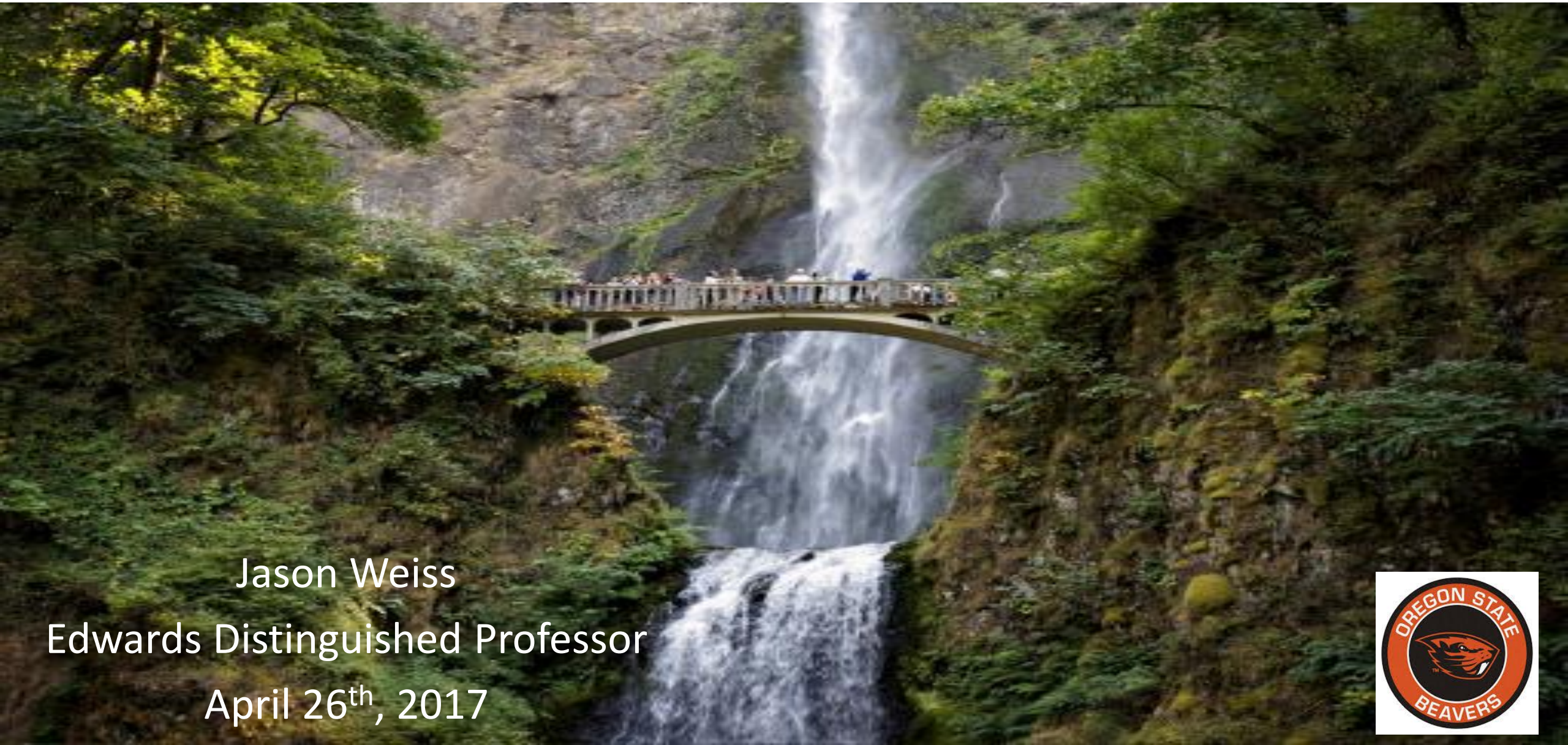


Shrinkage and Internal Curing



Jason Weiss

Edwards Distinguished Professor

April 26th, 2017




12 Years Later - Internal Curing Works

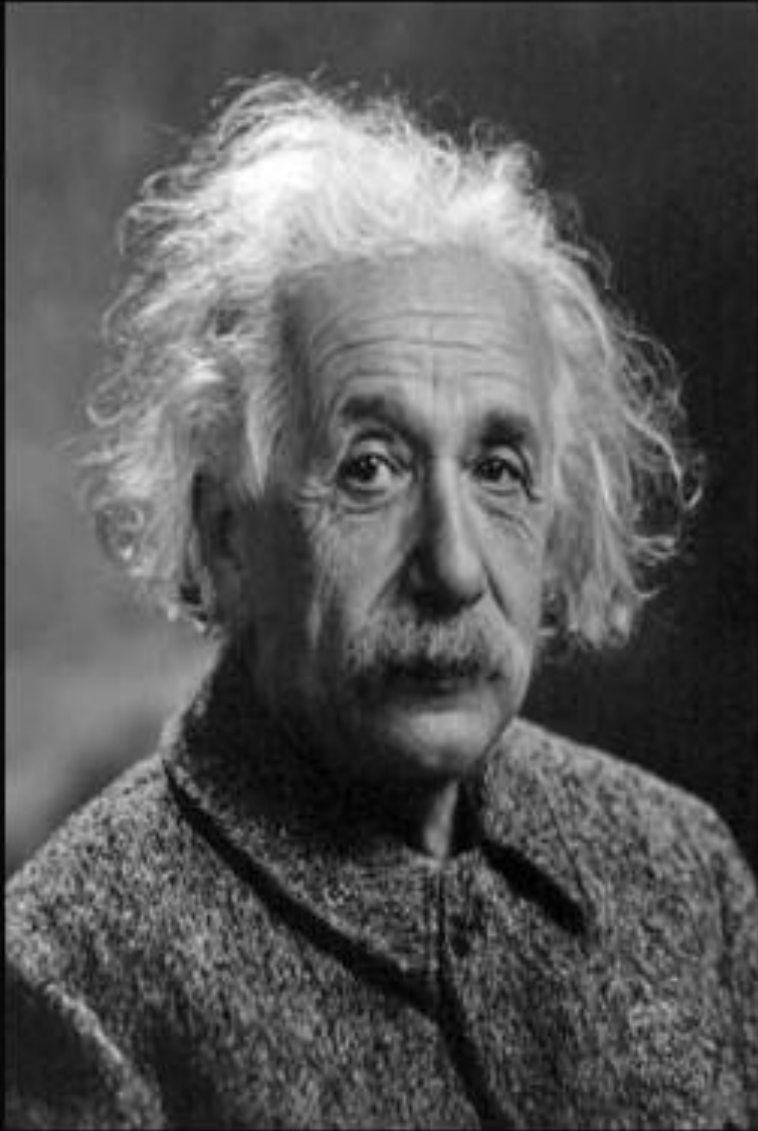
- Science has been demonstrated
- Constructability has been demonstrated
- Increased service life has been shown (IN 24 to 70 years; without considering the benefits of reductions in cracking)
- New QC procedures implemented
- Cracking due to material related substantially reduced in IC decks



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)



We can't solve problems by using the same kind of thinking we used when we created them.

(Albert Einstein)

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'

Fresh (Plastic) Shrinkage

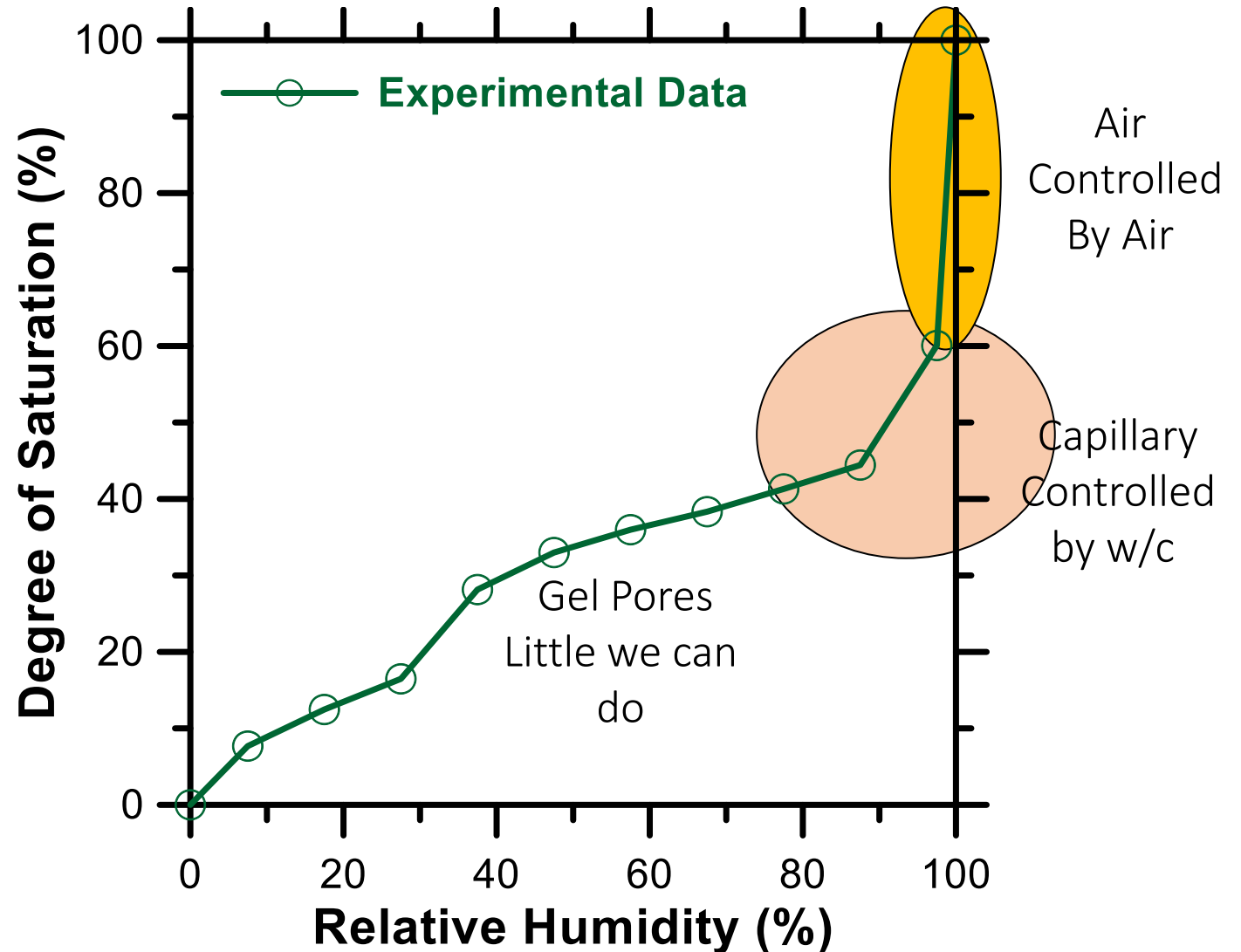
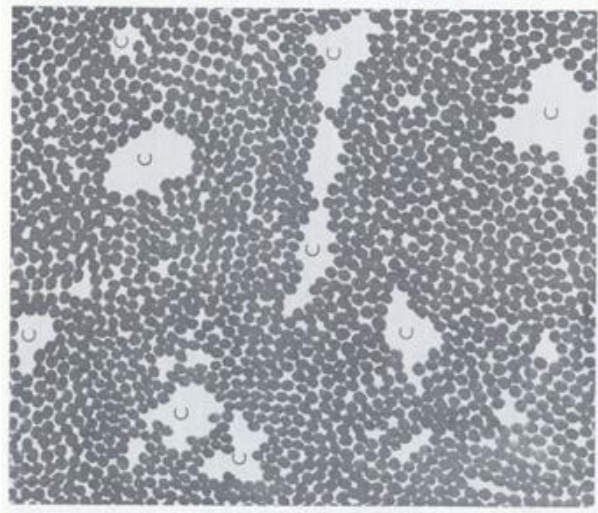
- Evaporation
- Settlement
- Autogenous

Hardened (Hygral) Shrinkage

- Autogenous
- * 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

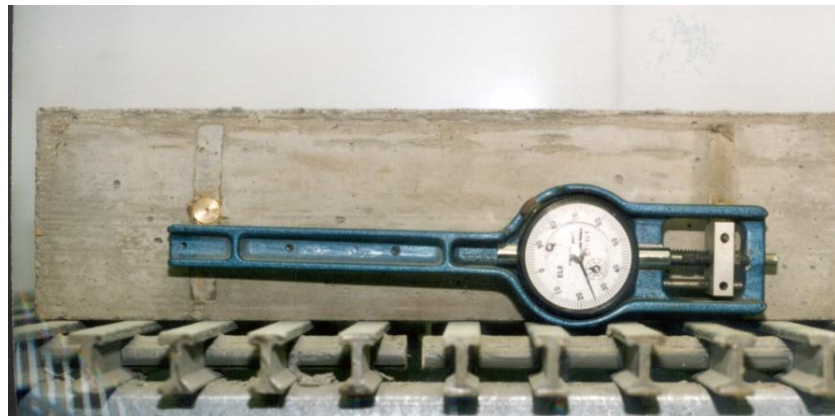
The game board features a central oval with a grid background. At the top of the oval is a digital display showing the number 123. On the left side, a red digital display shows 20. On the right side, a blue digital display shows 63. In the center of the oval, there is a table with three rows of adjectives and their corresponding scores:

Autogenous	4
Drying	3
Swooshy	1

Adjectives that describe concrete volume change

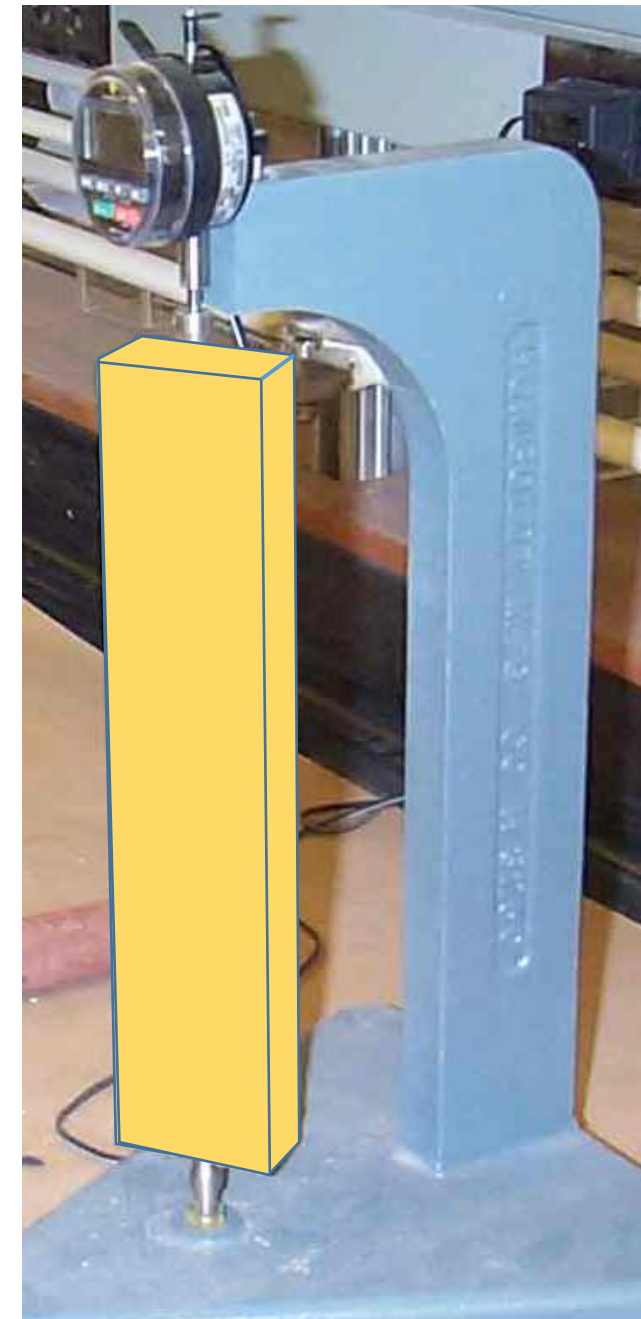
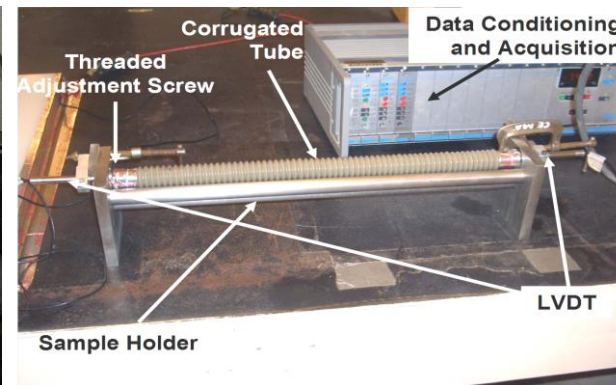
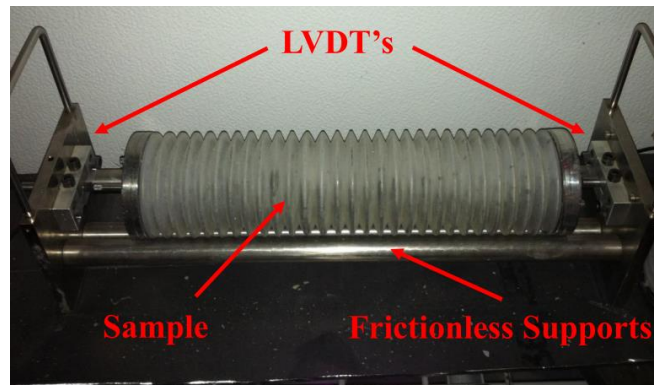
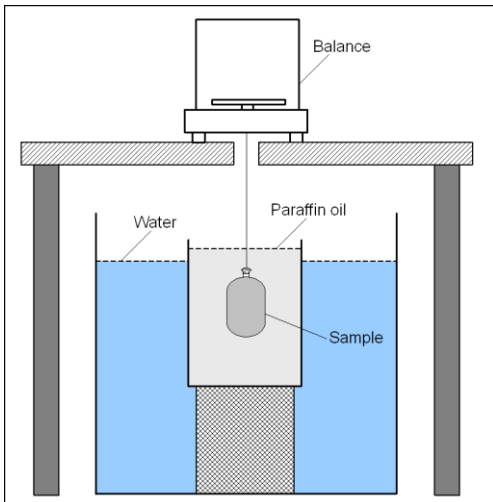
Drying Shrinkage

- 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



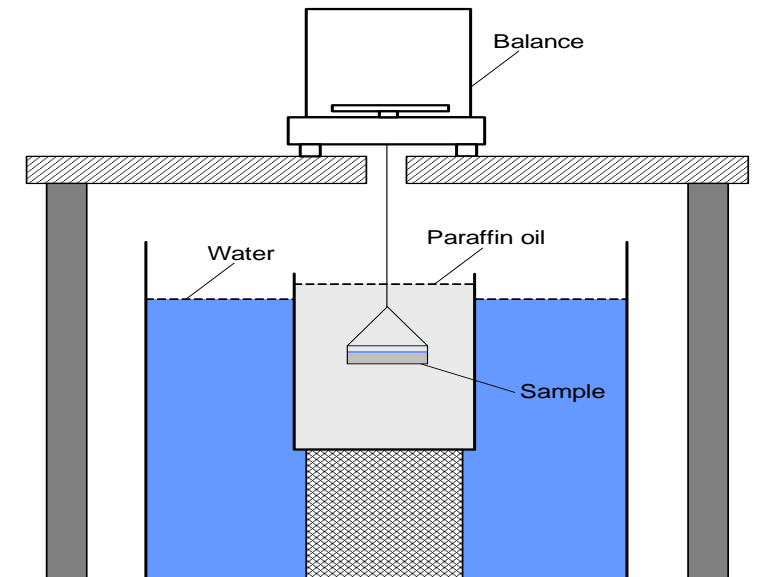
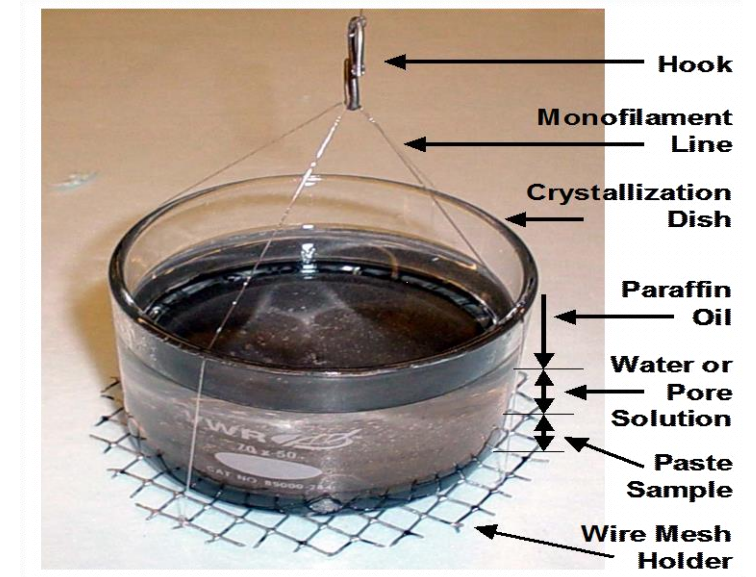
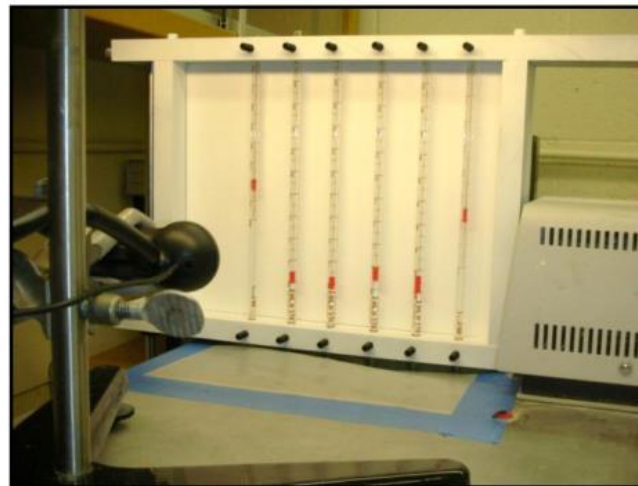
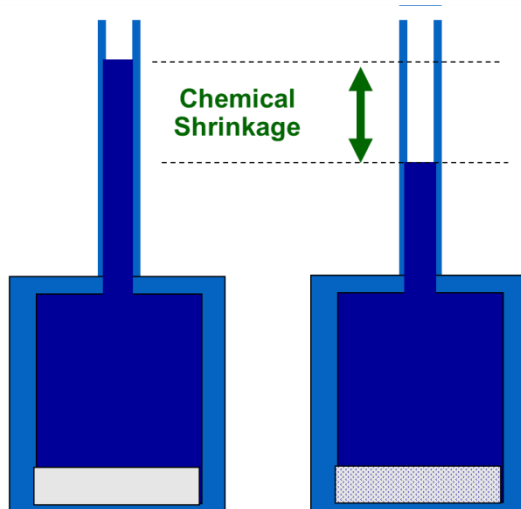
Autogenous (Sealed) Shrinkage

- 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



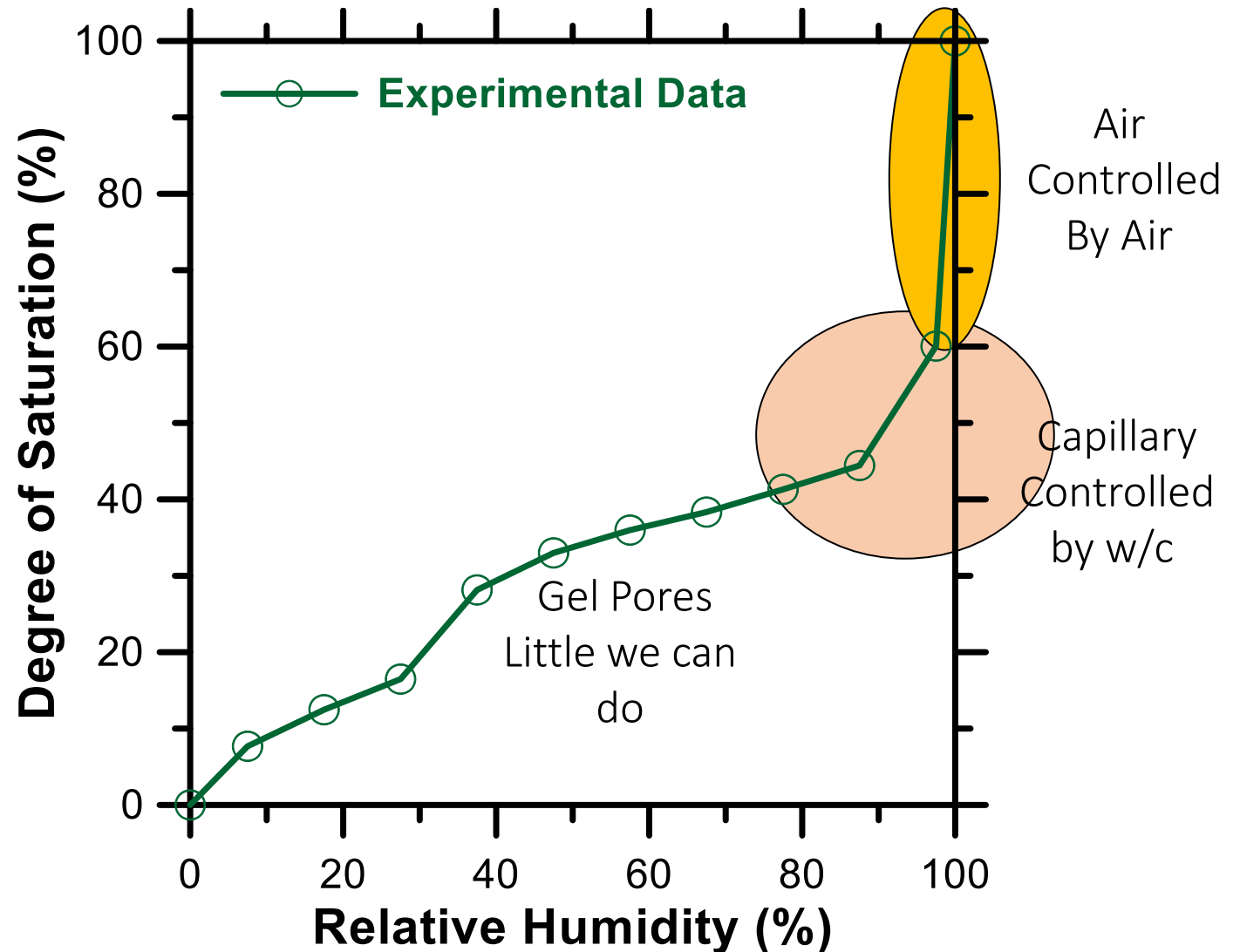
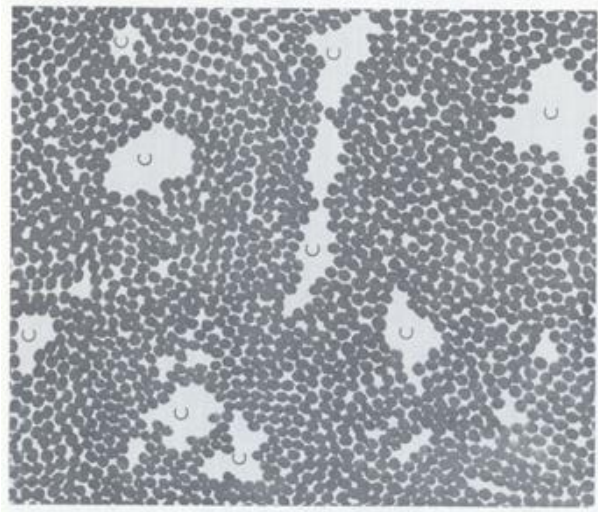
Chemical Shrinkage

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



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



The Heros of Our Story



Thomas Young

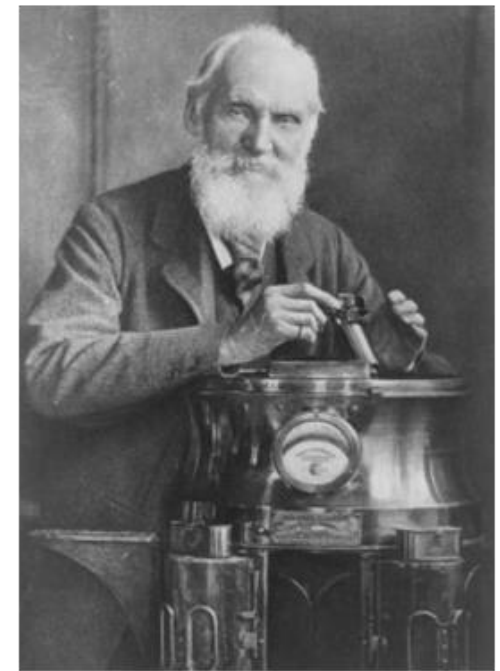
Thomas Young
(1773 – 1829)



Carl F. Gauss
(1777 - 1855)

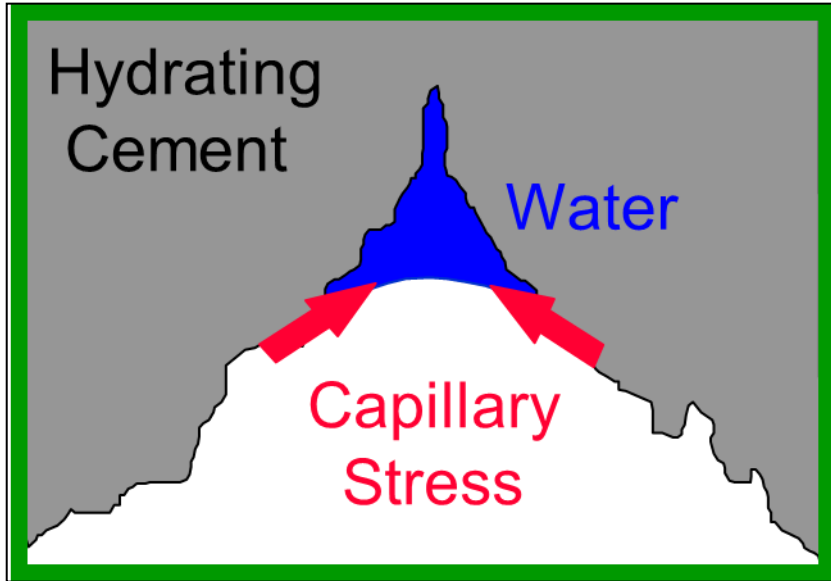


Marquis de Laplace
(1749 - 1827)

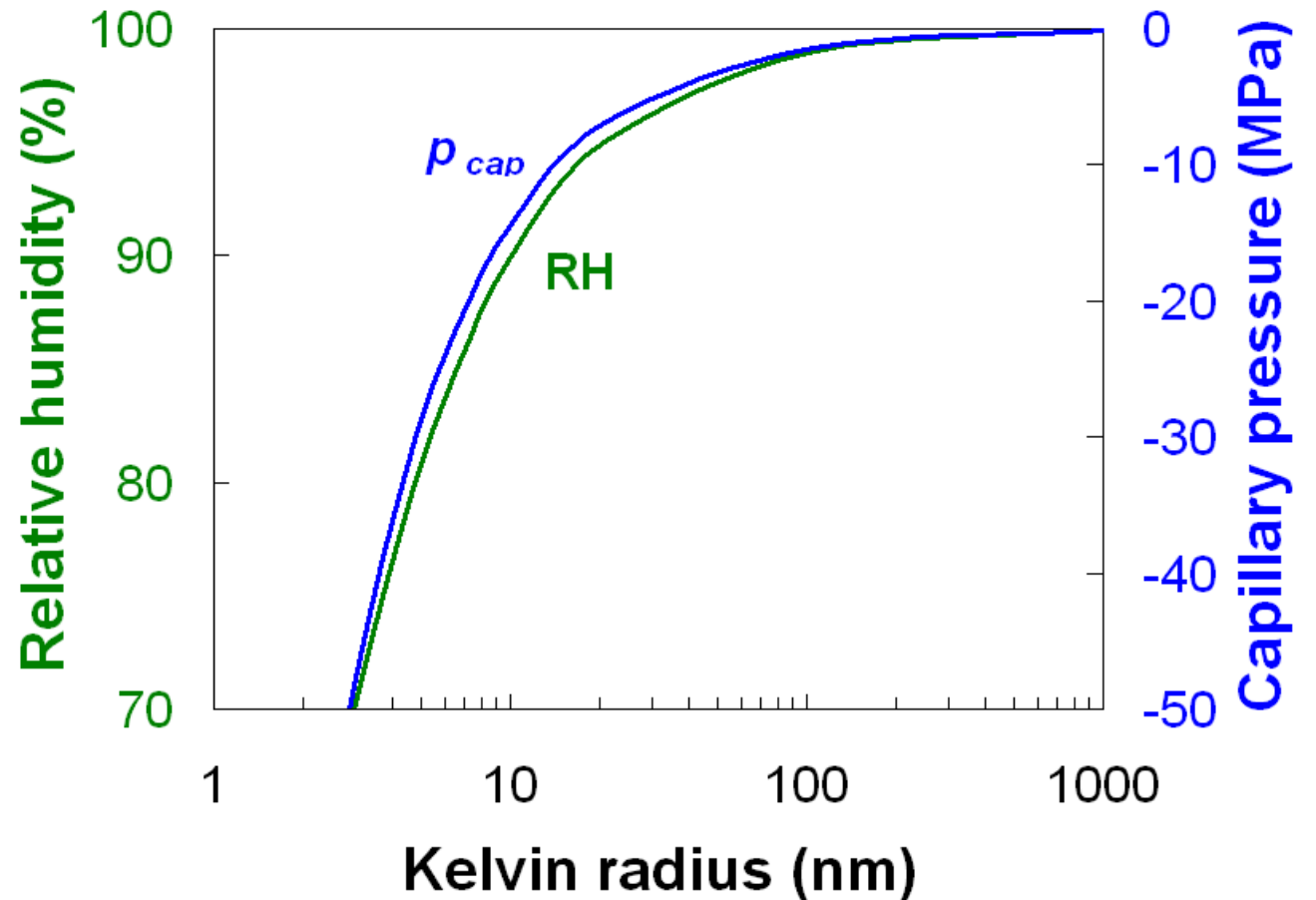


Lord Kelvin
(1824 - 1907)

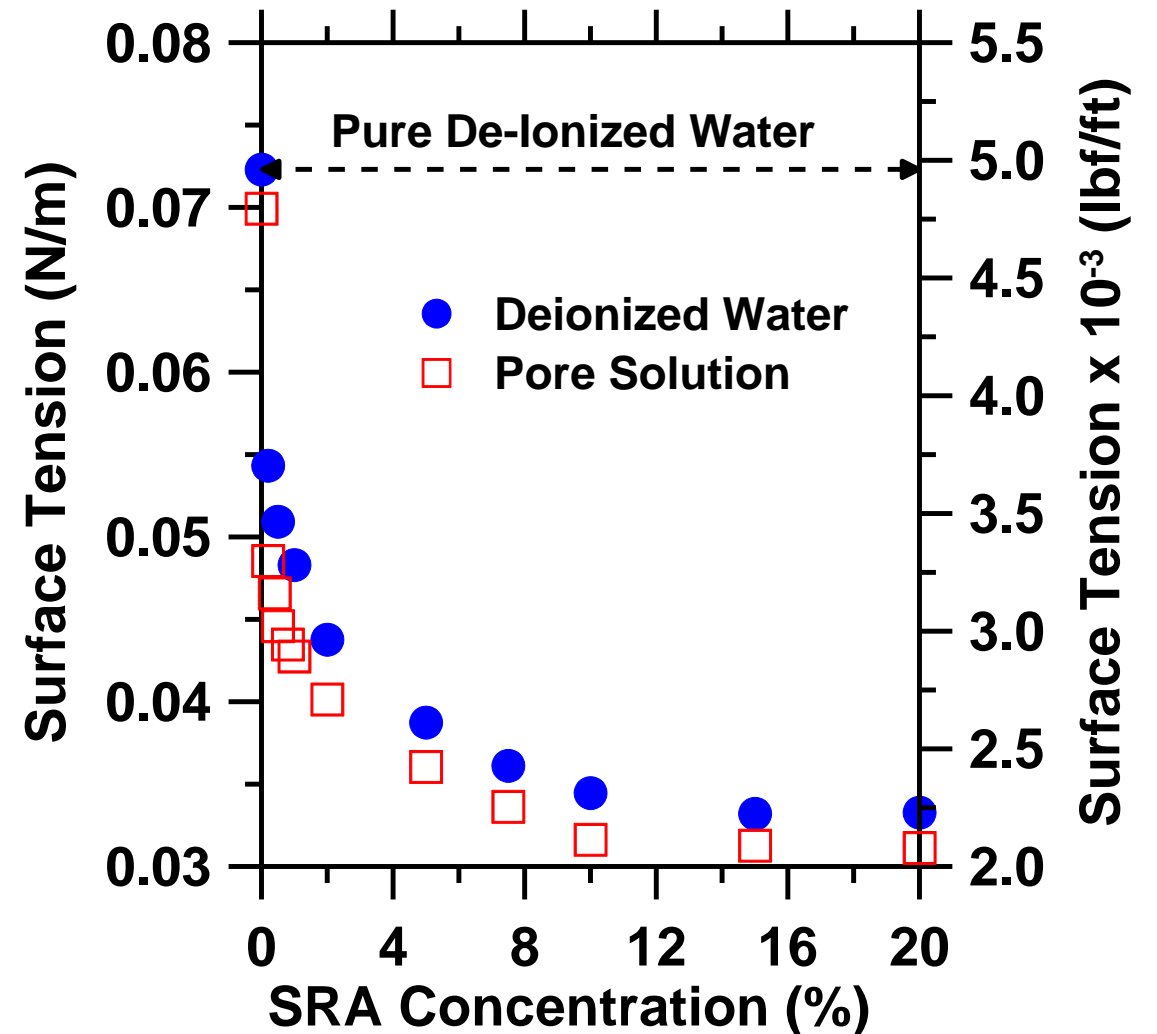
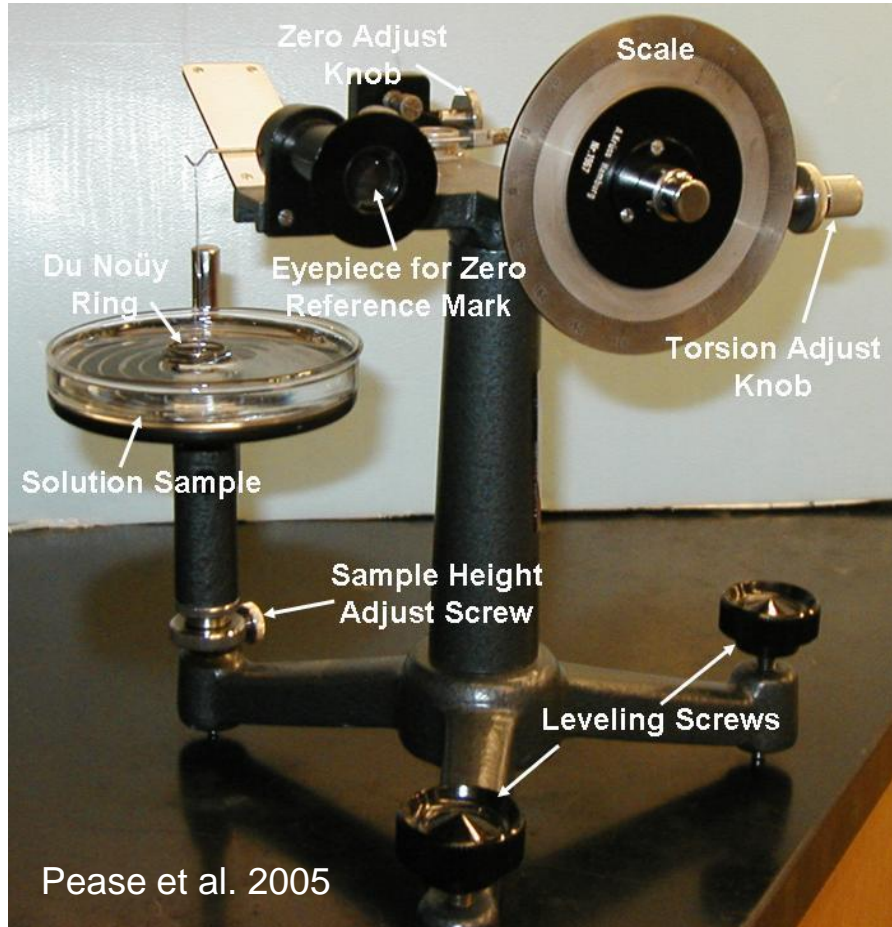
Capillary Pressure



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



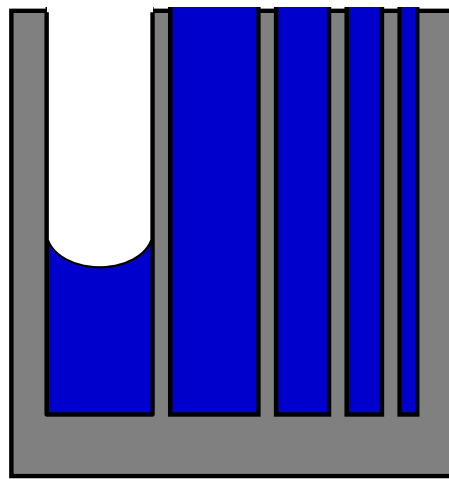
Shrinkage Reducing Admixtures



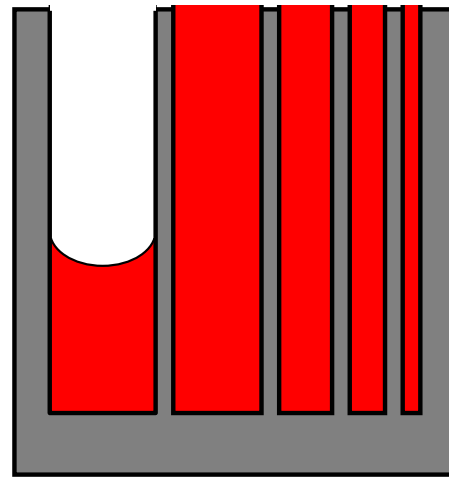
Rajabipour et al. 2008

Sealed Samples

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

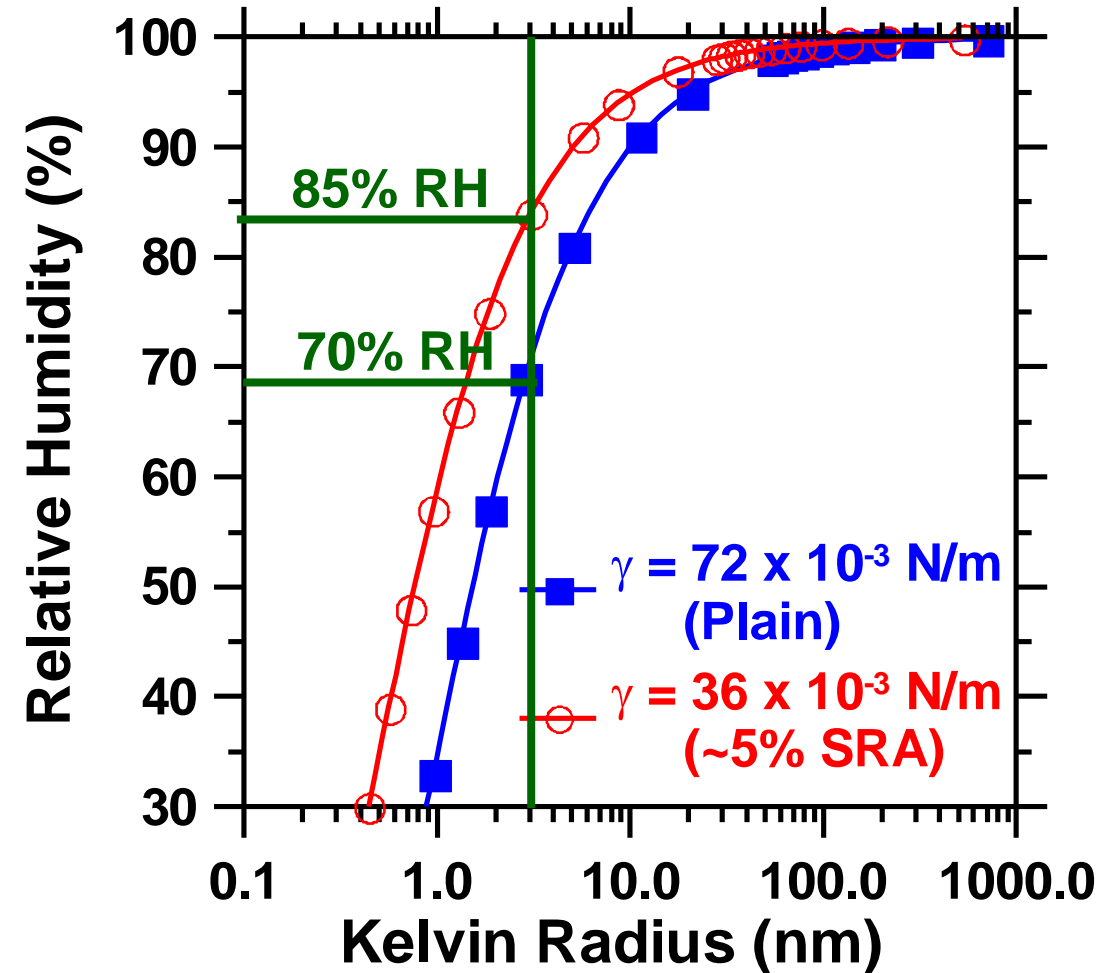


Sealed - Plain



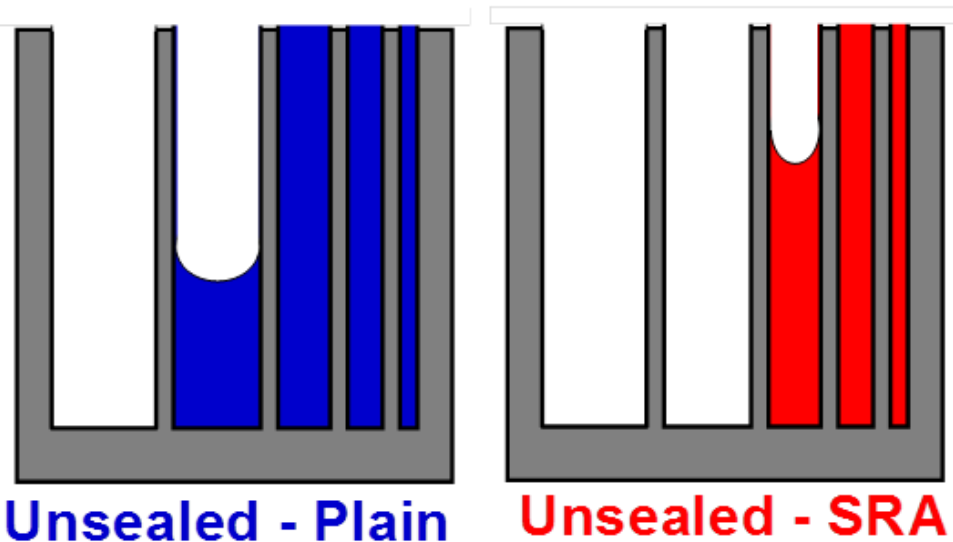
Sealed - SRA

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

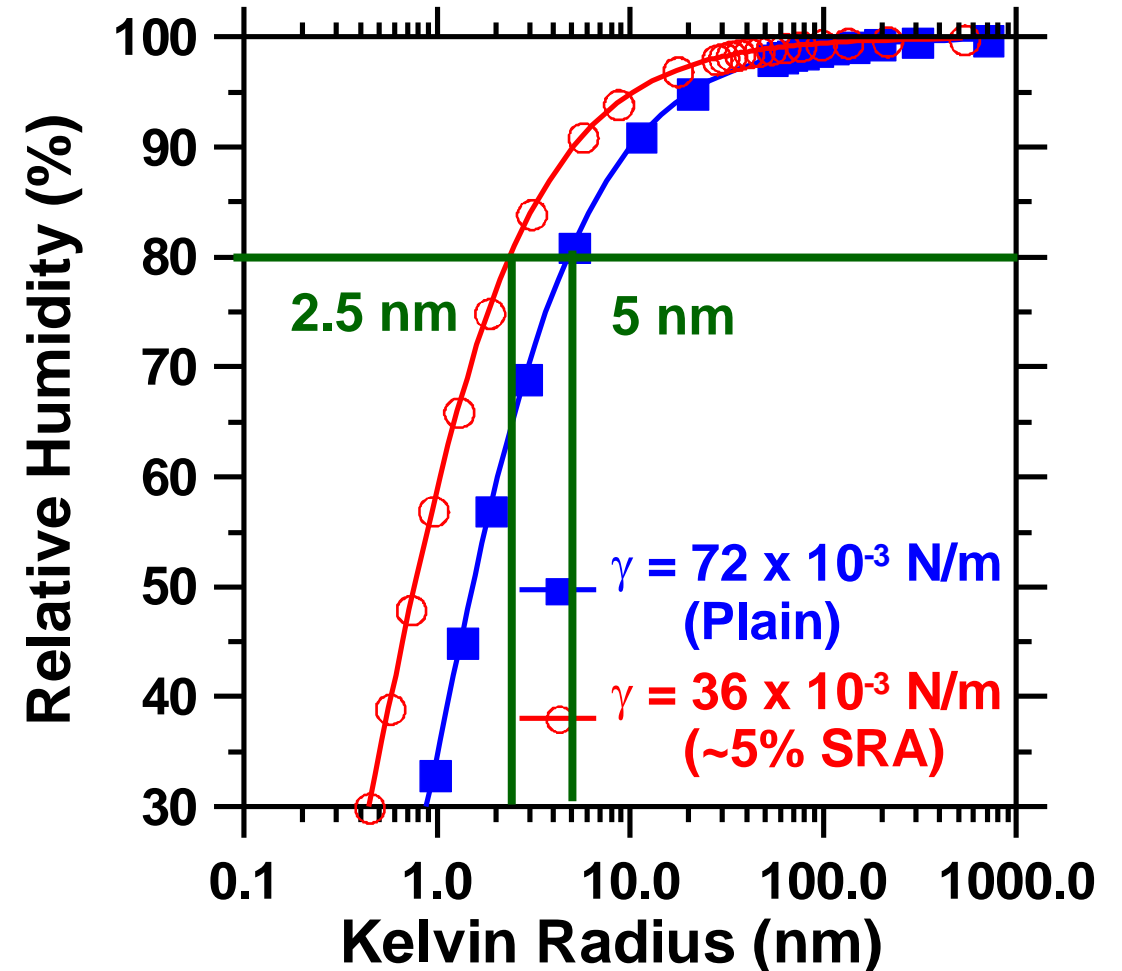


Drying Samples

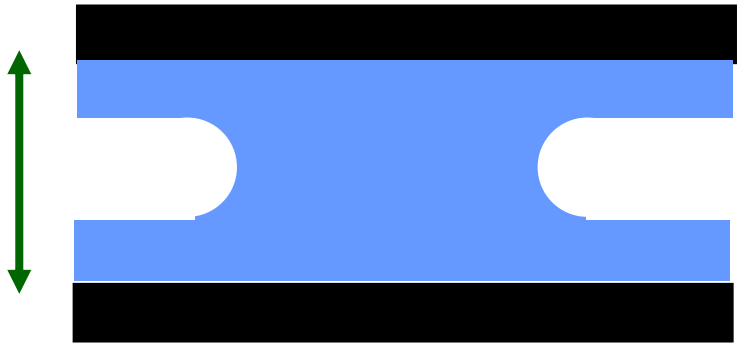
- RH is fixed
- More fluid is lost from SRA
- Stress is the same, except if capillary stress argument fails



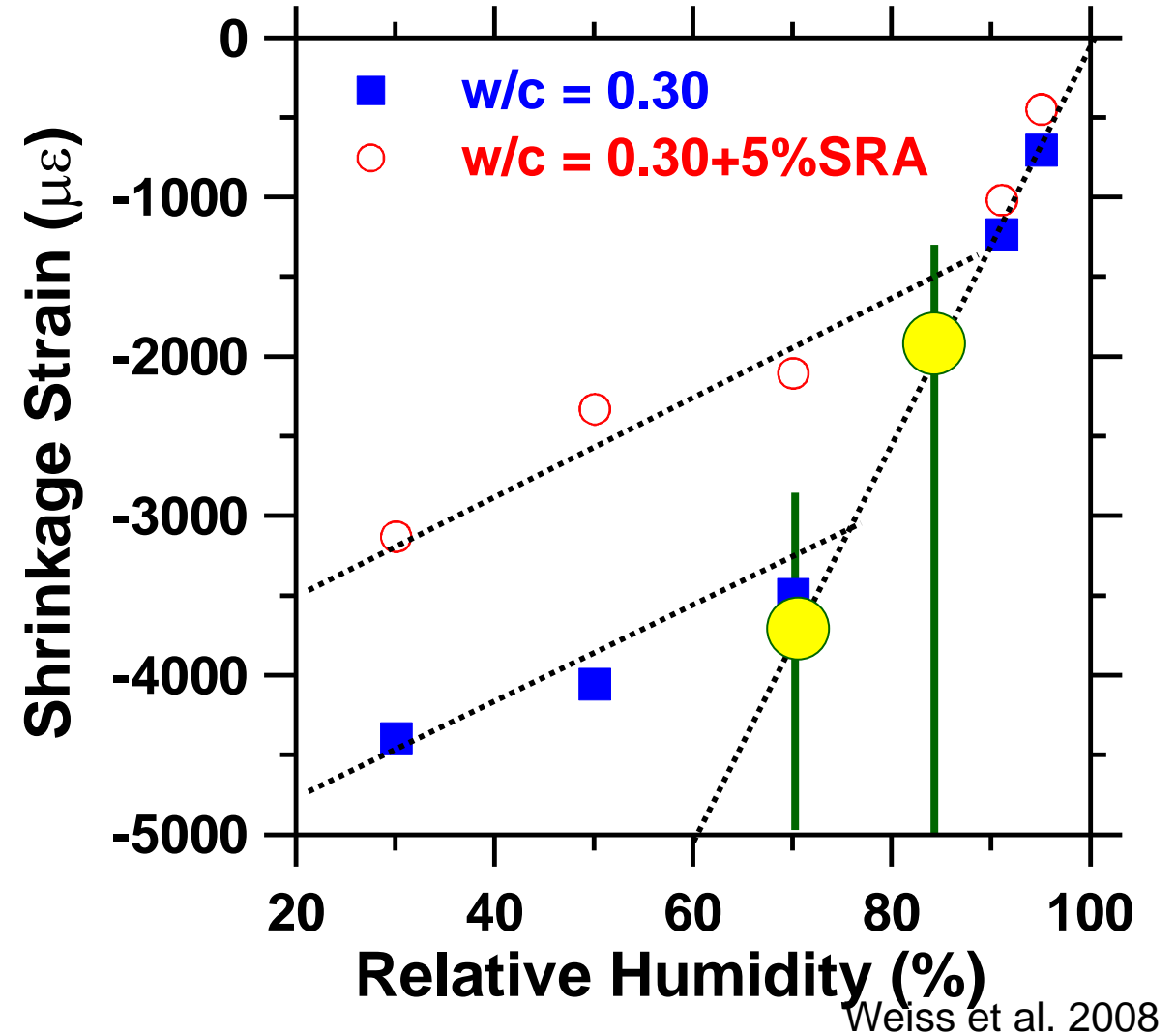
$$\ln\left(\frac{p}{p_0}\right) = \ln(RH) = -\frac{2\gamma \cdot \cos\theta \cdot V_W}{r \cdot RT} = p_{cap} \frac{V_W}{RT}$$



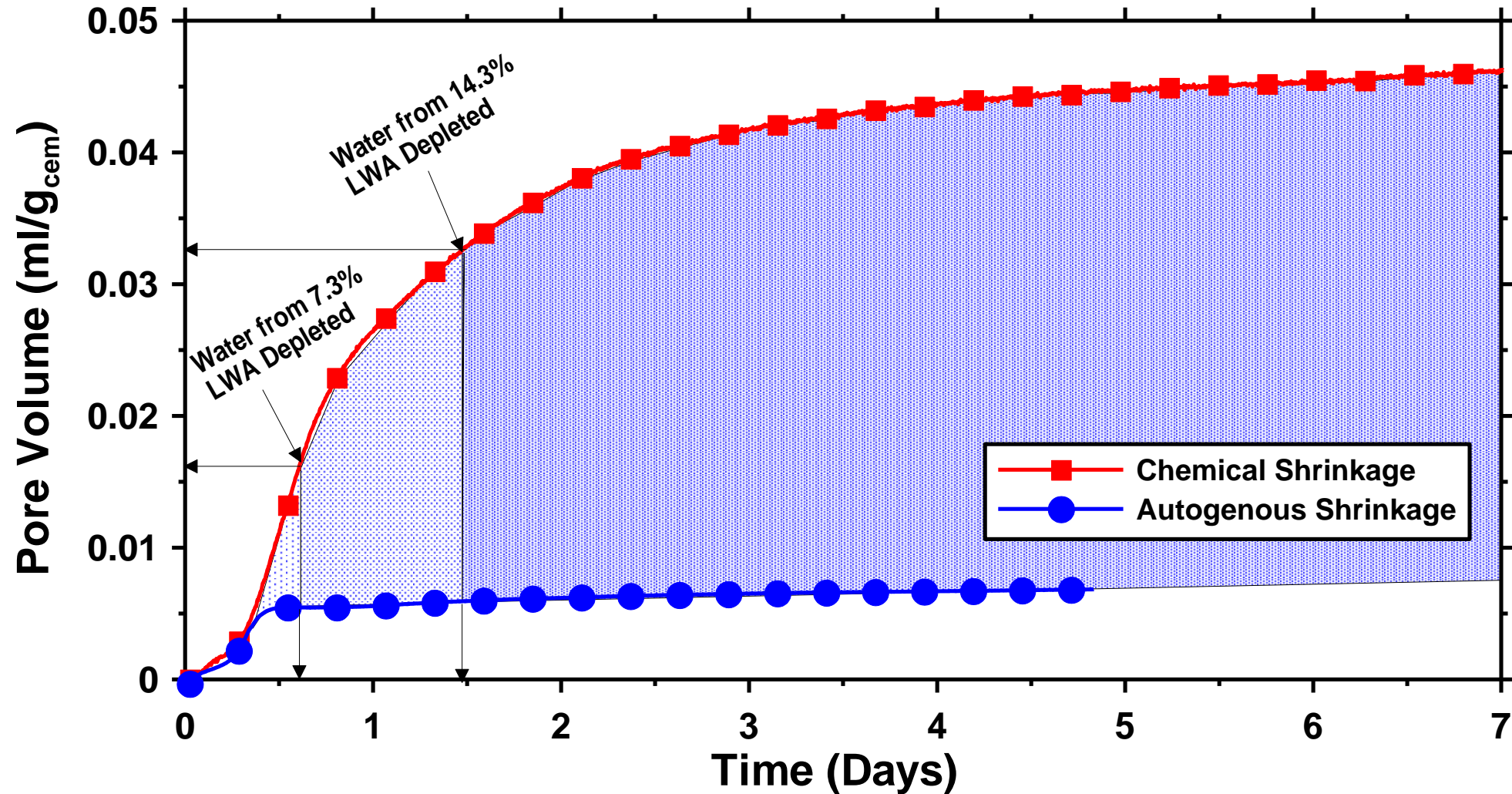
When are Pores Too Small for Capillary Stress



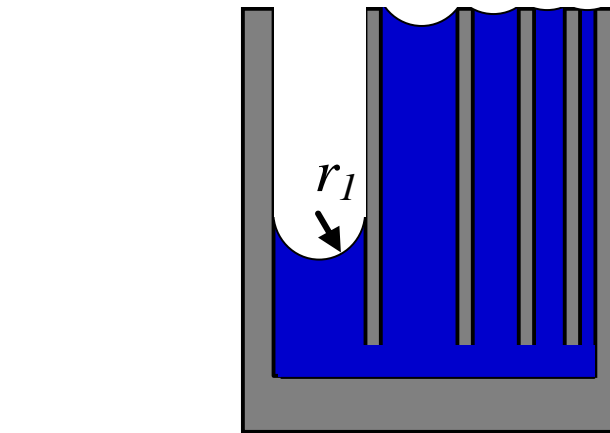
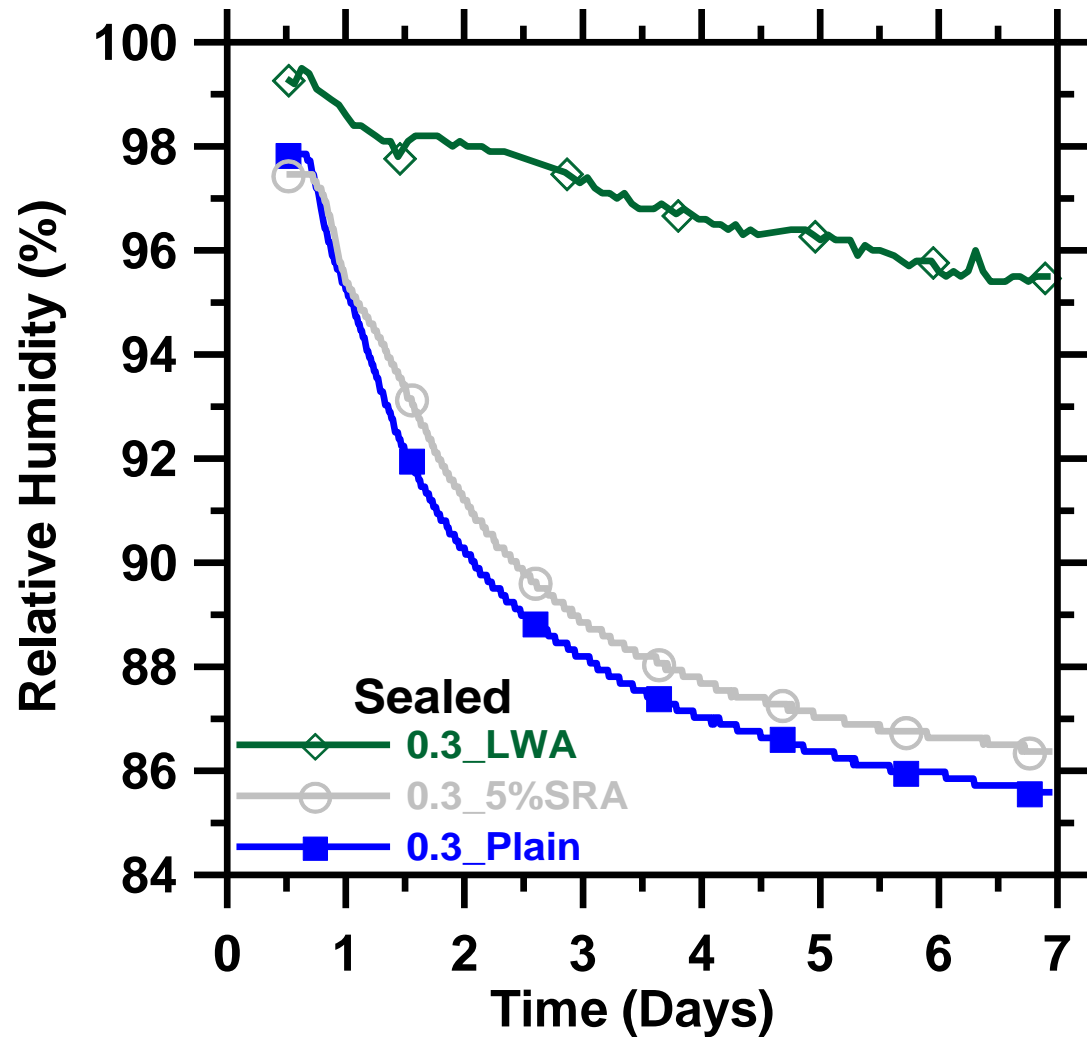
- Christenson - 1.5 nm
- Fischer and Israelachivili - 3 nm



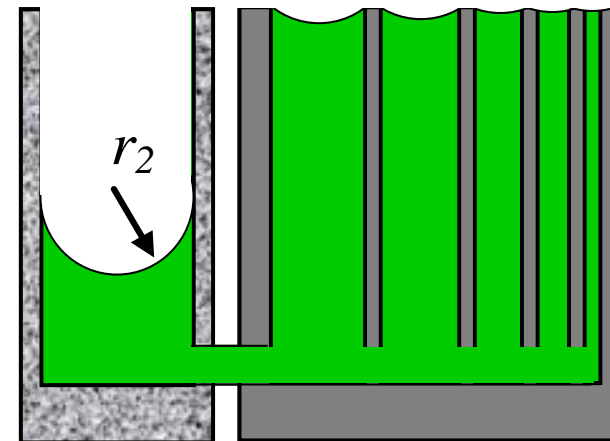
How Does this Relate to Internal Curing



Internally Cured Samples – Sealed



Sealed - Plain

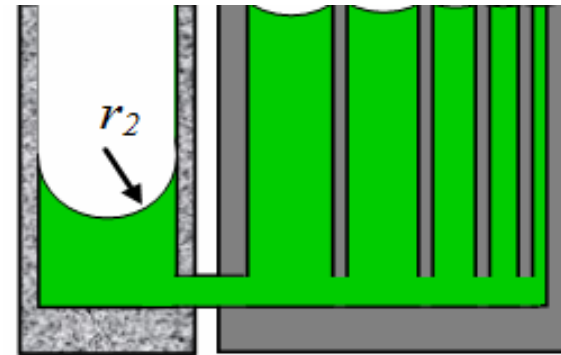
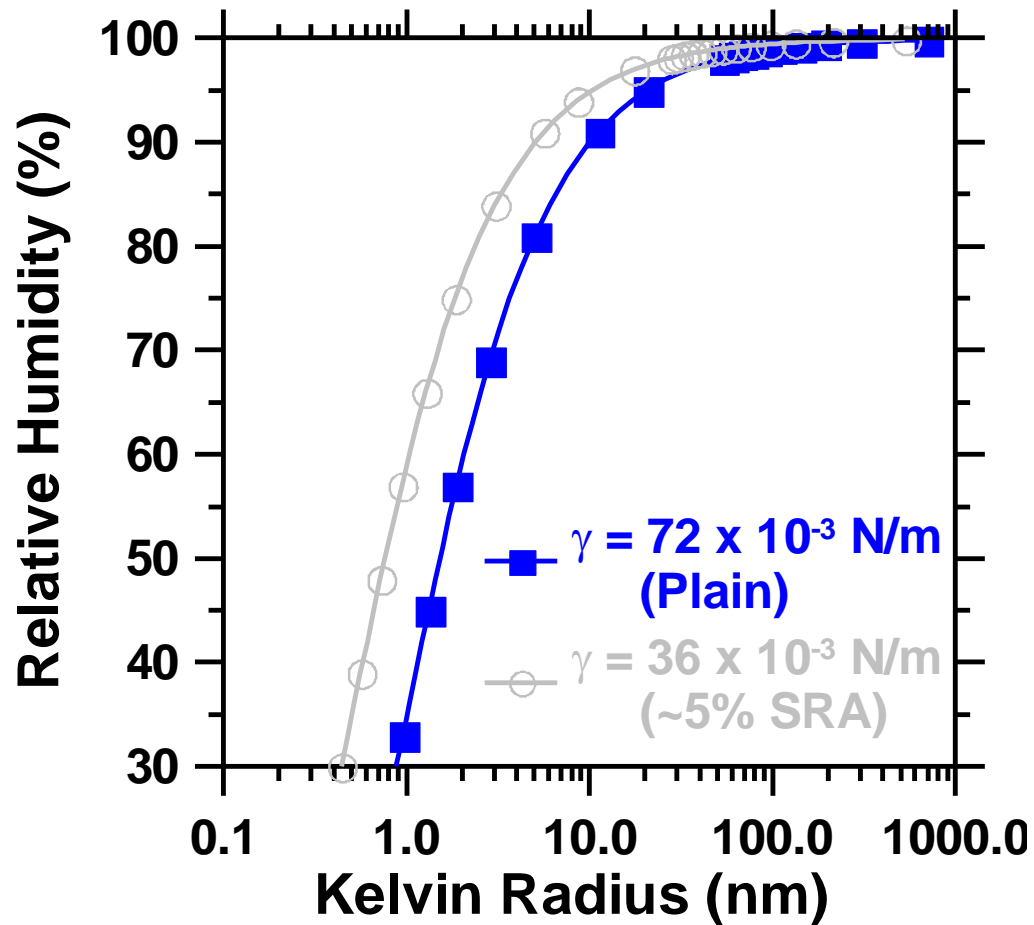


Sealed - LWA

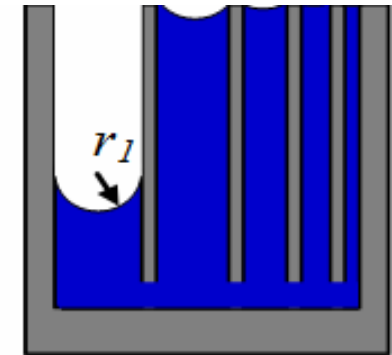
A Similar Volume of Water is Depleted

LWA higher r in Agg

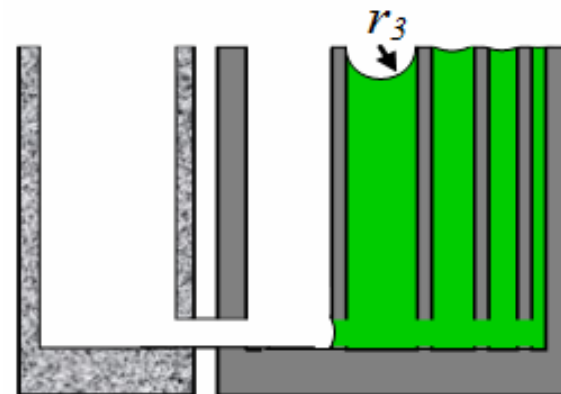
Internally Cured Samples – Drying



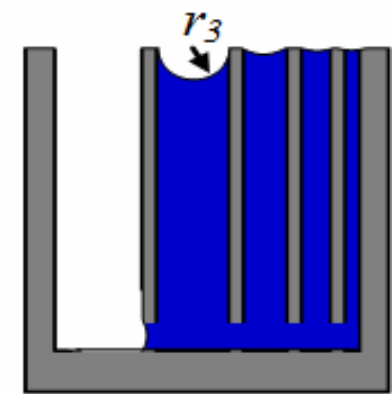
Sealed - LWA



Sealed - Plain



Unsealed - LWA



Unsealed - Plain

LWA Paste

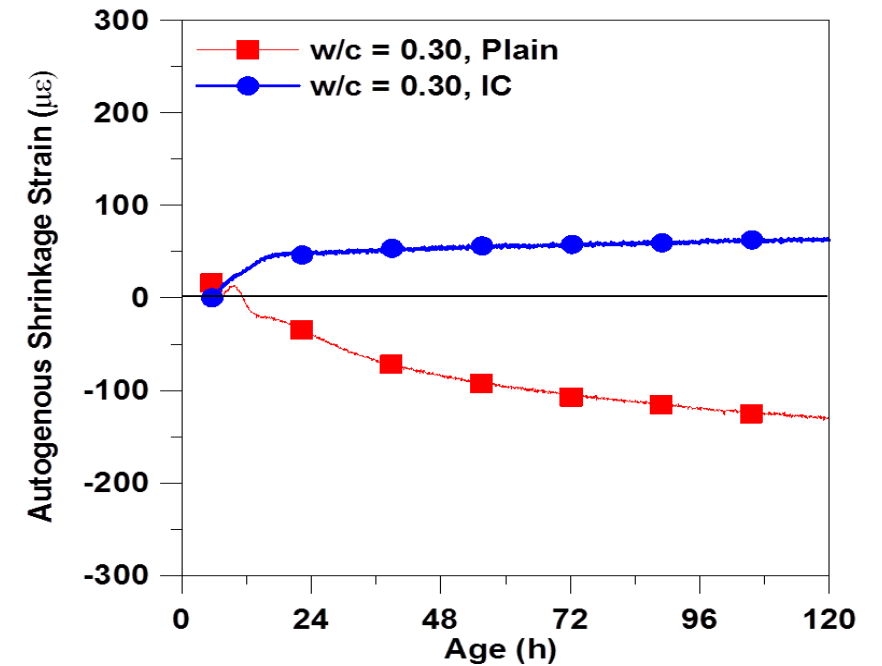
Paste

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.

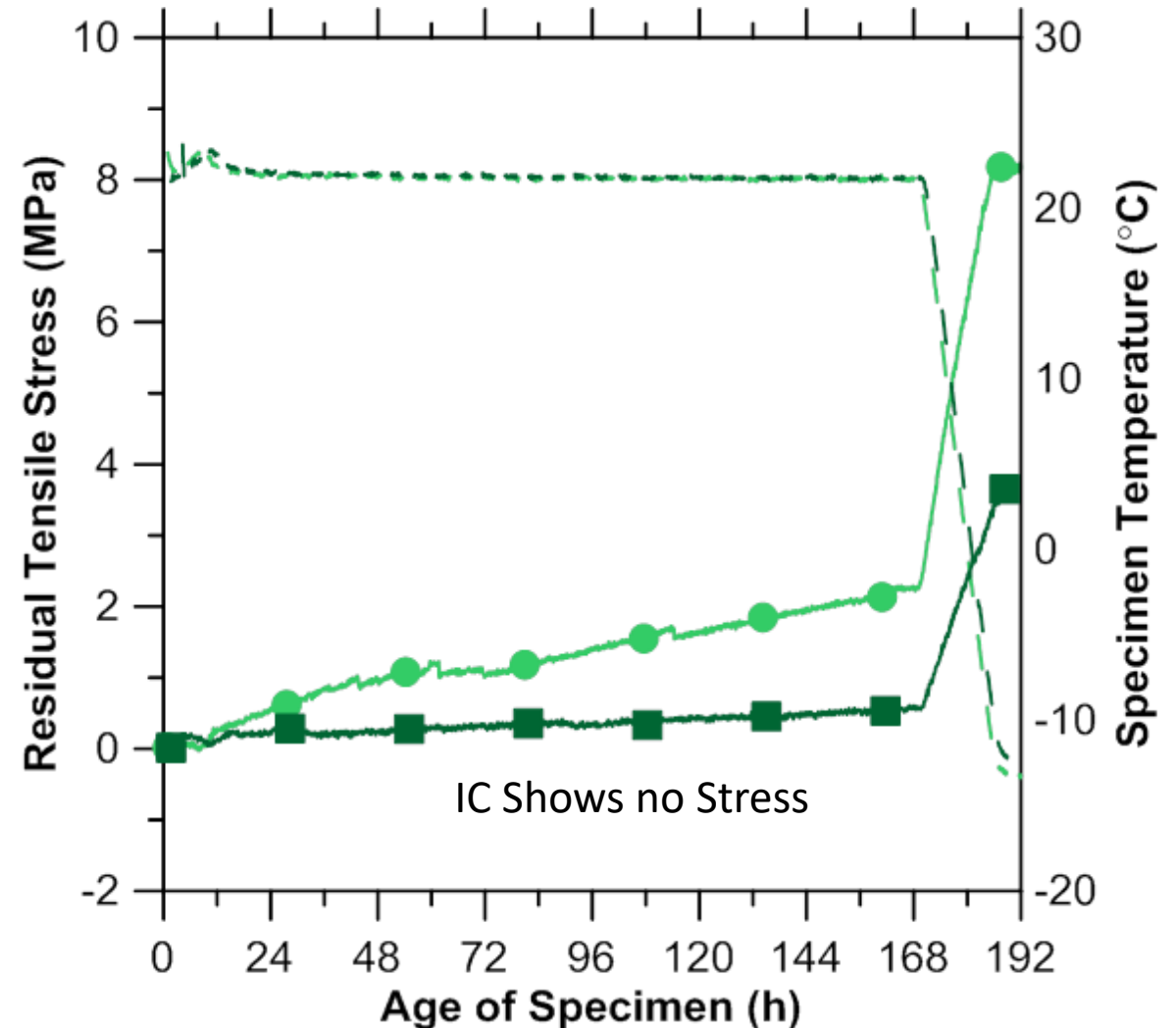
1.2. The values stated in SI units are to

1.3. *This standard does not purport to be a standard of health practices and determine the*

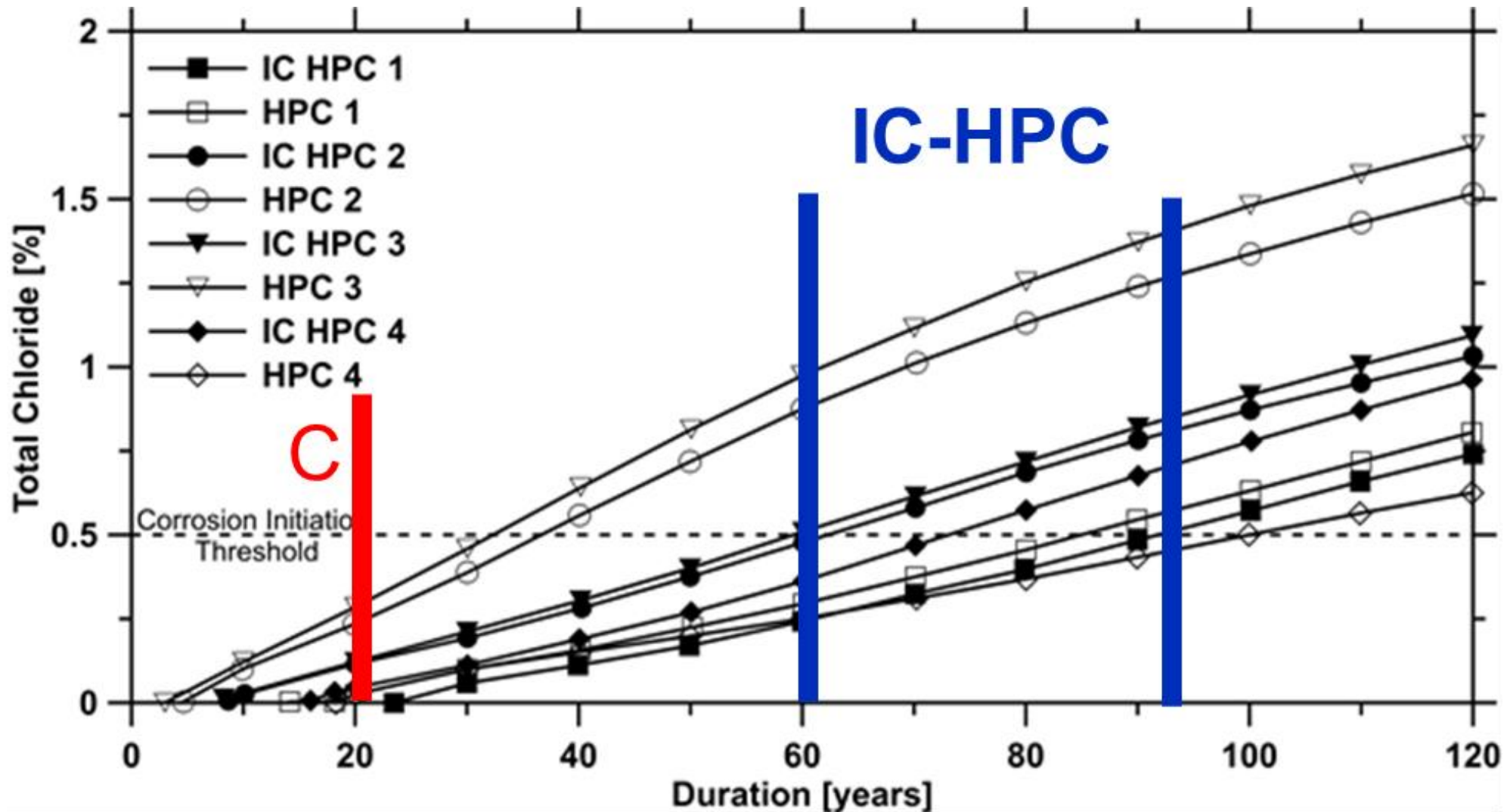
2. REFERENCED DOCUMENTS

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

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

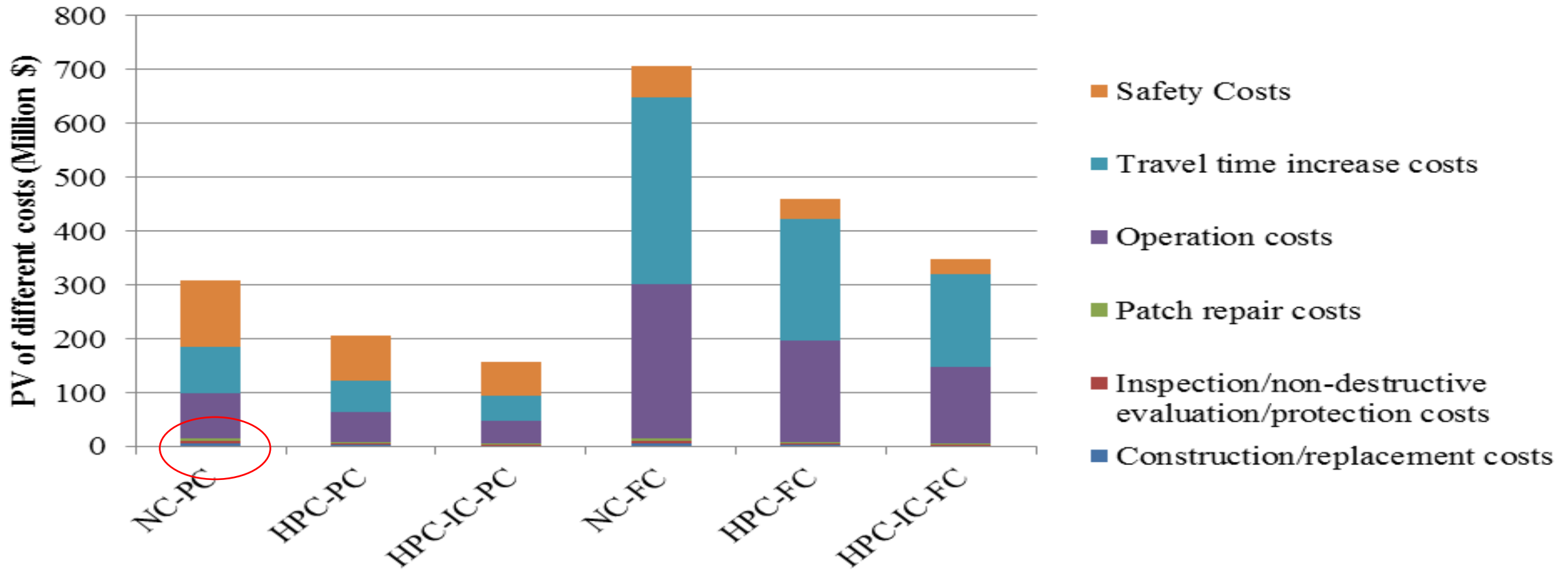


Time to Corrosion Studies (2013 decks)



Cost Implications (Considering Social Cost)

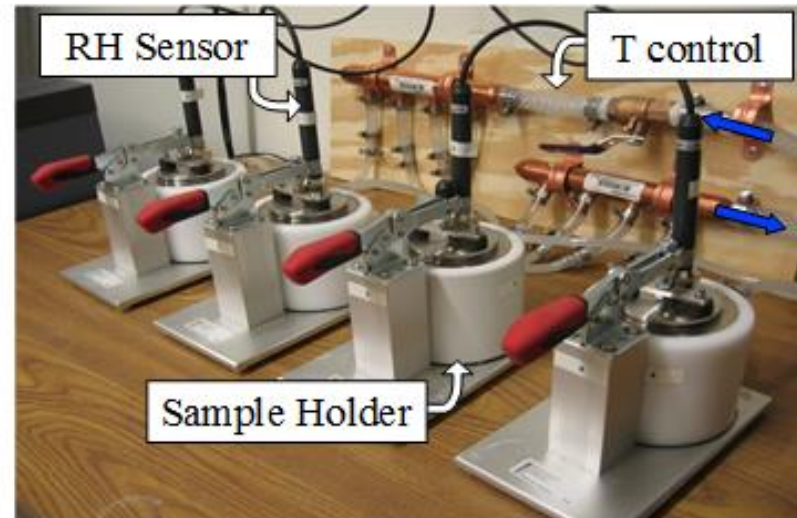
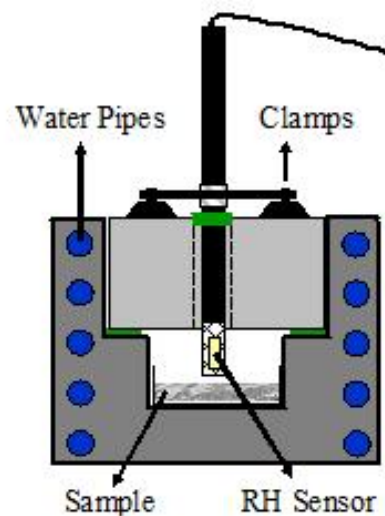
- 1 bridge not three, 5% materials, 1% project
- Sustainable, Safety, Public Benefits



**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

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

Add Internal Curing to
the Tool Box



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



Thank
you!

The screenshot shows the top navigation bar of the Oregon State University website with links for Calendar, Library, Maps, Online Services, and Make a Gift. Below this is the OSU logo and the text 'College of Engineering' and 'Civil and Construction Engineering'. A secondary navigation bar contains dropdown menus for About, Academics, Research and Innovation, Facilities, Our Impact, and My CCE. The main content area features a breadcrumb trail: Home » Facilities » Infrastructure Materials Laboratories » Kiewit Materials Performance Lab (KMPL). The title 'Internal Curing' is followed by a list of resources: Learning Modules, Papers by OSU Authors, Presentations, and Resources. The Resources section includes links to NIST Internal Curing Bibliography, NIST Internal Curing Website, and Expanded Shale, Clay, and Slate Institute (ESCSI) Internal Curing Website. A Worksheets section lists 'Mixture Proportioning Worksheet (Excel); (presentation)' and 'Aggregate Properties Worksheet (Excel); (presentation)'.

Additional Resources
<http://cce.oregonstate.edu/internalcuring>