

Evaluation of Test Methods for Permeability (Transport) and Development of Performance Guidelines for Durability TPF-5(179)

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INDOT Profile

- 6 district offices
- 3,722 employees
- \$396 million/annual operating budget
- \$1 billion/annual capital expenditures
- 28,410 total lane miles
 - 5,098 lane miles of interstate
 - 16,519 lane miles of two-lane roads
 - 5,320 INDOT-owned bridges



INDOT

- **INDOT Mission:**
 - INDOT will plan, build, maintain and operate a superior transportation system enhancing safety, mobility and economic growth

- **INDOT Values:**
 - Respect
 - Teamwork
 - Accountability
 - Excellence



Major Projects

■ Major Project Status

Project	% Miles Let	Open to Traffic	Final Letting
I-80/94 Interchange	100	Aug. 2011	2009
Accelerate 465	100	Dec. 2012	2010
US 24 Fort to Port	100	Nov. 2012	2010
I-69 Evansville to Crane	100	Nov. 2012	2011
Milton-Madison Bridge	100	April 2013	2010
US 31 Kokomo	100	Dec. 2013	May 2012
SR 25 Hoosier Heartland	100	Dec. 2013	July 2012
US 31 Plymouth to South Bend	92	Dec. 2014	April 2013
I-69 Crane to Bloomington	73	Dec. 2014	Oct. 2012
US 31 Hamilton County	16	Dec. 2015	Oct. 2012



Participating States

- FHWA,
- Indiana,
- Michigan,
- Minnesota,
- Illinois,
- Wisconsin,
- Kansas,
- Montana,
- Pennsylvania,
- Iowa,
- New York,
- Colorado



Project Tasks

- Phase I: Literature Review of Concrete Permeability (Transport) Test Procedures and Models that Link Tests with Performance
- Phase II: Evaluate Promising Concrete Permeability (Transport) Tests and Recommend Procedures for Further Use
- Phase III: Develop New or Improve Existing Permeability (Transport) Testing Procedures. Develop Protocols to Use these Tests, Evaluate the Precision and Bias of these Tests



Project Tasks

- Phase IV: Correlate Permeability (Transport) Tests with Laboratory Tests that Evaluate Durability
- Phase V: Develop Performance Criteria Guidelines that Relate Permeability (Transport) Tests with Exposure Conditions and Performance
- Phase VI: Preparation of Technology Transfer and Educational Materials





Project Goal

- **Transport Properties**
- to evaluate and develop testing procedures that directly evaluates the transport properties of concrete

- **Durability and Service Life**
- to relate these properties to anticipated field performance with the use of exposure conditions.



Before We Start



- This will be a quick overview of the findings
- More detailed findings have been provided in meetings and go to meeting updates
- In addition, papers denoting the findings are included with each progress report

TPF-5(179)

QPR #15

**Evaluation of Test Methods for
Permeability (Transport) and Development
of Performance Guidelines for Durability**

Quarterly Progress Report

To the

Pooled-Fund Research Program

(The participating states are: FHWA, Indiana, Michigan, Minnesota, Illinois,
Kansas, Montana, Pennsylvania, Iowa, New York, and Colorado)

For the Period of

January 1st, 2012

to

March 30th, 2012

Limited Use Document

This quarterly progress report is furnished only for review by members of the pooled fund research program and is to be regarded as fully privileged. The Dissemination of

Prepared by Indiana Department of Transportation, Purdue University, and the National Ready Mixed Concrete Association; Principal Investigator: Tommy Nantung, tnantung@indot.in.gov, (765) 463-1521 ext. 248



Tests Considered

- Chloride ions transport
 - Rapid chloride permeability
 - Rapid Migration Test
 - Chloride Diffusion Test
- Water absorption and Drying
- Electrical - Surface, Bulk, and EIS
- Gas - oxygen permeability/diffusivity;
- Durability: sulfate attack, freeze/thaw resistance and chloride induced corrosion.



Outline of Update Today



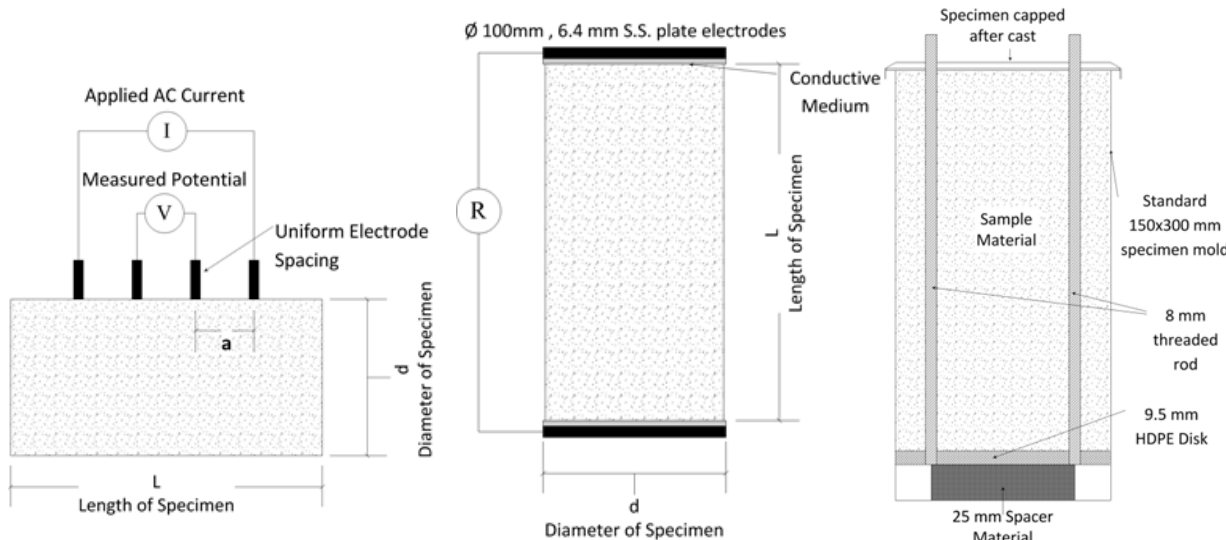
- Electrical Property Update
- Accelerated Conditioning
- Gas Diffusivity/Permeability





Electrical Tests

- Numerous tests exist,
- Generalize form to relate geometries to a single material property for standardization

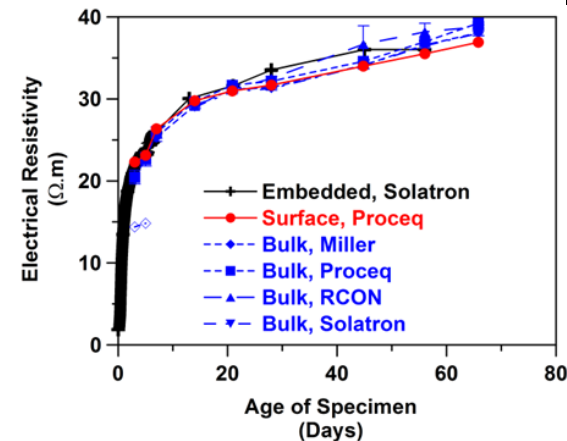


$$k = \frac{2\pi a}{1.09 - \frac{0.527}{\frac{d}{a}} + \frac{7.34}{\left(\frac{d}{a}\right)^2}}^*$$

$$k = \frac{\pi d^2}{L}$$

$$k = 0.2^{**}$$

$$\frac{1}{\sigma} = \rho = Rk$$

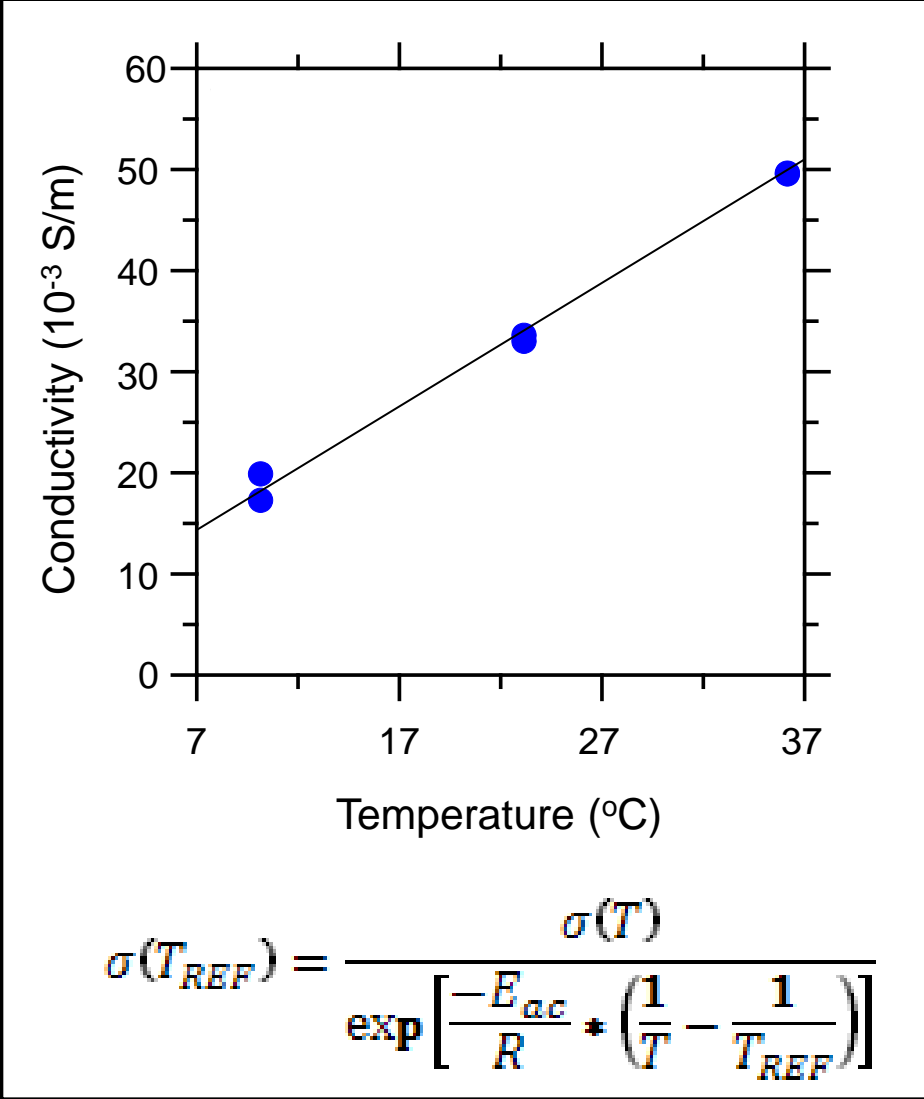




Temperature Correction



- Standards discuss the fact that this is at lab temperature
- Unfortunately many people do not see the importance of this
- Developing a protocol to evaluate conduction parameter



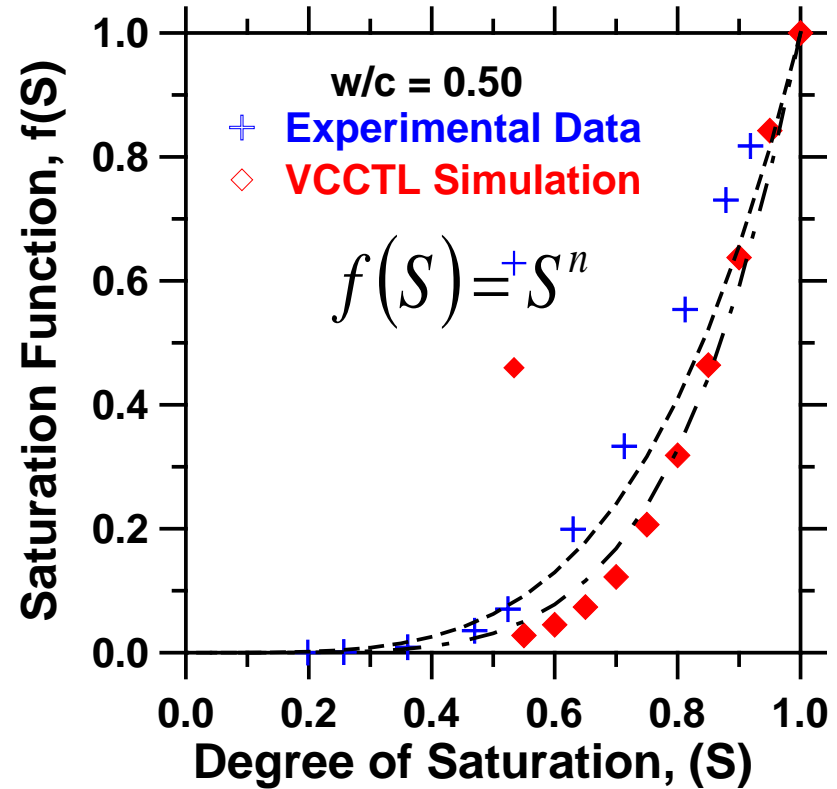
Sant et al. 2008



Moisture Correction



- RCPT - vacuum sat. (i.e., DOS = 100%)
- AASHTO in water Fog Room by some
- All of these differ
- Faster testing can be done if we know DOS
- Important since field never saturated



$$\sigma_t = \sigma_o \phi \beta \cdot f(S)$$

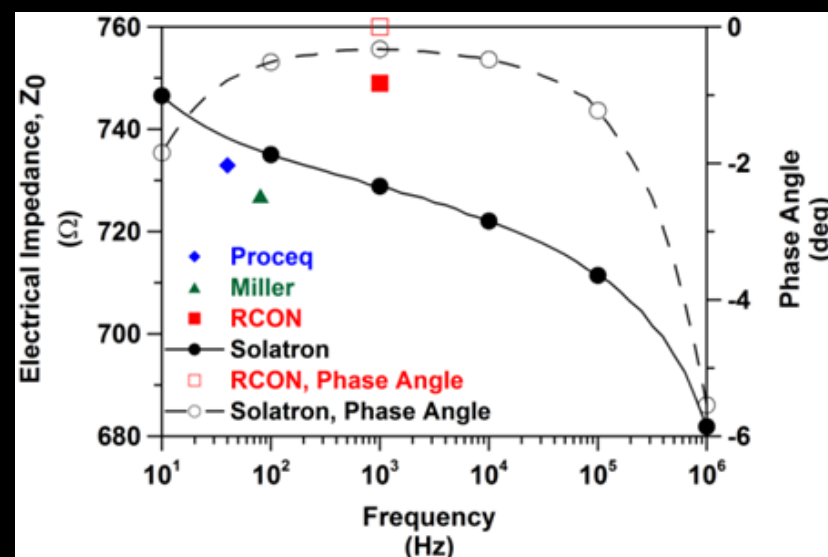
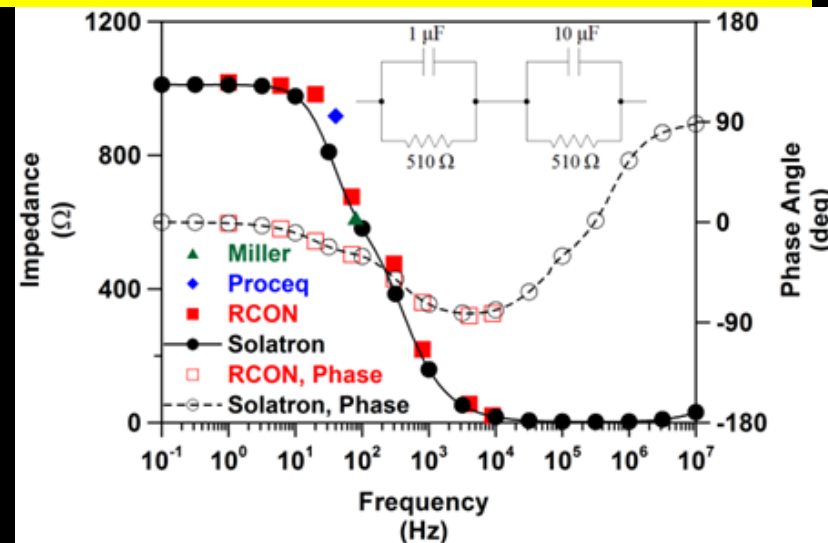
Weiss et al. accepted



Comparing Different Meters



- Several commercial devices exist
- Compared to model circuits shown
- One ω – Proceq, Miller
- Sweep ω – RCON, Solartron
- Optimal ω is approx. 10^4 to 10^5 Hz



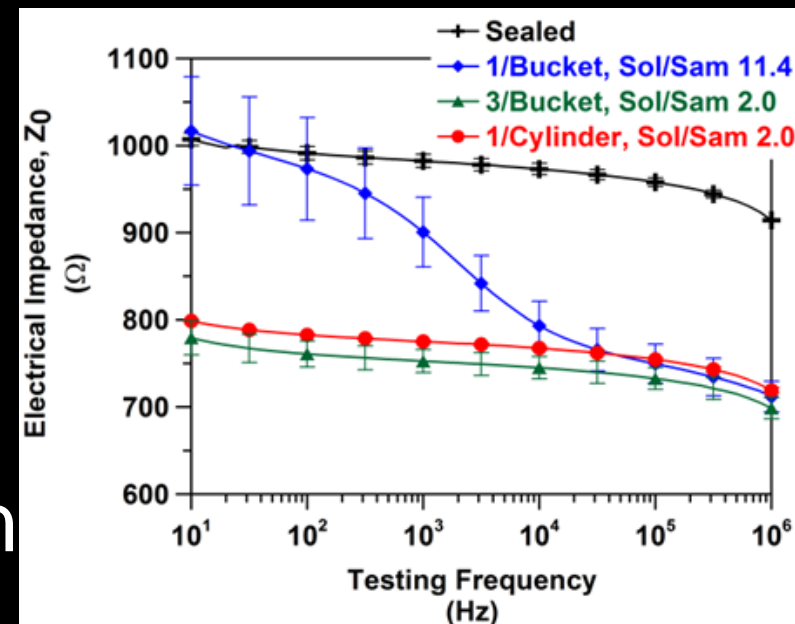
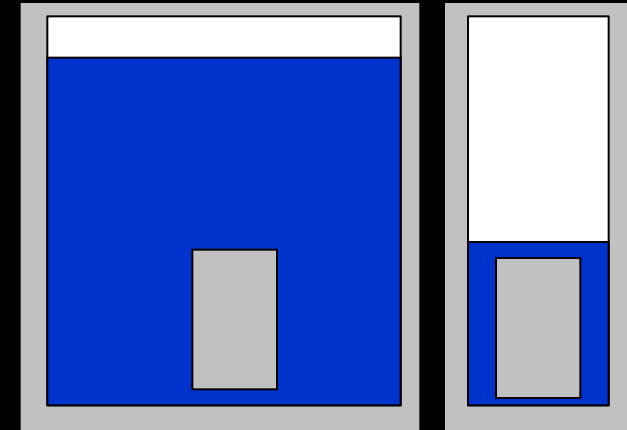
Spragg et al. Submitted



Solution to Sample



- We noticed differences in samples stored in different size containers
- 3 cyl. in 5 gal bucket of lime water is 2.0
- Data shows influence of sealed vs. saturated
- Data shows influence of solution size
- Recommend specification



Spragg et al. Submitted



Standard Development Progress



- Test variability COV 2.4% (Poursae & Weiss 2009)
- Multi state, multi lab round robin testing for two methods for precision and bias statements (Spragg et al. 2011)
- Highlights curing importance
- Drafting AASHTO standard for Bulk resistivity (are thinking about embedded probes)
- Working with NIST on ASTM test harmony

Average multi-laboratory coefficient of variation

Testing Age	multi-laboratory coefficient of variation
28-days	7.75 %
56-days	9.83 %
91-days	13.22 %



Outline of Update Today



- Electrical Property Update
- Accelerated Conditioning
- Gas Diffusivity/Permeability





Sample Conditioning

- Boundary conditions
 - Noticed early on that the absorption testing boundary conditions are difficult to obtain and very important
 - Electrical tests (and others) show a great dependence on degree of saturation
- Conditioning samples
 - This is a large part of getting the test measurements to be meaningful
 - This is a large component of timing



Rapid Conditioning Studies



- Vacuum Saturation
 - Powerful (1 mm)
 - Programmable
 - Large Capacity
 - Consistent
- New Drying
 - Using new drying approaches that are 4 - 6 times faster than conventional approaches
 - Investigating new sensors for DOS





New Standards

- Need for Drying Standards
 - ASTM C1585 – Requested Corrections
 - Old ASTM standards not for concrete
 - NFAC – Drying standard we are using
 - Working with NIST in their draft standards
- Modifications to consider/report DOS and we are working toward something that can be placed in standard/recommendation language



Outline of Update Today

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Two Lab Comparison



- Casting
- Demolding of samples at 24 h
- Sealing the samples in plastic bags for 28 days
- Storing the samples in temperature (23 C) and RH (at 50% RH and at 65% RH) controlled chambers
- Testing at mass equilibrium (18 months)
- Sending the samples to EMPA

EMPA



- Repetition of tests: oxygen permeability and diffusivity

	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Cement [kg/m ³]	631.25	547.37	534.13	481.16
Fly Ash [kg/m ³]	1240.42	1240.42	1240.42	1240.42
Water [kg/m ³]	211.89	242.79	247.20	264.86
Sand [kg/m ³]	304.08	293.05	292.51	290.34
WRA [kg/m ³]	3.81	-	-	-
w/c	0.30	0.40	0.42	0.50

Oxygen Permeability



4 samples each mixture and each RH condition

Oxygen Diffusivity



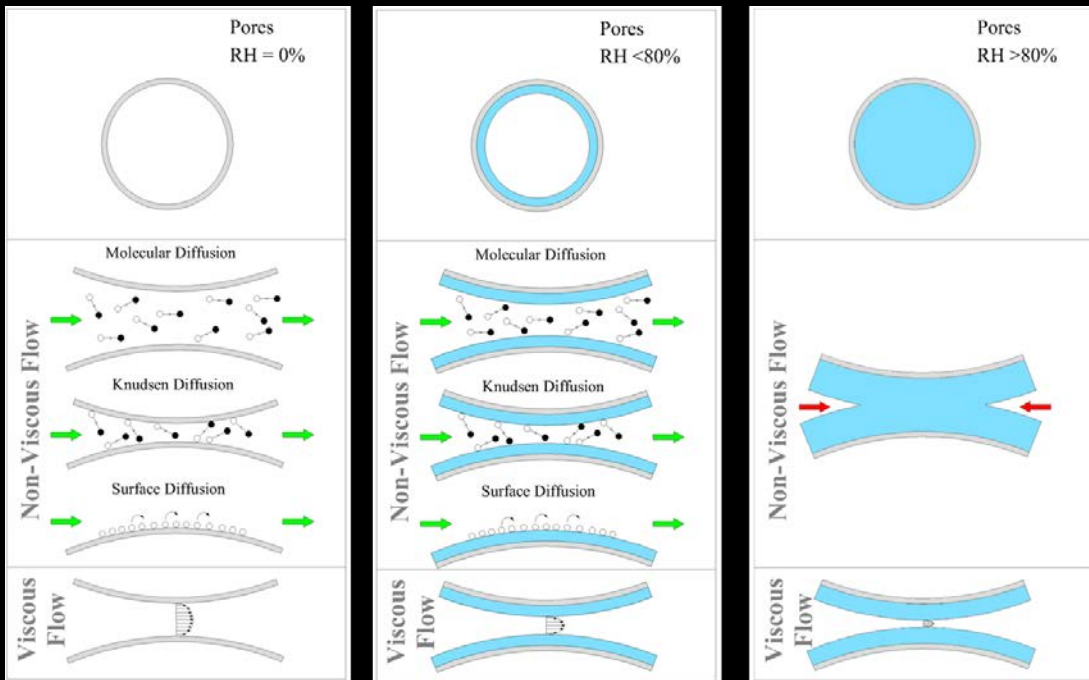
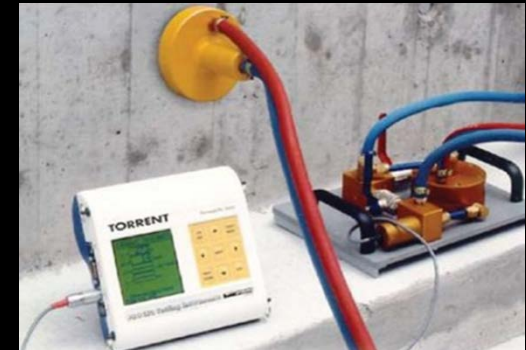
2 samples each mixture and each RH condition



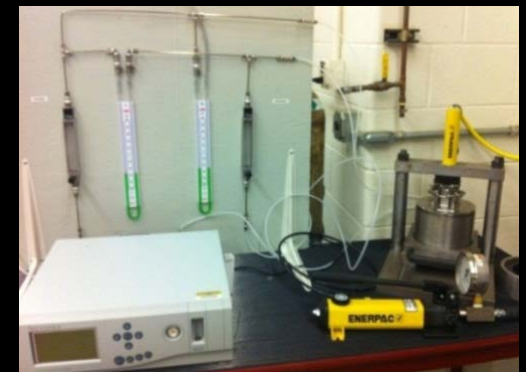
Gas Transport Tests



- Torrent Permeameter
- Oxygen Permeameter
- Oxygen Diffusivity

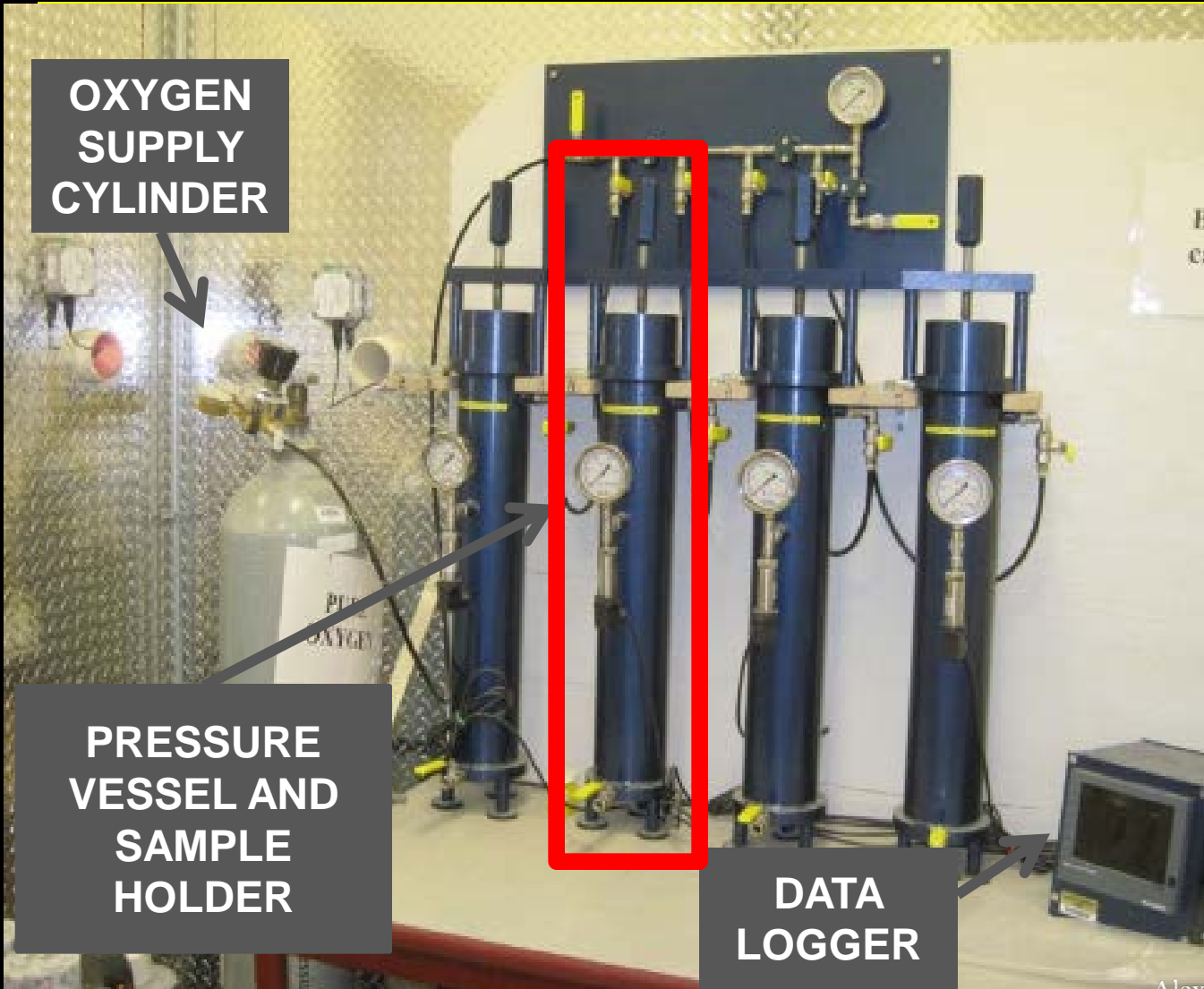


(Abbas 1999, Loser et al 2010, Xi et al.1994, Gardener 2007)





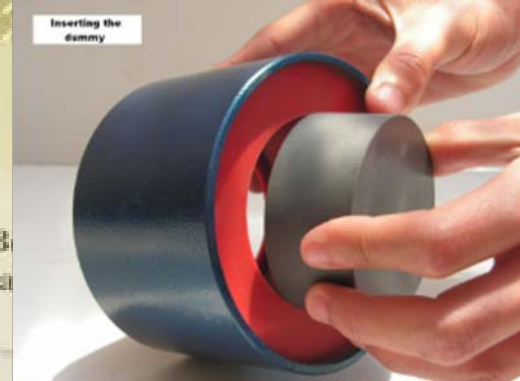
South African Permeameter



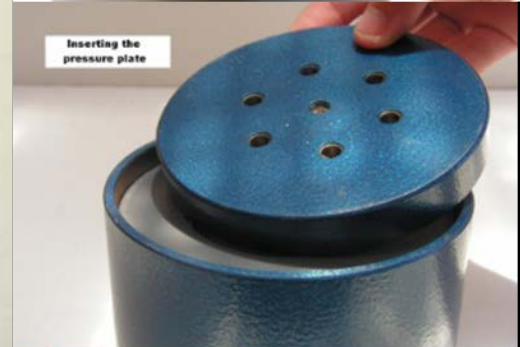
OXYGEN
SUPPLY
CYLINDER

PRESSURE
VESSEL AND
SAMPLE
HOLDER

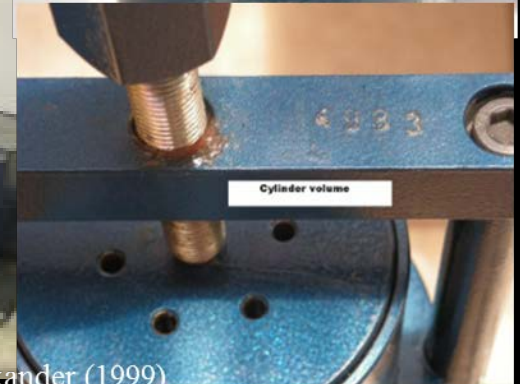
DATA
LOGGER



Inserting the dummy



Inserting the pressure plate



Cylinder volume

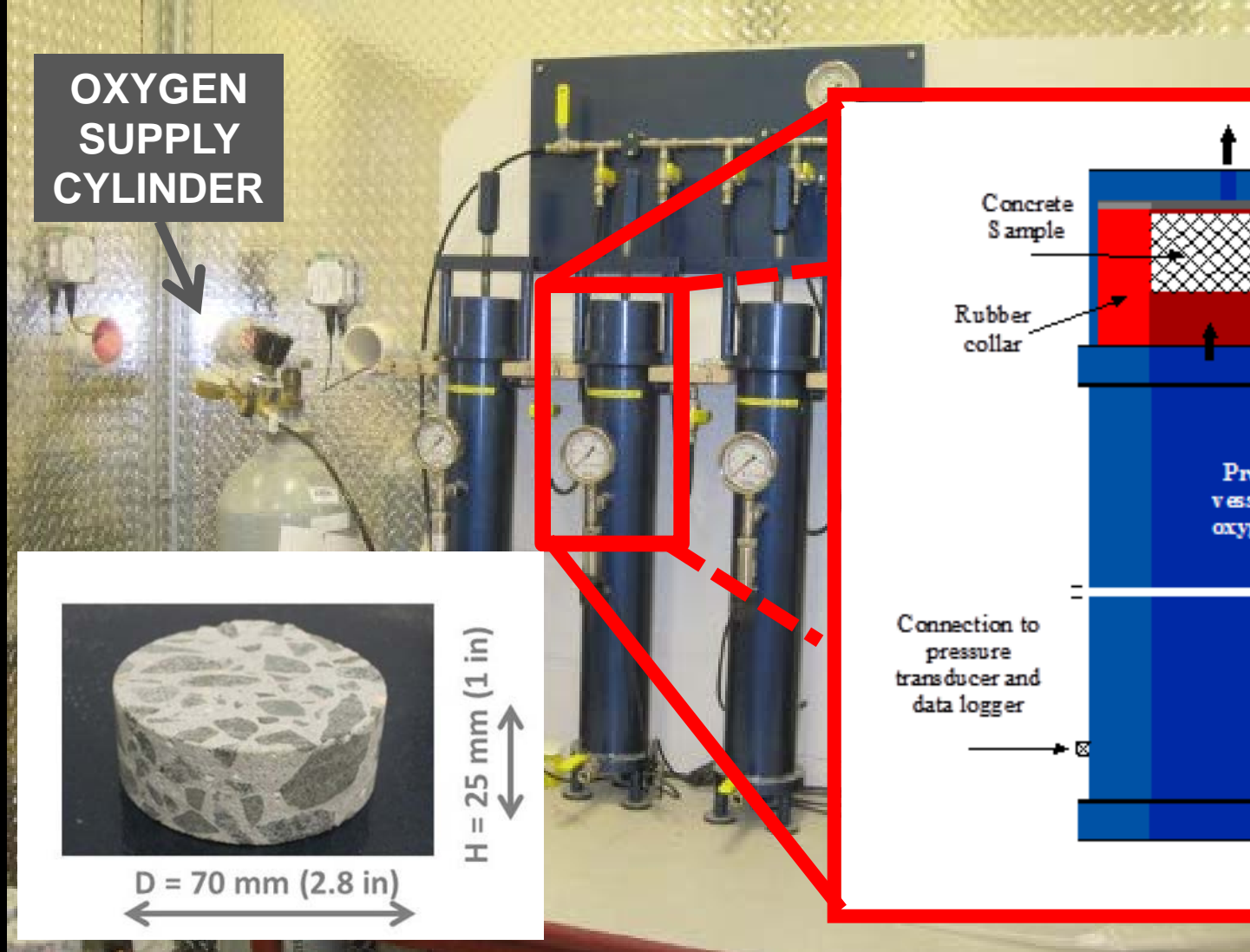
Alexander (1999)



South African Permeameter

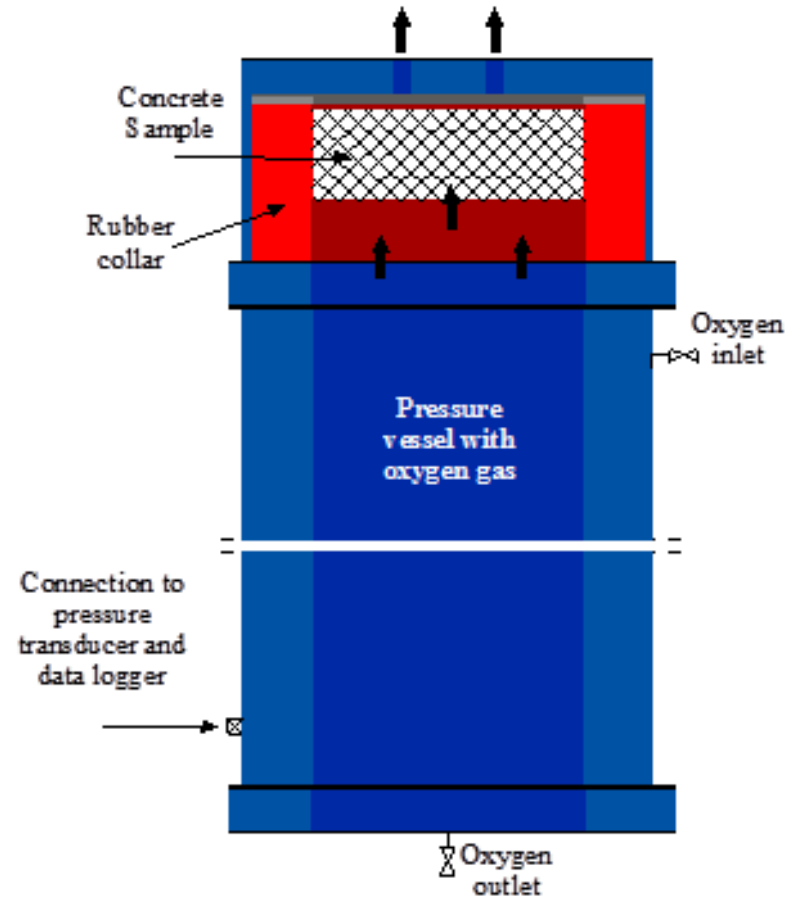


OXYGEN
SUPPLY
CYLINDER



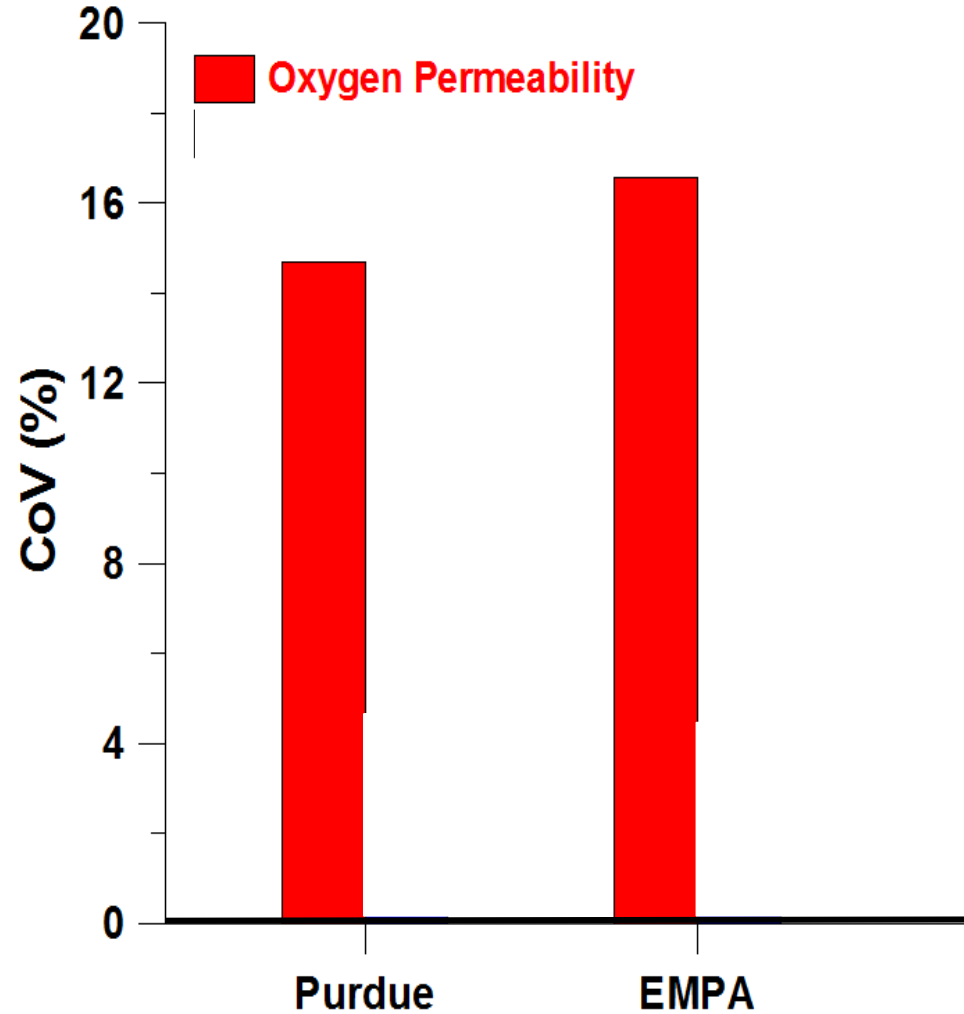
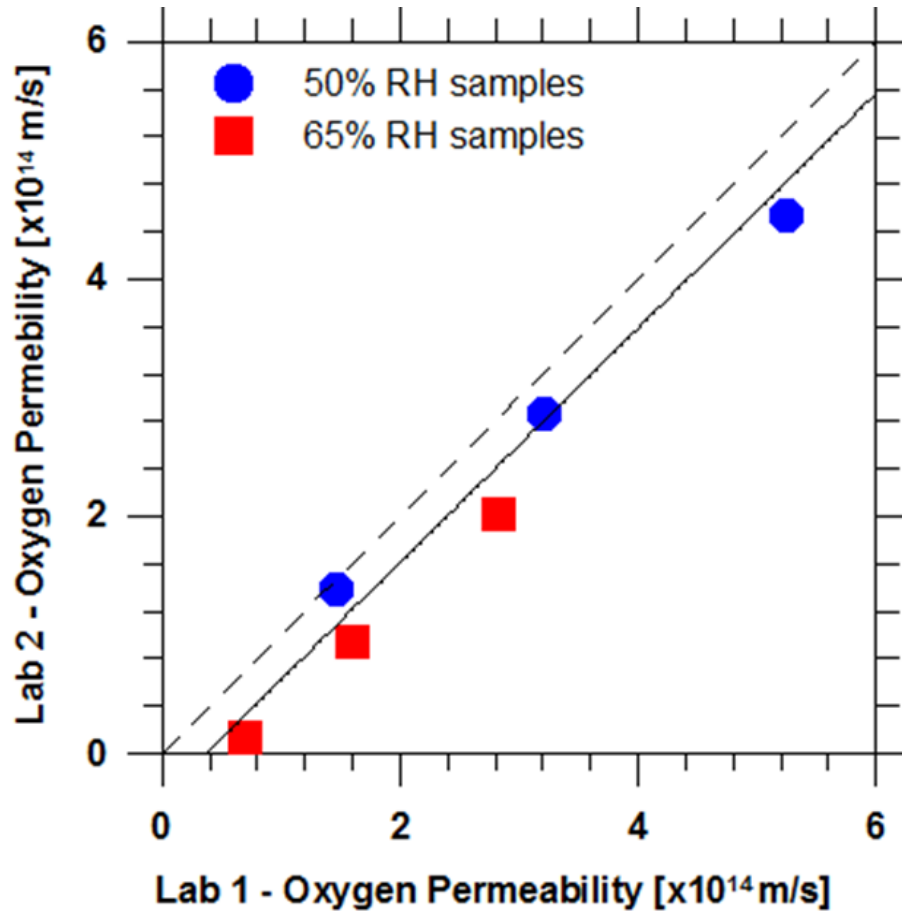
D = 70 mm (2.8 in)

H = 25 mm (1 in)





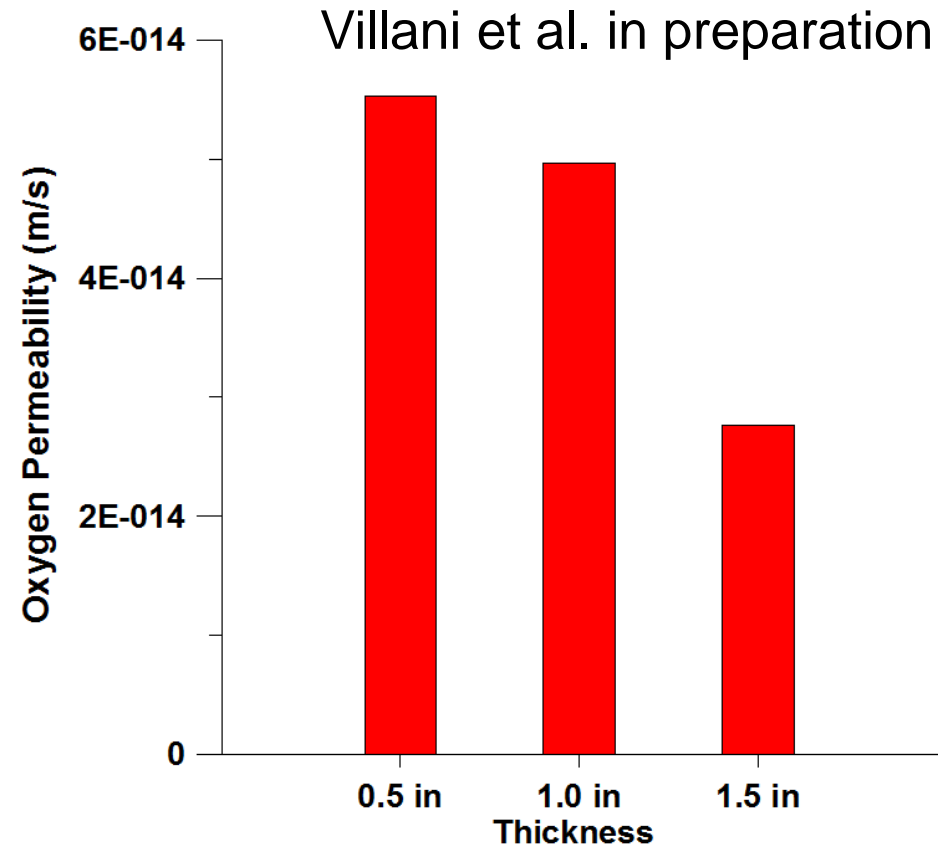
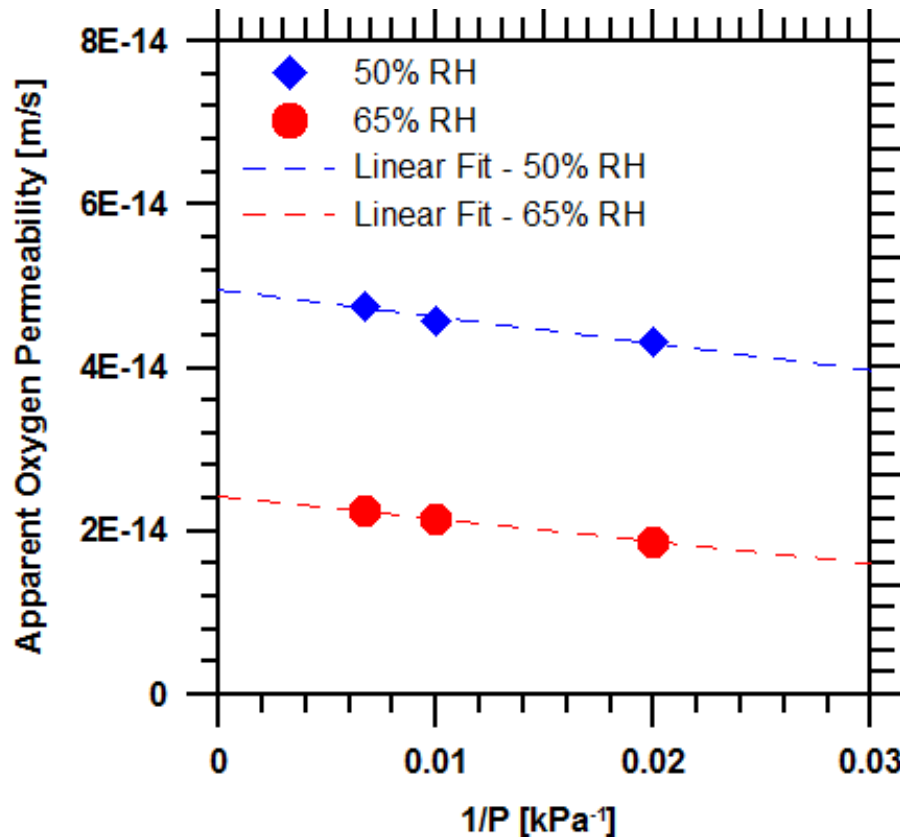
O Permeability Results



Villani et al. in preparation



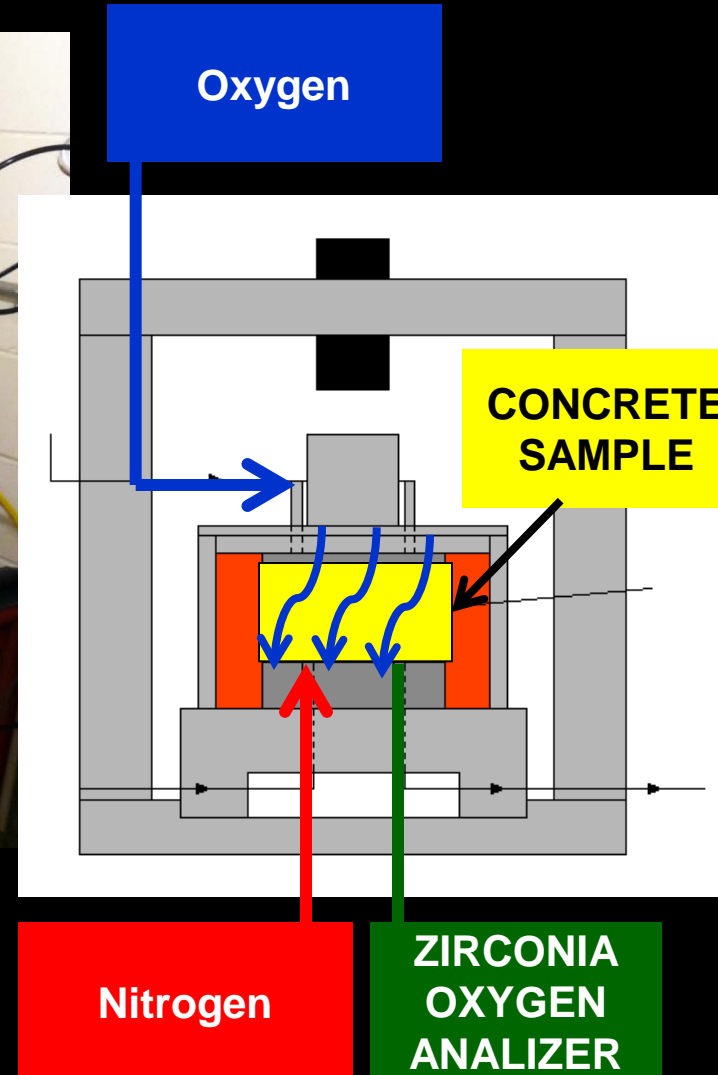
Gas Pressure and Sample Size



- Experiment performed to understand the variability which appears a bit high



Oxygen Permeability



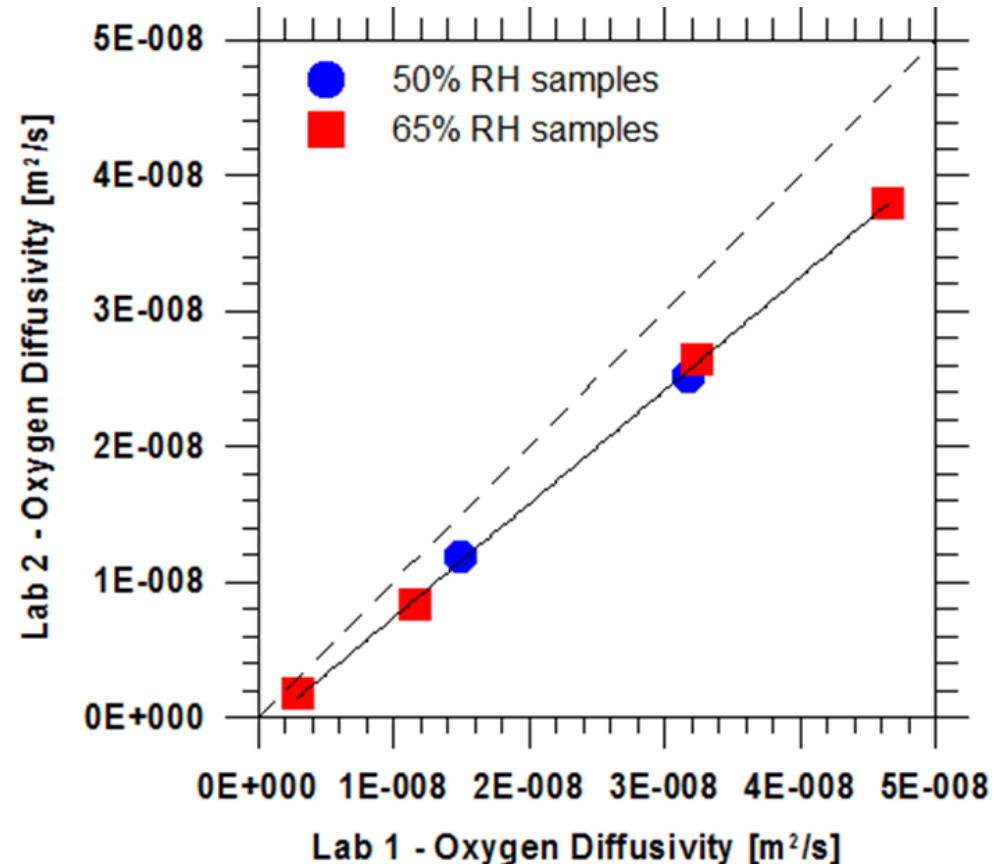
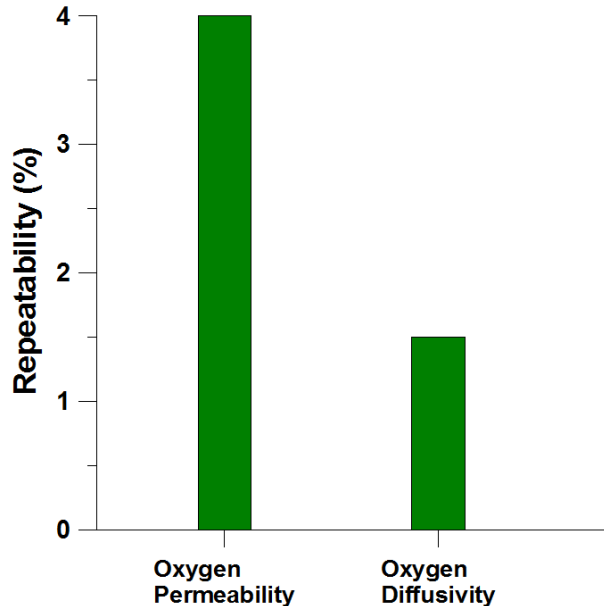
$$D_N = \frac{Q_{m^3/s} \cdot L}{A \cdot \Delta C}$$



Oxygen Permeability



- Low Variation



- Systematic difference due to pressure difference and a correction was developed

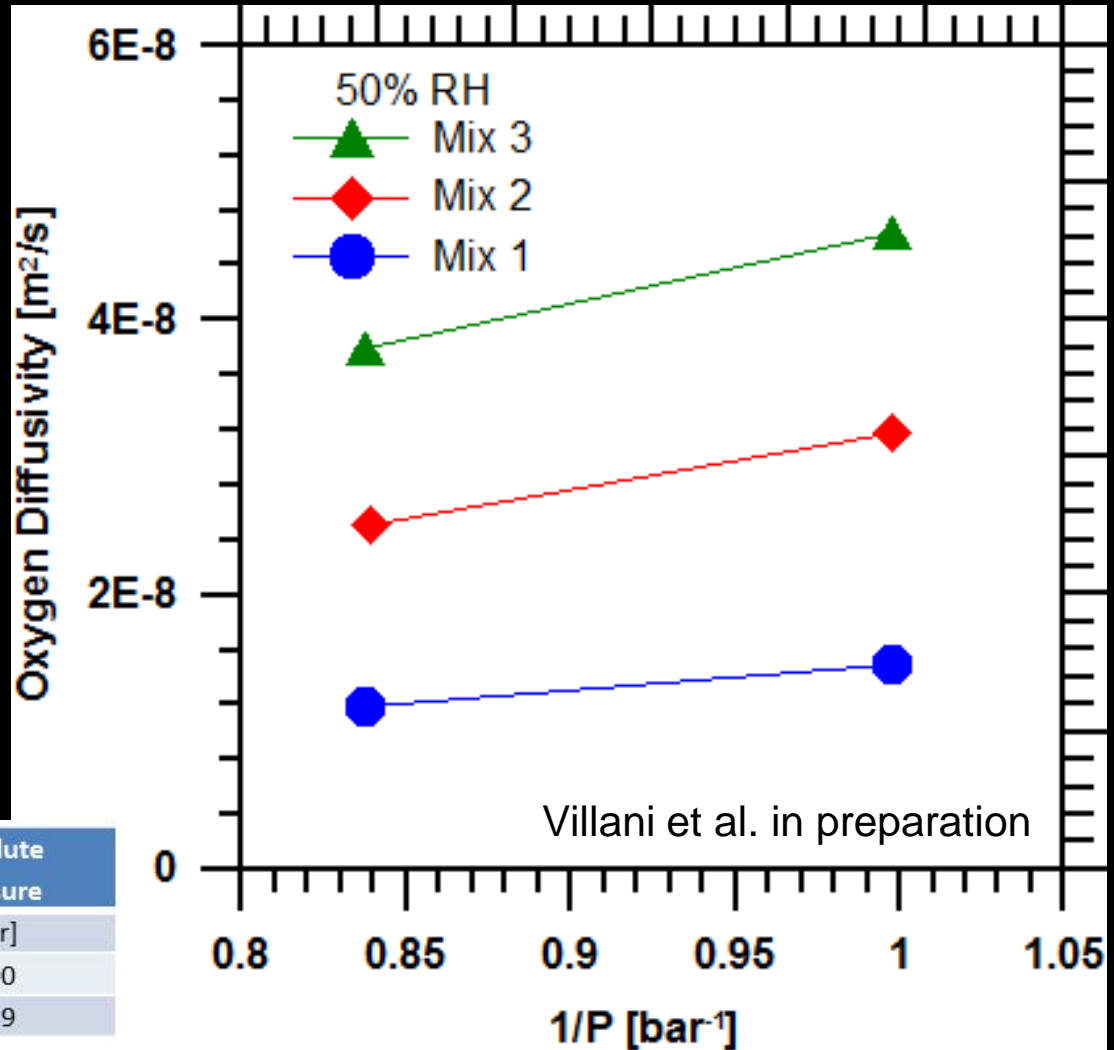
Villani et al. in preparation



Oxygen Permeability

$$D_N = \frac{Q_{m^3/s} \cdot L}{A \cdot \Delta C}$$

The difference in permeability explains the variation in oxygen diffusivity and a correction is implemented



Laboratory	Nitrogen Flow Rate	Absolute Pressure
	[ml/mm]	[bar]
Purdue	124	1.00
EMPA	222	1.19



Results:

Mathematical Formulation Review



Oxygen Permeability

M.G. Alexander, Y. Ballim, J.M. Mackechnie, Concrete durability index testing manual, Research Monograph no. 4, Departments of Civil Engineering, University of Cape Town and University of the Witwatersrand (1999)

$$\omega = 36 \left[\frac{g}{mol} \right]$$

$$\omega = 0.036 \left[\frac{kg}{mol} \right]$$

$$k = \frac{\omega V g dz}{RA\Phi} = \frac{\omega \left[\frac{g}{mol} \right] \cdot V [m^3] \cdot g \left[\frac{m}{s^2} \right] \cdot d [m] \cdot z \left[\frac{1}{s} \right]}{R \left[\frac{kg \cdot m^2}{s^2 \cdot mol \cdot ^\circ K} \right] \cdot A [m^2] \cdot \Phi [^\circ K]} = k \left[\frac{m}{s} \right]$$

Oxygen Diffusivity

Inconsistent derivations in the literature. We have investigated and will move forward using the derivations that match our derivations

WONG
(2006-2009)

$$\Delta C = \left[100 - \left(\frac{R_1}{R_2} \cdot \frac{(G_1 - G_0)}{2} \cdot \sqrt{\frac{32}{28}} \right) \cdot \frac{P_1}{100} - \frac{(G_1 + G_0)}{2} \cdot \frac{(P_1 - U_1)}{100} \right]$$

LAWRENCE
(1984)

$$\Delta C = \left[100 - \left(\frac{R_1}{R_2} \cdot \frac{(G_1 - G_0)}{2} \cdot \sqrt{\frac{32}{28}} \right) \cdot \frac{P_1}{100} - \frac{(G_1 + G_0)}{2} \cdot \frac{(P_1 - U_1)}{100} \right]$$



Conclusions

- Tests are all up and running
- Rapid conditioning is showing progress (rapid/controlled drying underway)
- Electrical test standard draft to circulate
- Sorption standard modifications submitted
- Gas test standard ready to be drafted
- Ongoing tests to relate measures to performance is going well
- Ready to collect samples from the states
- Next SAC meeting will be hands on