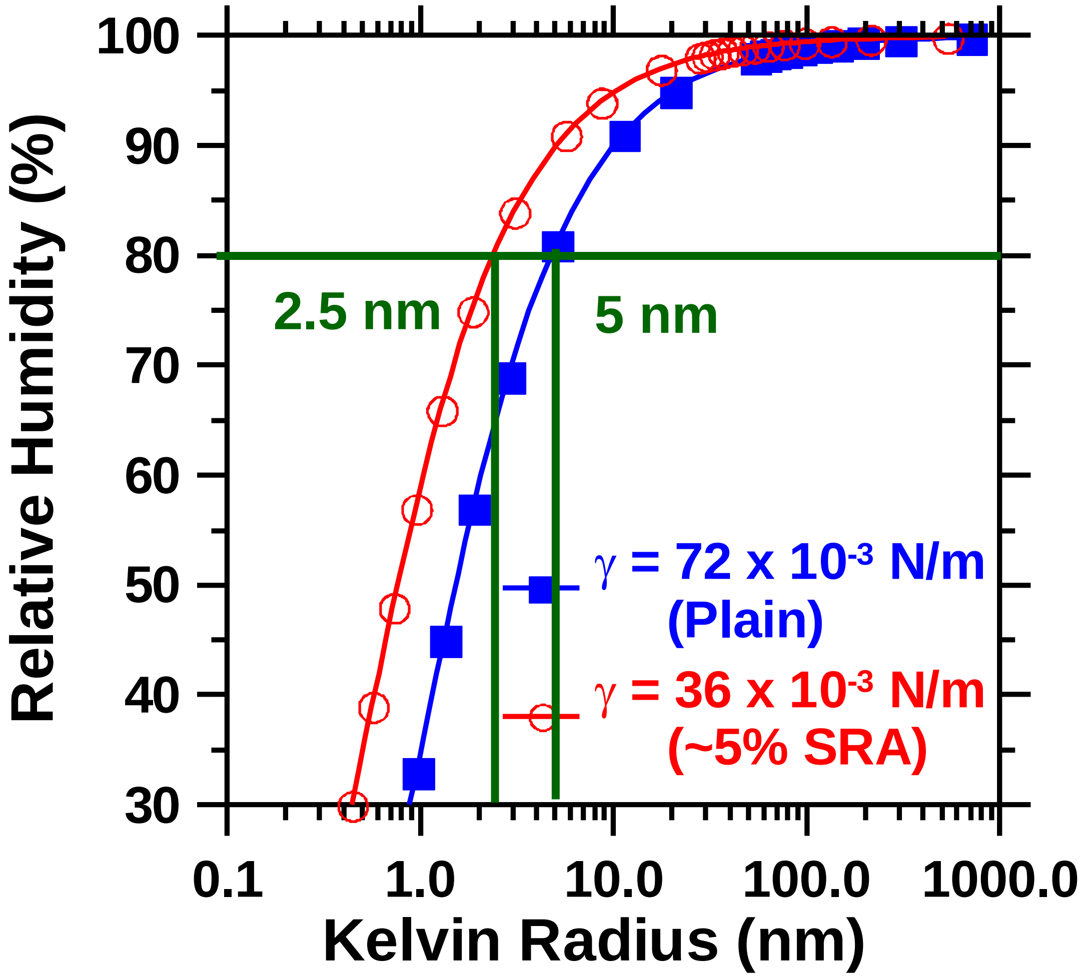


Drying Samples

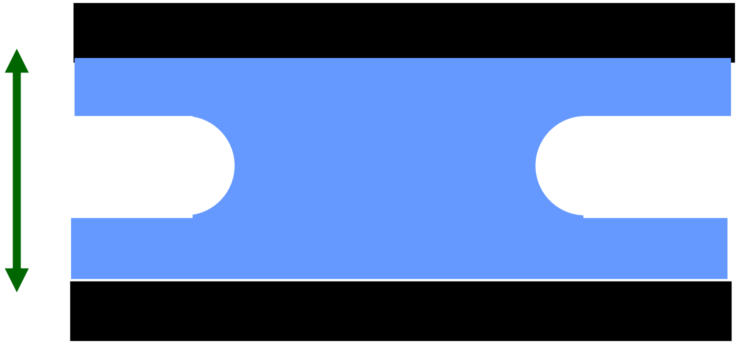
$$\ln\left(\frac{p}{p_0}\right) = \ln(RH) = -\frac{2\gamma \cdot \cos\theta \cdot}{r}\frac{V_W}{RT} = p_{cap}\frac{V_W}{RT}$$

- RH is fixed
- More fluid is lost from SRA
- Stress is the same, except if capillary stress argument fails

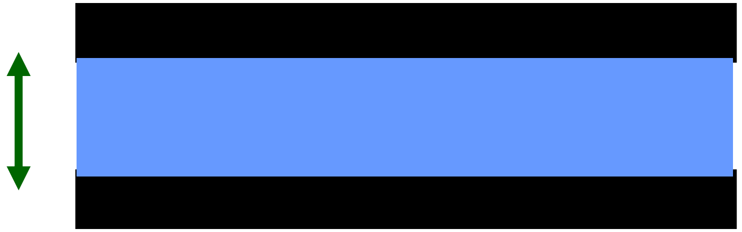


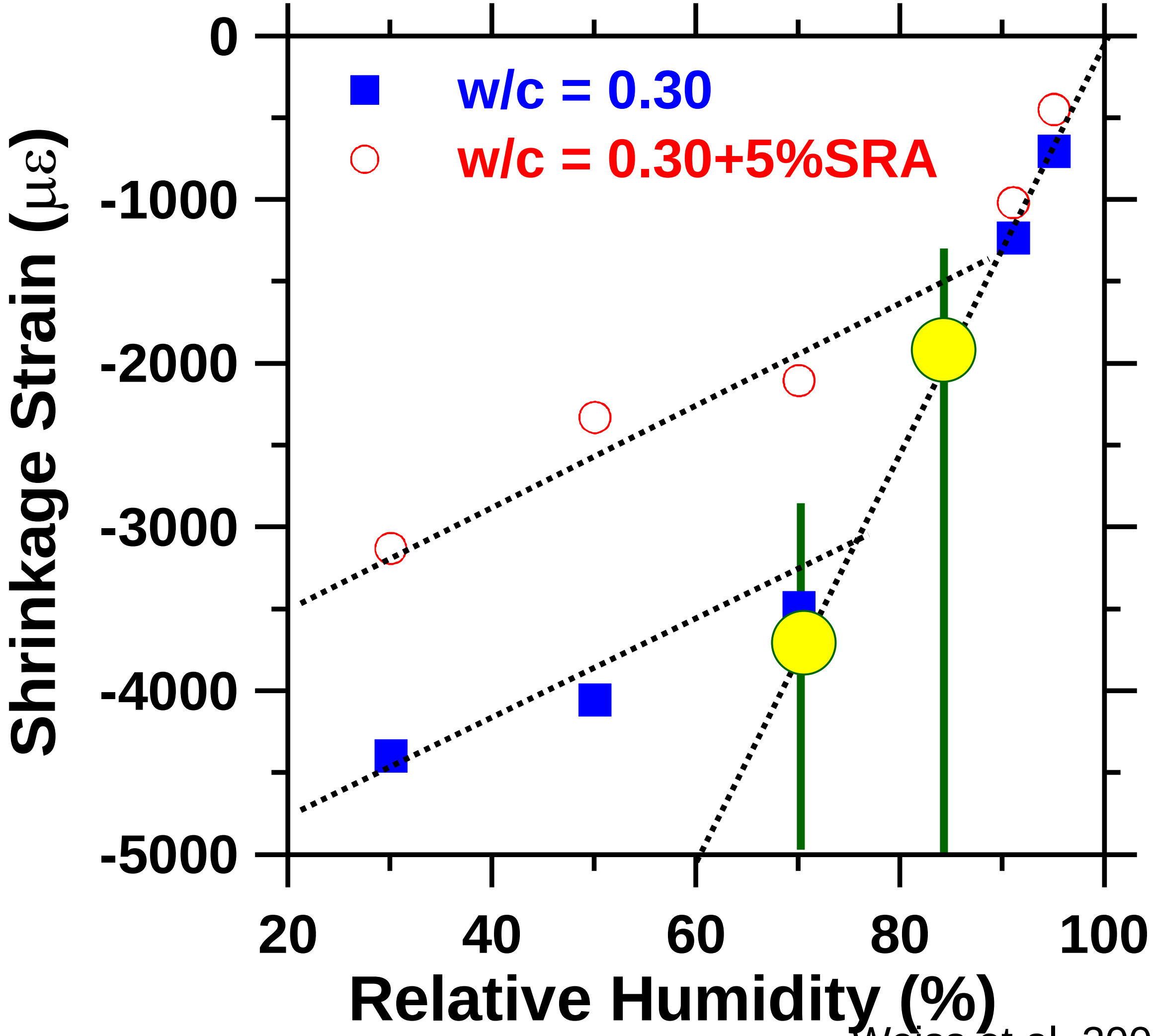


When are Pores Too Small for Capillary Stress



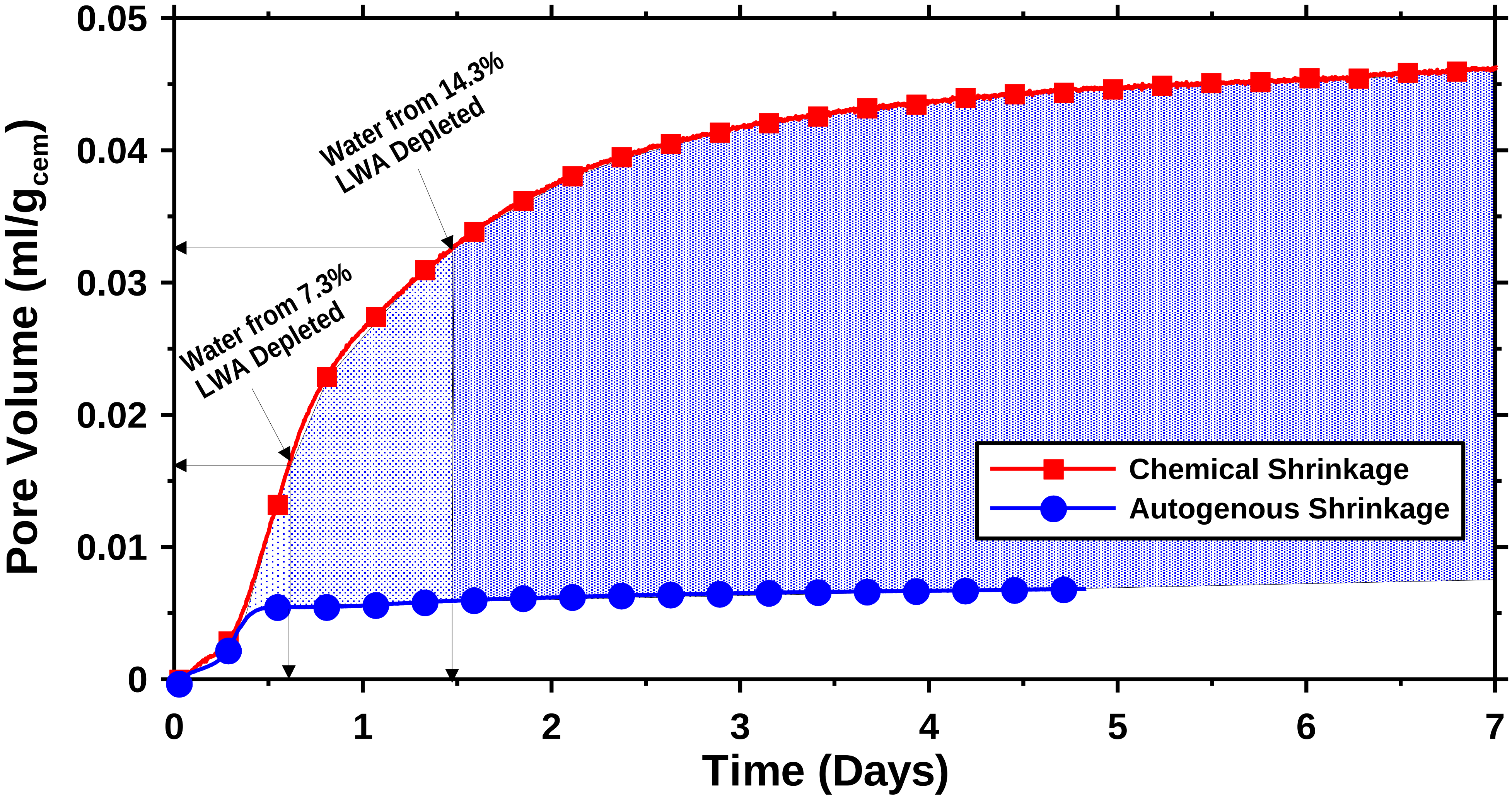
- Christenson - 1.5 nm
- Fischer and Israelachivili - 3 nm



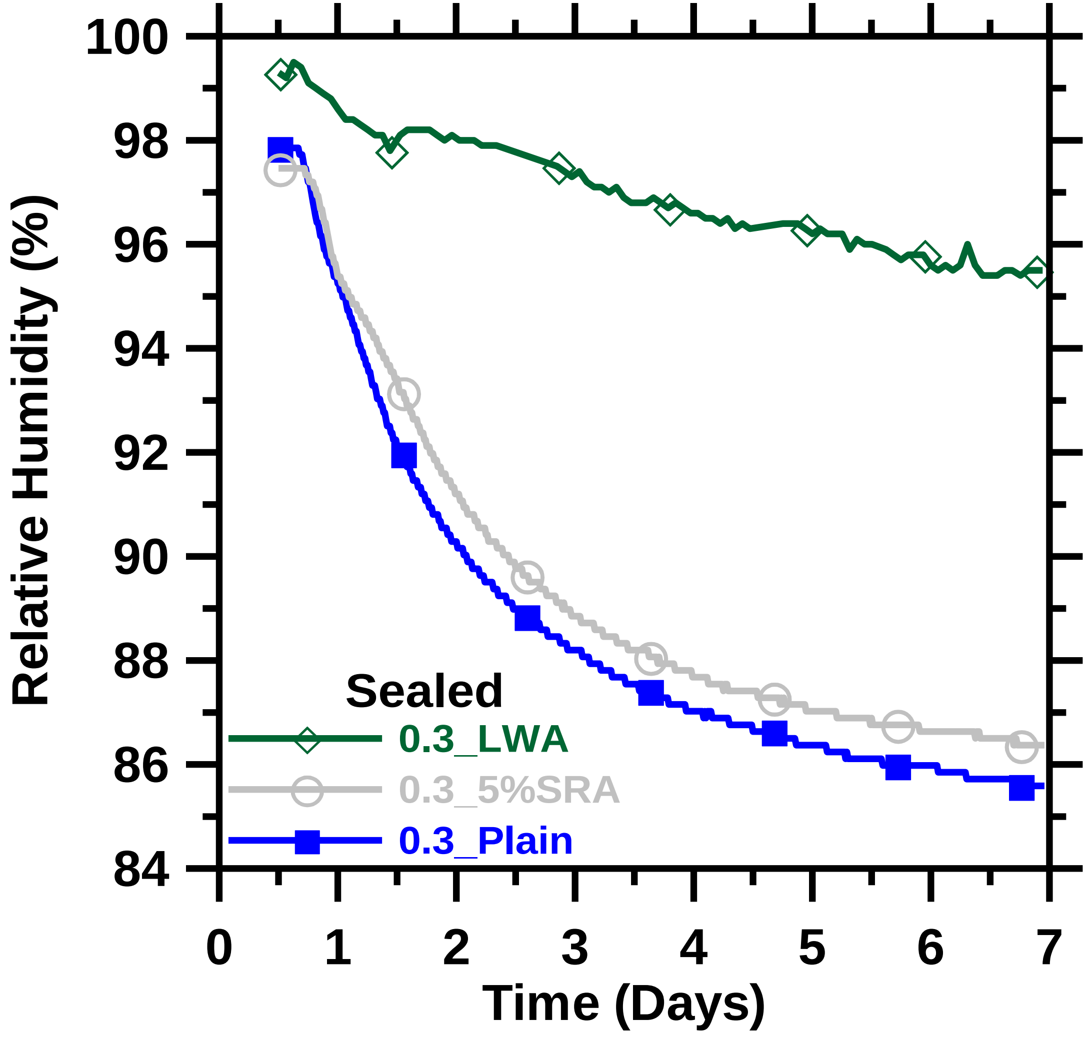


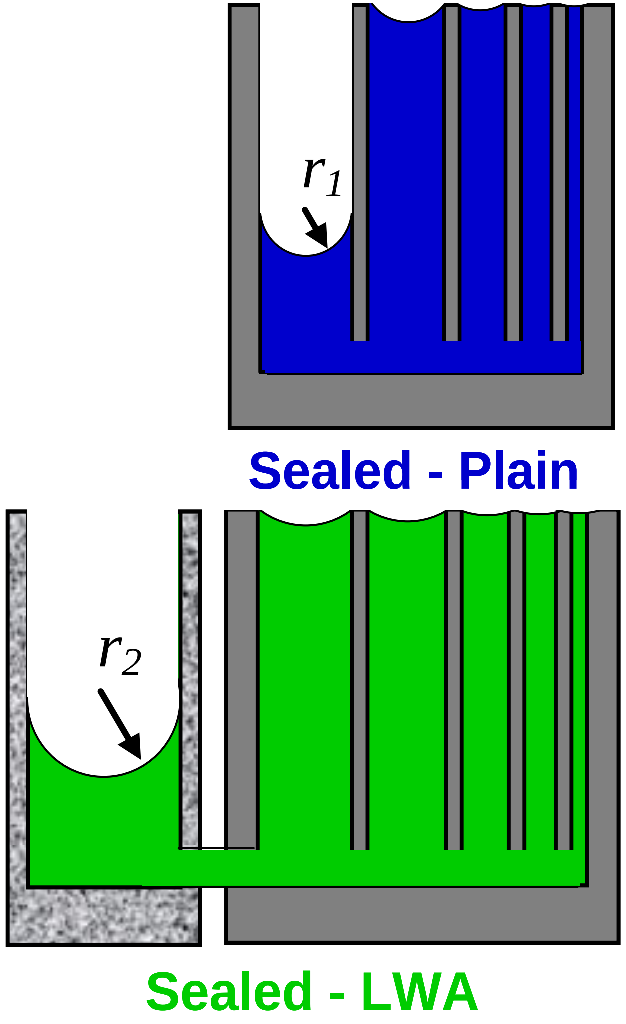
Weiss et al. 2008

How Does this Relate to Internal Curing



Internally Cured Samples – Sealed

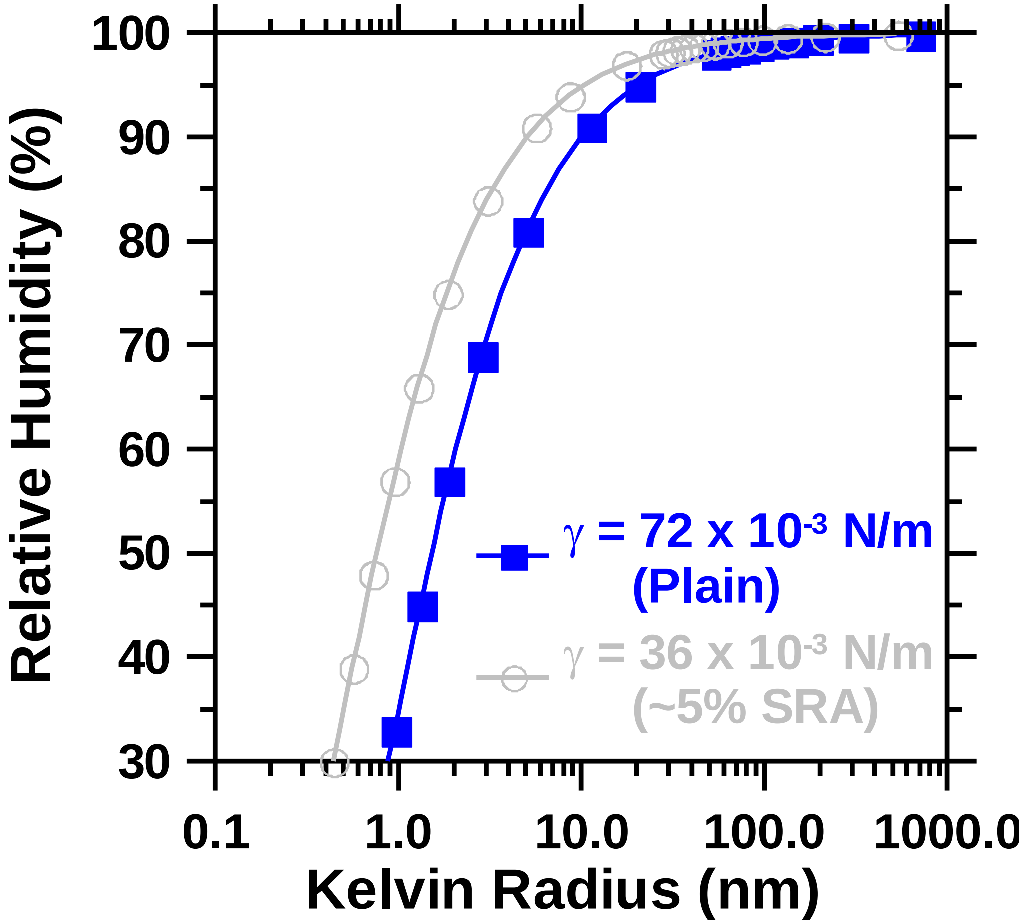


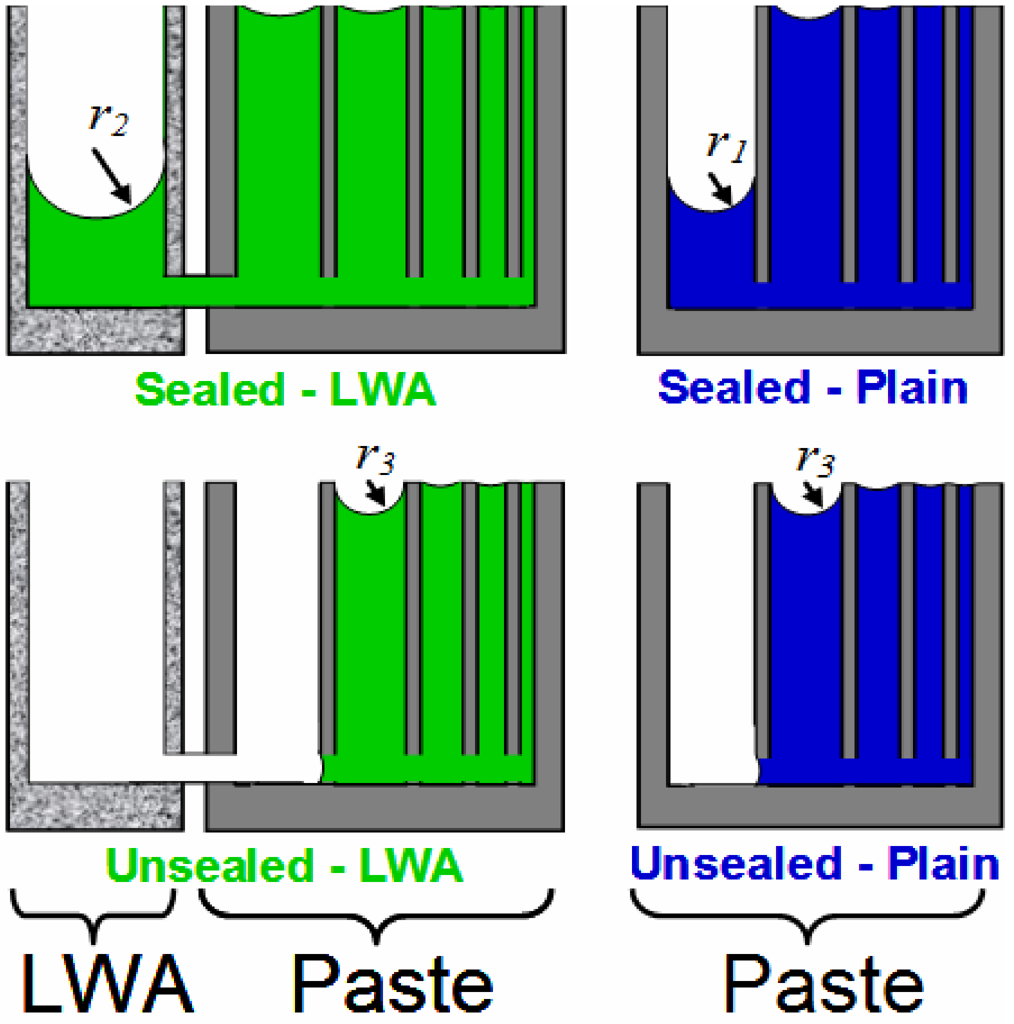


A Similar Volume of Water is Depleted

LWA higher r in Agg

Internally Cured Samples – Drying





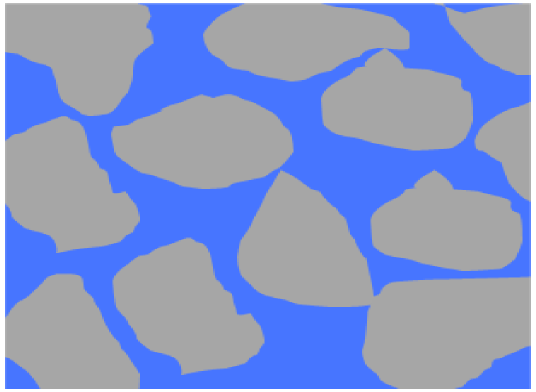
A Brief Summary of What We Know

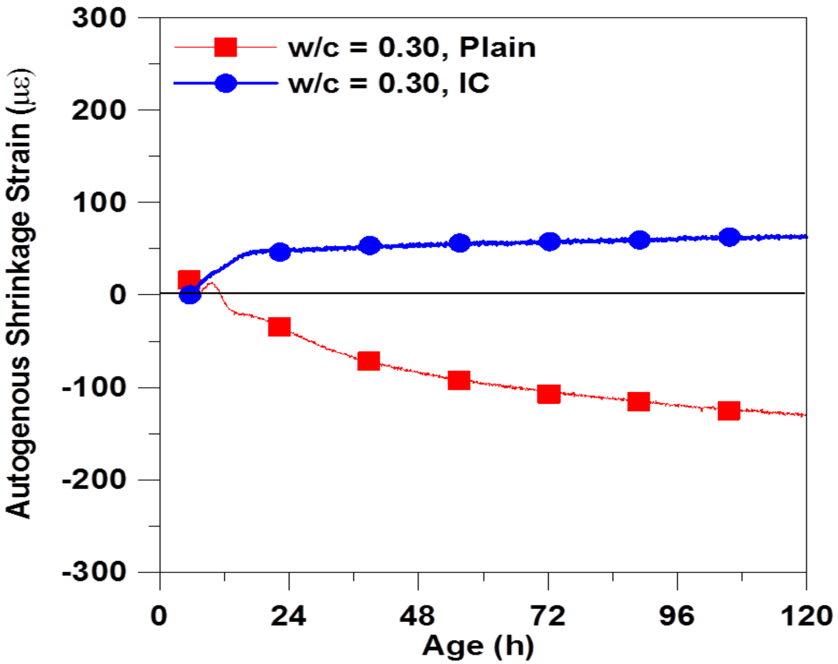
Autogenous Shrinkage		
	SRA concrete	LWA concrete
Vol of water consumed by hydration	↔	↔
Menisci radius	↔	↑
Capillary pressure	↓	↓
Internal RH	↑	↑
Free shrinkage of paste	↓	↓
Mass loss (evaporation)	0	0

Drying Shrinkage*		
	SRA concrete	LWA concrete
Saturation of paste	↓	↔
Menisci radius	↓	↔
Capillary pressure	↔	↔
Internal RH	$RH_{ambient}$	$RH_{ambient}$
Ultimate free shrinkage of paste	↓	↔
Ultimate mass loss (evaporation)	↑	↑
Rate of shrinkage prior to equilibrium	↓	↓

What are the Benefits of IC

- Reduced Autogenous Shrinkage/Cracking
- Increased Cement Hydration





Barrett (2013)

- Improved Curing when Short Cure Times are Permitted
- Potential to Reduce Curling

Dual Ring Test (AASHTO Provisional)

Standard Method of Test for

Evaluating Stress Development and Cracking Potential due to Restrained Volume Change Using a Dual Ring Test

AASHTO Designation: T XXX-12

1. SCOPE

1.1. This test method covers the evaluation of stress development and cracking potential in concrete when volume changes caused by shrinkage and temperature changes are restrained. The procedure is comparative for the degree of restraint of the ring and is not intended to determine the time of initial cracking of a concrete cast in any specific type of structure.

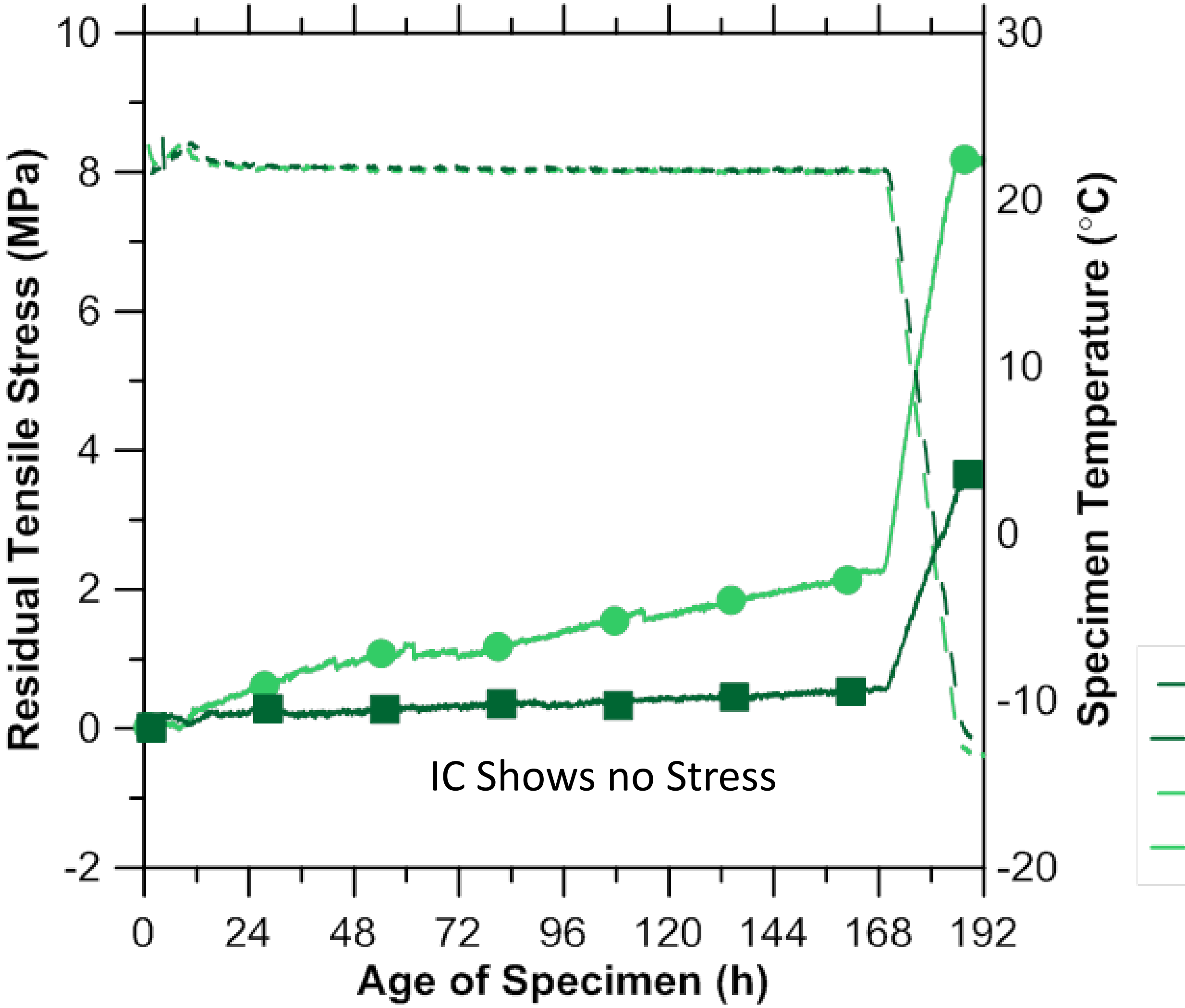
1.2. The values stated in SI units are to

1.3. *This standard does not purport to a*
use. It is the responsibility of the
health practices and determine the a

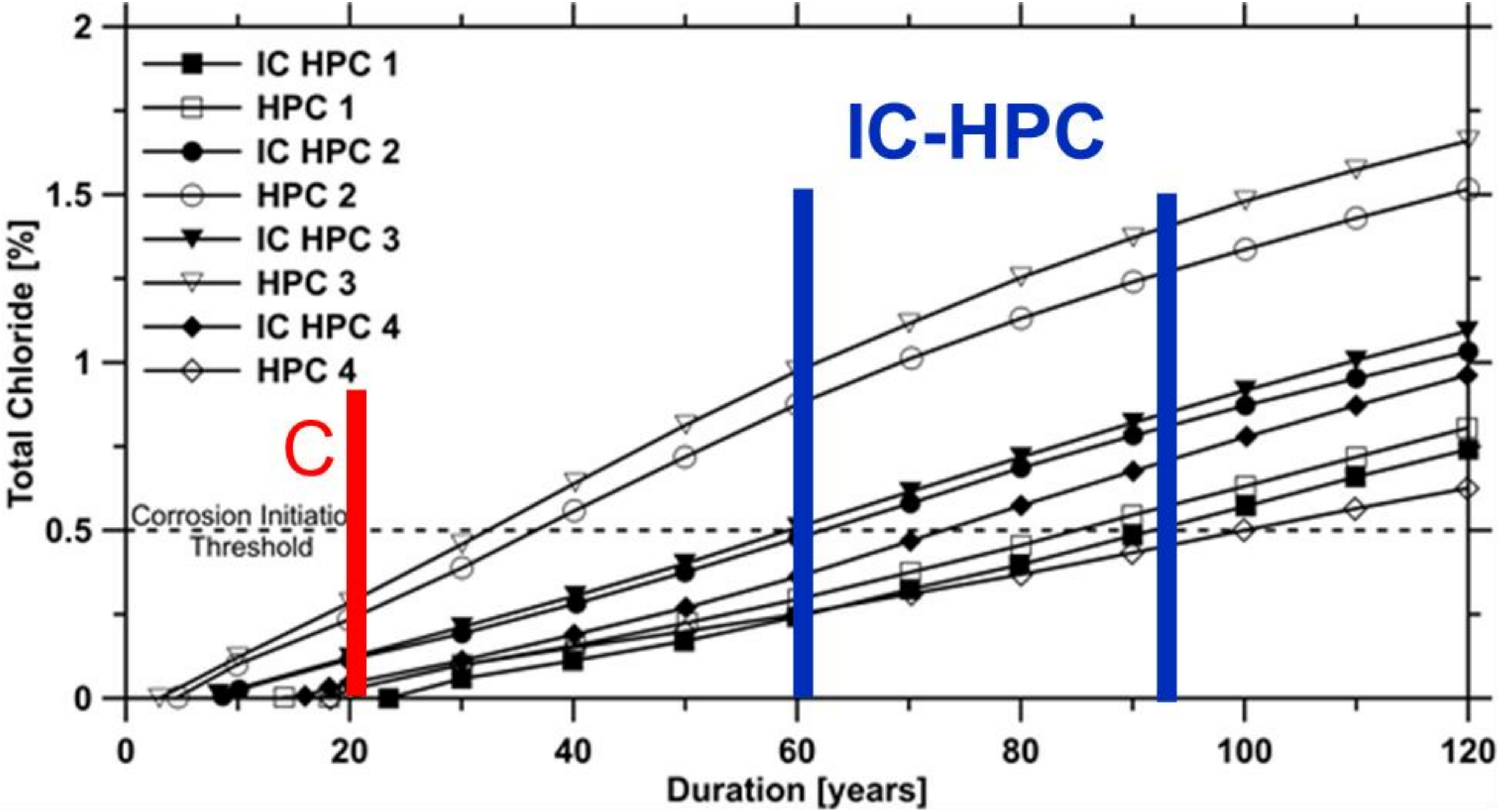
2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards:*
R 39, Making and Curing Concrete

2.2. *ASTM Standards:*
C 305, Practice for Mechanical M
Consistency

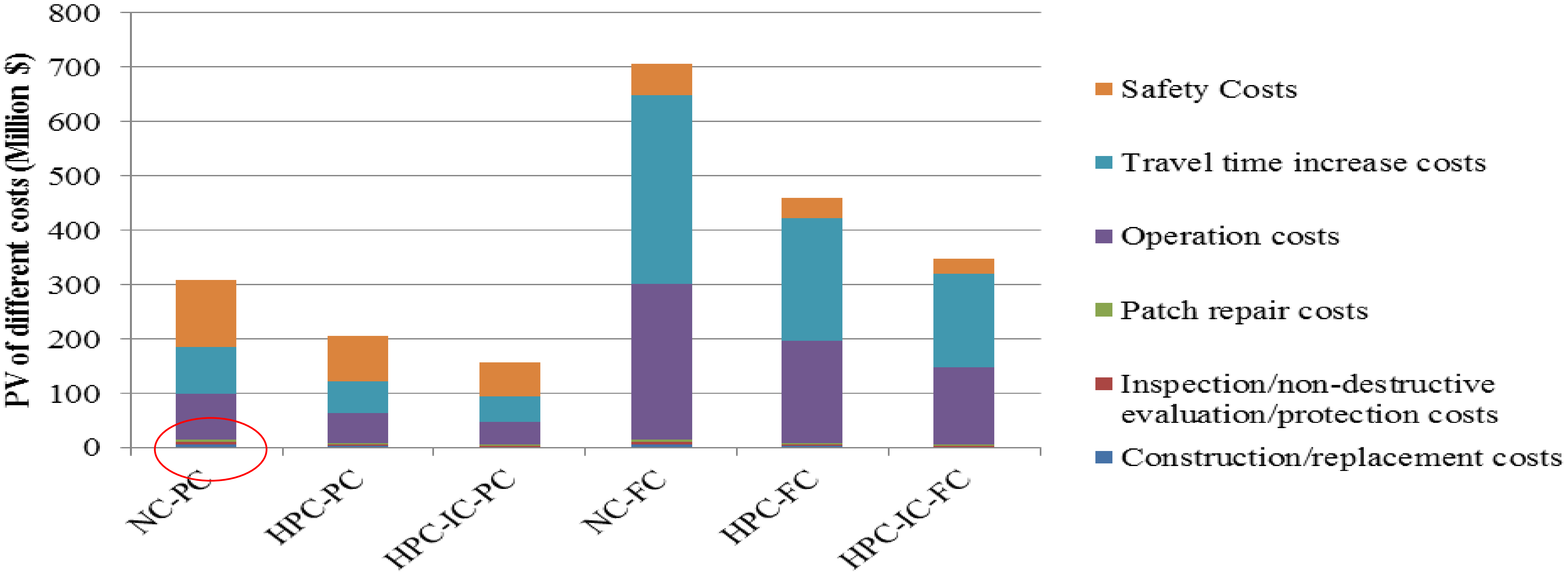


Time to Corrosion Studies (2013 decks)



Cost Implications (Considering Social Cost)

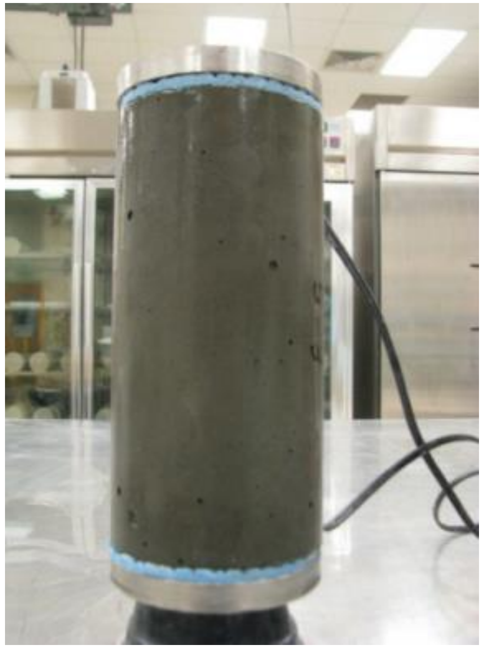
- 1 bridge not three, 5% materials, 1% project
- Sustainable, Safety, Public Benefits

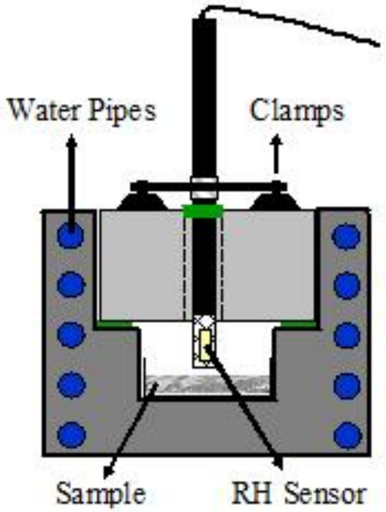


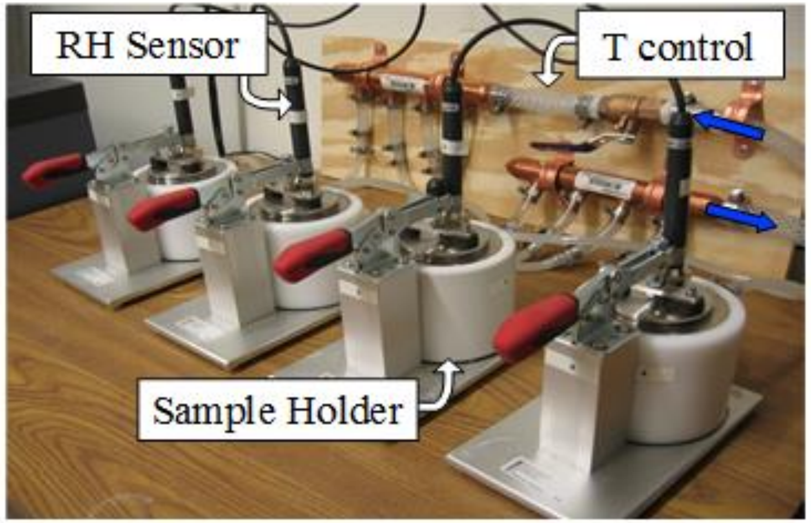
BREAKING NEWS

A Better Test for Internal Curing

- What is it that we want ?
- Do we have concrete that is hard for ions to be transported in? F
- Do we have a high RH when self-dessicating concrete is sealed? RH







Conclusions

- Internal Cured HPC has been shown to be scientifically valid, able to be built in the field, to extend service life and to reduce cracking
- While many studies have been performed experiments are still ongoing to evaluate this material
- ASTM C39, C157 are not the best way to evaluate IC
- Restrained shrinkage cracking, transport, and RH tests are better

- Personally I think we now have a choice

The Choice is Yours

Add Internal Curing to the Tool Box

Continue Testing Internal Curing
As a Trial Material – What Criteria Do We Need ?

Choose to Not Internal Cure and Continue Placing Decks as We Are While we Search For Solutions to Reduce Cracking

Thank you!

Additional Resources

http://cce.oregonstate.edu/internalcuring