Lab mix plan to evaluate Natural Pozzolans and water demand

- (4) mixes per material combination w/varying w/cm ratios
  - 611 lbs. of total cementitious per yard
  - Fixed 25% SCM replacement
  - Targeted a 4 - 5" slump with 5 - 6% total air content

	I/II cement 25% Class F ash	IL cement 25% Class F ash	IL cement 25% Nat. Pozzolan	C595 Blended Nat. Pozzolan cement
0.37	High Range WR	High Range WR		
0.40	Mid Range WR	Mid Range WR		
0.43	Low Range WR	Low Range WR	High Range WR	High Range WR
0.46	No WR	No WR	Mid Range WR	Mid Range WR
0.49			Low Range WR	Low Range WR
0.52			No WR	No WR

Goals:
- Natural Pozzolans vs. Fly Ash (& smaller extent C150 vs. C595 IL)
- Understand the limitations of adding extra water to NP mixes
  - Can the water demand of NP's be met w/o adverse effects?
- NP's are being used successfully today:
  - Can they be used more sustainably/cost effectively/etc?

Summary of Workability & Air Contents

- I struggled more w/the target slumps and airs with the mixes with higher dosages of HRWR's
- Both natural pozzolan mixes required more water than either of the mixes with fly ash

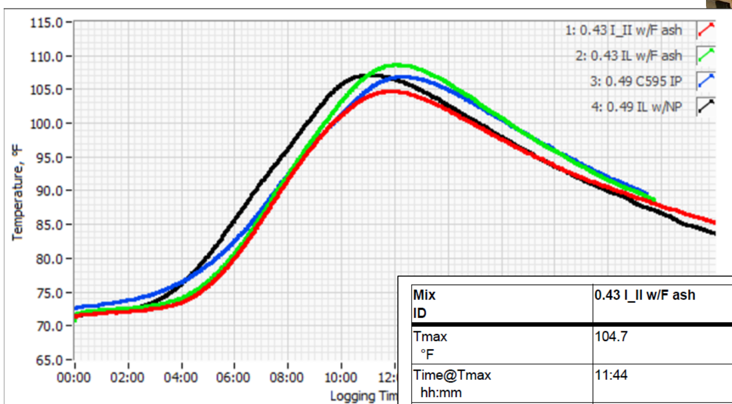
	I/II cement 25% Class F ash	IL cement 25% Class F ash	IL cement 25% Nat. Pozzolan	C595 Blended Natural Pozzolan cement
0.37	7.5" - 5.0oz/cwt HR - 7.2%	4.75" - 5.0oz/cwt HR - 6.0%		
0.40	4.25" - 5.7oz/cwt MR - 6.8%	4.75" - 5.7oz/cwt MR - 6.2%		
0.43	5" - 3.8oz/cwt LR - 6.8%	5" - 3.8oz/cwt LR - 5.7%	5" - 8.7oz/cwt HR - 7.0%	8.5" - 5.7oz/cwt HR - 7.0%
0.46	6.5" - No WR - 7.4%	5.75" - No WR - 5.6%	3" - 6.9oz/cwt MR - 5.6%	4.5" - 5.9oz/cwt MR - 5.6%
0.49			4" - 5.0oz/cwt LR - 5.3%	4.25" - 5.0oz/cwt LR - 5.7%
0.52			4" - No WR - 5.6%	4.5" - No WR - 5.5%

HR = High Range Water Reducer
MR = Mid Range Water Reducer
LR = Low Range Water Reducer

Semi-Adiabatic Calorimetry

- Used to easily compare heat gain/set times
  - Equal weights of mortar sieved from concrete mixes
  - Data logger captures each mix's heat gain
  - Plot used to calc. estimated time of initial/final sets

Each cementitious blend with the Type A WR (varying w/c)



Using the same WR:
- the increased w/c ratios didn't affect sets with NP's

Mix ID	0.43 I_II w/F ash	0.43 IL w/F ash	0.49 C595 IP	0.49 IL w/NP
Tmax °F	104.7	108.7	106.9	107.2
Time@Tmax hh:mm	11:44	12:01	12:26	11:04
Init Set hh:mm	05:36	05:41	05:10	04:38
Final Set hh:mm	07:08	07:19	07:10	06:20

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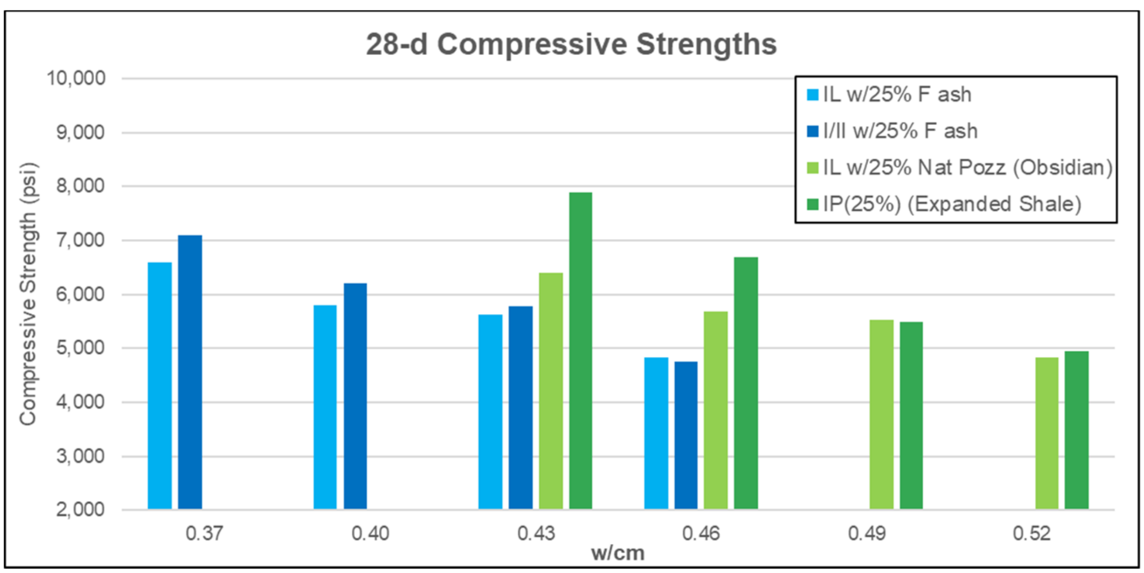
Strengths



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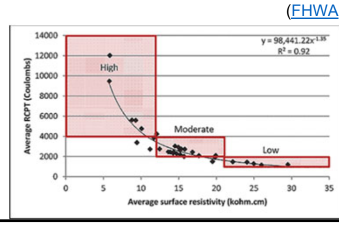
Durability testing

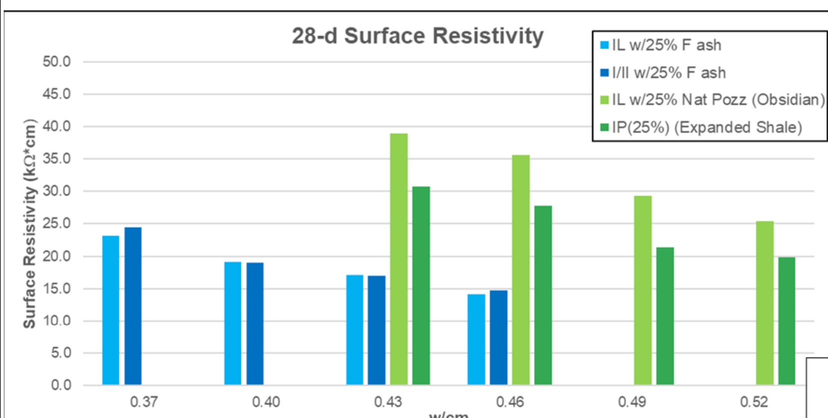
- For years there's been no easy/quick test method for assessing a mix's durability performance
- **Specs have relied on limiting the w/cm as a surrogate**

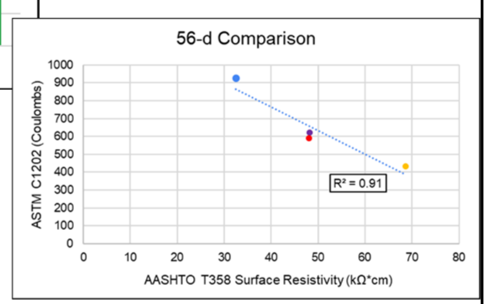
- ASTM C1202 - Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
  - Measures amount of electrical current passing thru 2" core
  - Significant prep, time and handling of caustic solutions
  - Has been specified for years…lower coulomb values better
- AASTHO T358 - Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration (2015)
  - Easier test to perform
  - Some DOT's have started requiring this test
  - Can be run on the 28-d comp cyls
  - Higher resistivity values better
  - Excellent correlation to C1202

(FHWA)



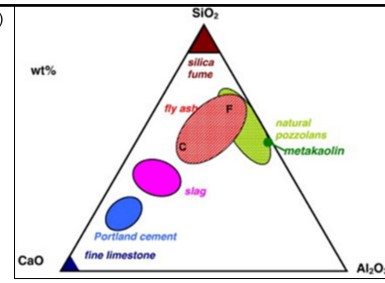
Surface Resistivity's (AASHTO T358)





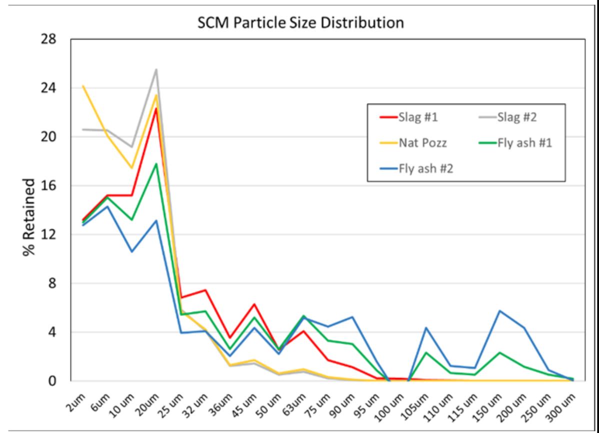
Properties of different SCM's

(Lothenbach, et al, Science Direct)



- Chemistry
  - CaO content
  - Si/Al oxide contents
- Shape
  - Spherical vs. Angular
- Fineness/Particle Size Distribution
  - Finer grinds typically increase water demand
  - Finer grinds will react faster
  - Too much of one size affects water demand
    - Similar to aggregate particle packing
- Capacity to Absorb Water
  - Glassy vs. Porous
  - % Total Porosity???

All of these properties will affect fresh, hardened & pozzolanic properties of the SCM



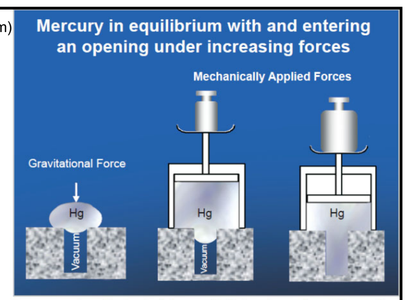
Absorptive Capacity Testing of NP's

(micromeritics.com)

- What is causing the higher water demand…
- Without reducing strength or increasing permeability?

Mercury Intrusion Porosimetry by Micromeritics in Norcross, GA:

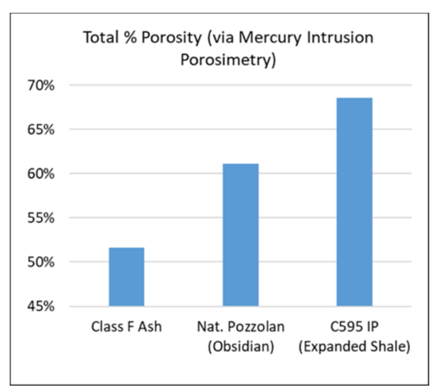
- Increase pressure (>50,000 psi) to fill pores in SCM's
- Larger pores fill at lower pressures…smaller pores at higher
- Incremental pressure applied…capacitance changes
- Capacitance change is proportional to the volume change = porosity



Since mercury does not wet most substances and will not spontaneously penetrate pores by capillary action, it must be forced into the pores by the application of external pressure.

Results from Micromeritics:

- Total % Porosity of Nat. Pozzolans higher than fly ash
- More potential for both pozzolans to absorb batch water



- Aggregates, if dry, will absorb batch water
  - We account for this in our batching adjustments

If the natural pozzolans in this study absorb batch water:

- How much do they absorb?
- How quickly do they absorb it?
- Is there a new effective w/cm ratio?
- How much of that water is available for internal curing?

Basis for moving to performance specifications

(ppic.org)

Concrete mix design development is a balancing act!

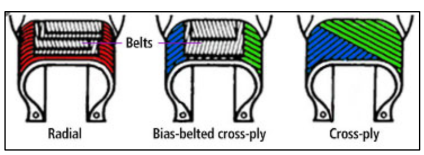
a) Strength
b) Workability (and how long you have it)
c) Durability
d) Dimensional stability
e) Repeatability
f) Economics
g) Sustainability
h) Finishability

Prescriptive specifications limit the innovative potential of the concrete supplier as these specifications were built on the studies of other materials

Overall concrete durability is important…
but when necessary, so is finishability

Specifications – How do you want to purchase your vehicle's tires?

Prescriptive
- Ratio of Synthetic to Natural Rubber
- % of steel belting to total weight of tire
- Radial vs. Cross Ply



Performance
- Dry and Wet braking performance
- Quiet Ride
- Fuel Efficiency
- Mileage/Durability

Prescriptive Specifications
- What type of cement to use
- Maximum allowable % SCM replacement
- Maximum w/cm ratios
- Minimum cement contents
- Sand/Aggregate ratios

Current concrete specifications are a combination of the two

Performance Specifications
- Strength
- Workability
- Shrinkage
- ASR/Sulfate Mitigation
- Permeability/Resistivity

Provides the manufacturer the ability to optimize performance and efficiency while meeting customer needs

ACI 318-19 ACI Building Code Requirements

- Current specified durability requirements to ensure adequate durability, protecting against:
  - F - Freezing & Thawing
  - S - Sulfate
  - P/W - In contact w/water
  - C - Corrosion Protection of Reinforcement

Only time a w/cm limit should be specified is when an exposure class requires it

(ACI 318-19)

Table 19.3.2.1—Requirements for concrete by exposure class

Exposure class		Maximum w/cm[1,2]	Minimum f'_c, psi	Additional requirements			Limits on cementitious materials
				Air content			
F0		N/A	2500	N/A			N/A
F1		0.55	3500	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete			N/A
F2		0.45	4500	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete			N/A
F3		0.40[3]	5000[3]	Table 19.3.3.1 for concrete or Table 19.3.3.3 for shotcrete			26.4.2.2(b)
				Cementitious materials[4] — Types			Calcium chloride admixture
				ASTM C150	ASTM C595	ASTM C1157	
S0		N/A	2500	No type restriction	No type restriction	No type restriction	No restriction
S1		0.50	4000	II[5][6]	Types with (MS) designation	MS	No restriction
S2		0.45	4500	V[6]	Types with (HS) designation	HS	Not permitted
S3	Option 1	0.45	4500	V plus pozzolan or slag cement[7]	Types with (HS) designation plus pozzolan or slag cement[7]	HS plus pozzolan or slag cement[7]	Not permitted
S3	Option 2	0.40	5000	V[8]	Types with (HS) designation	HS	Not permitted
W0		N/A	2500	None			
W1		N/A	2500	26.4.2.2(d)			
W2		0.50	4000	26.4.2.2(d)			
				Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by mass of cementitious materials[9,10]			
				Nonprestressed concrete	Prestressed concrete	Additional provisions	
C0		N/A	2500	1.00	0.06	None	
C1		N/A	2500	0.30	0.06		
C2		0.40	5000	0.15	0.06	Concrete cover[11]	

(Use authorized by ACI)

ACI 329-14 Report on Performance-Based Requirements for Concrete

- Based on P2P Phase II Report (2008) provides more details
  - Pre-qualification (PQ) and Field Verified (VFR) tests

- ACI 318 Freeze/Thaw Prescriptive Criteria (F2)
  - Max 0.45 w/cm
  - 4,500 psi
  - ¾" Coarse…6% target total air

→

- Proposed Freeze/Thaw Performance Criteria (F2)
  - Minimum chloride resistance (RCPT) (FVR)
  - C666 or C672 or C457 (PQ)
  - Minimum total air content (3%...or more) (FVR)

Table 2.a – Freezing and thawing exposure

Exposure Class	Prescriptive alternative[5] for resistance to penetration		Performance alternative[5] for resistance to penetration	Prescriptive alternative[5] for air content	Performance alternative[5] for air content. Establish required air content by methods 2.3.1, 2.3.2, or 2.3.3
	Max w/cm	Min f'_c psi	Chloride resistance R'_c (Coulomb)*		
F0	-	-	---		
F1	0.45 (PQ[3])	4500	2000[1] 2500[2] (PQ[3])	Table 3a	C 666 durability factor ≥ 80%, or C 672 mass loss ≤ 1.0 kg/m², or C 457 Spacing factor ≤ 0.008 in. Air content ≥ 3.0% per 2.3.1, 2.3.2, or 2.3.3. (PQ[3])
F2	0.45 (FVR[4])	4500	2000[1] 2500[2] (FVR[4])	Table 3a	C 666 durability factor ≥ 85%, or C 672 mass loss ≤ 1.0 kg/m², or C 457 Spacing factor ≤ 0.008 in. Air content ≥ 3.0% per 2.3.1, 2.3.2, or 2.3.3. (FVR[4])
F3	0.45 (FVR[4])	4500	2000[1] 2500[2] (FVR[4])	Table 3a with additional prescriptive requirements of Table 3b.[6]	C 666 durability factor ≥ 90%, or C 672 mass loss ≤ 1.0 kg/m², or C 457 Spacing factor ≤ 0.008 in. Air content ≥ 3.0% per 2.3.1, 2.3.2, or 2.3.3. (FVR[4])

Industry Resources

(NRMCA.org)

- Natural Pozzolan Association
  - pozzolan.org
  - 208-252-2808
- NRMCA P2P
  - Specifications in Practice documents
  - Selected Published Papers/Reports

NATURAL POZZOLAN ASSOCIATION

Website: Pozzolan.org
Email: Info@pozzolan.org
Tel: 2082522808

P2P INITIATIVE

Summary….

- Natural pozzolans are available, being used successfully, and act different than fly ash
- These new SCM's don't behave like the materials our prescriptive specs were built around
- If the industry is going to make progress on the sustainability goals in front of us, producers will need to be able to innovate. Moving to performance specifications…including eliminating the maximum w/cm…will likely be required.

Start becoming familiar with & permitting performance specifications where you can!

Questions…feel free to email:

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