Investigation of Materials and Methods to Reduce Concrete Permeability

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- Concrete permeability can be strongly linked to mechanisms of distress such as freeze/thaw salt scaling and ASR deterioration that affect concrete durability.
- SCM's and lower w/c ratio are known methods to reduce permeability.
- Availability of quality SCMs has led MDOT to investigate the use of Permeability Reducing Admixtures as an alternative to improve durability.

Joint Erosion due to shear failure

Salt-Frost Erosion of Concrete Mortar

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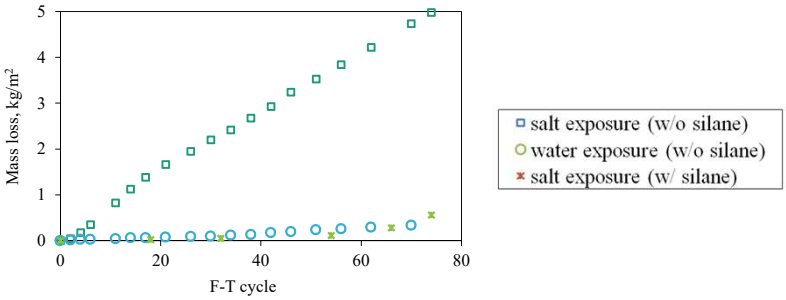
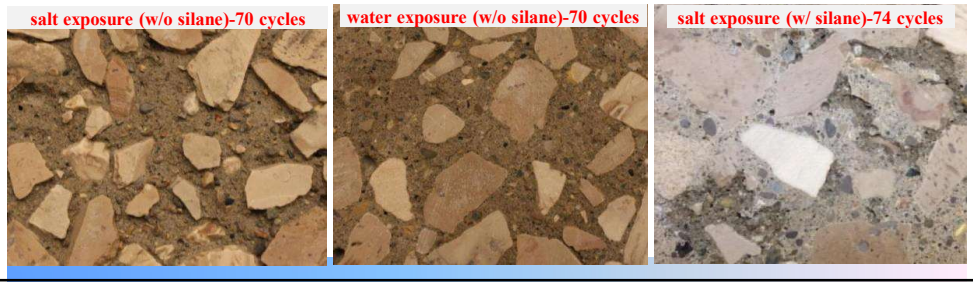
- Hydrophobic surface treatment using silane

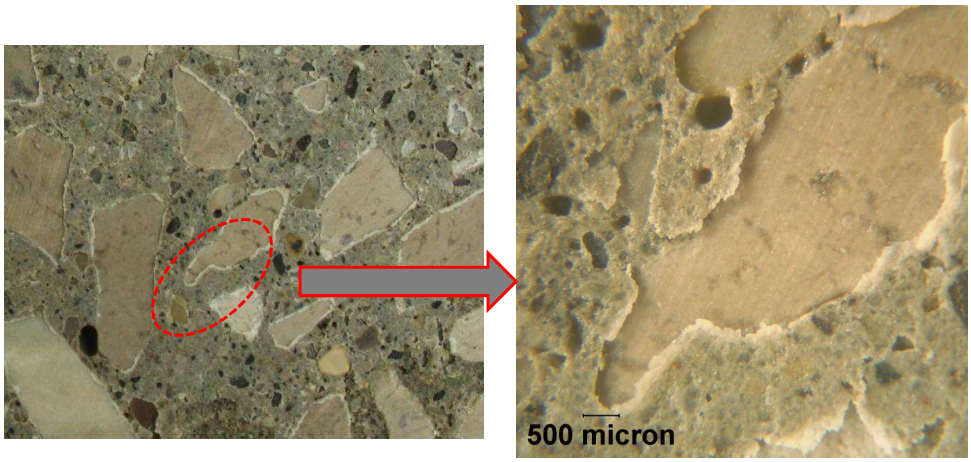




What is Salt-Frost Scaling? ICE-GROWTH Damage IN CONCRETE

- Paste swelling under salt exposure

0.45 w/c ratio Control Concrete-2 F-T cycles



Evaluation of Permeability Reducing Admixtures (PRA) for improved Concrete Durability

- A team approach was used for a two year (2017-18) research project to evaluate PRAs, SCMs, and lower w/c ratio.
- MDOT molded concrete samples, conducted fresh concrete tests, tested compressive strength and resistivity.
- UM tested for deicer scaling, internal frost damage, autogenous shrinkage, sorptivity, hardened air content, and rapid chloride permeability on concrete samples.
- MTU made mortar samples, tested for deicer resistance, sorptivity, chloride penetration, and ASTM 1260 expansion (ASR).

ACI Committee 212 Classification of Permeability Reducing Admixtures

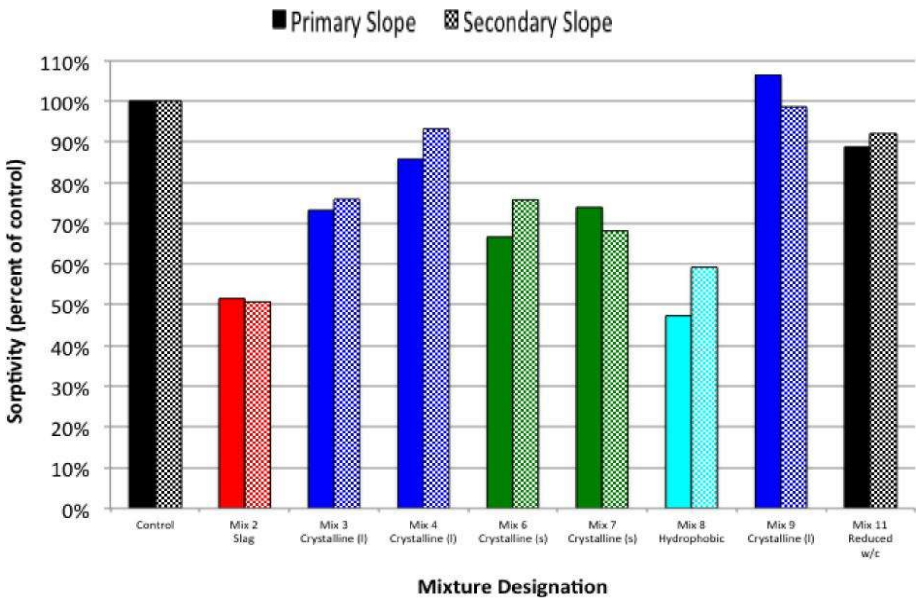
- Hydrophobic water repellents are compounds that form a coating on the surface of the pores slowing water transport.
- Crystalline products are hydrophilic chemicals that react with water to form calcium silicate hydrate (CSH) that block pores.
- Finely divided solids work by increasing the density of the paste. SCMs including fly ash and slag cement could also be considered in this PRA category.
- Overlaps in current ACI 212.R3-16 classification can make it difficult to select a PRA for an intended use case.

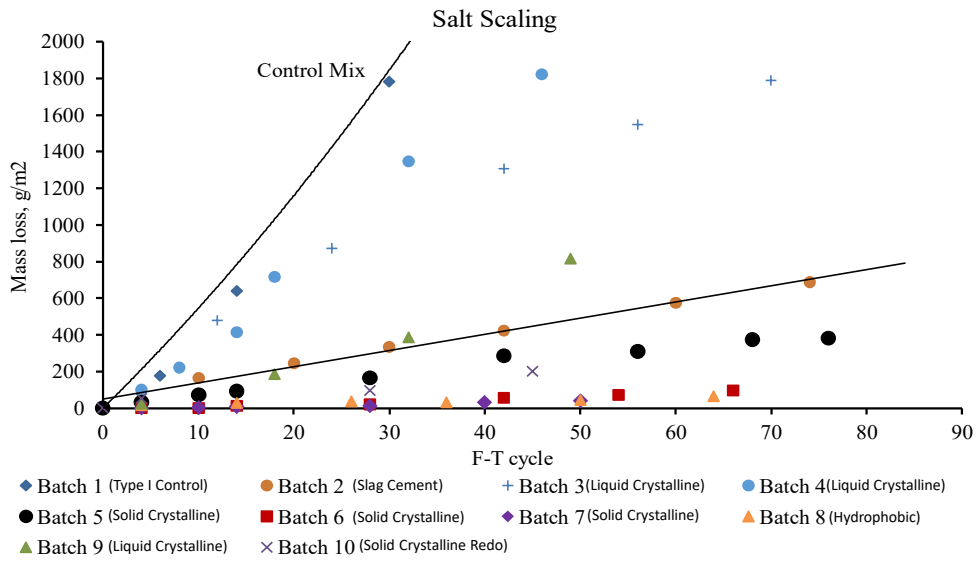
2017 PRA testing matrix for mortar and concrete samples

- Nine mortar mixes made at MTU included a Type I Portland cement control, 30% slag cement replacement, three liquid and two solid crystalline PRAs, one liquid hydrophobic PRA, and a reduced w/c mix. Mortar mixes were tested at 0.45 w/c except for one reduced w/c mix.

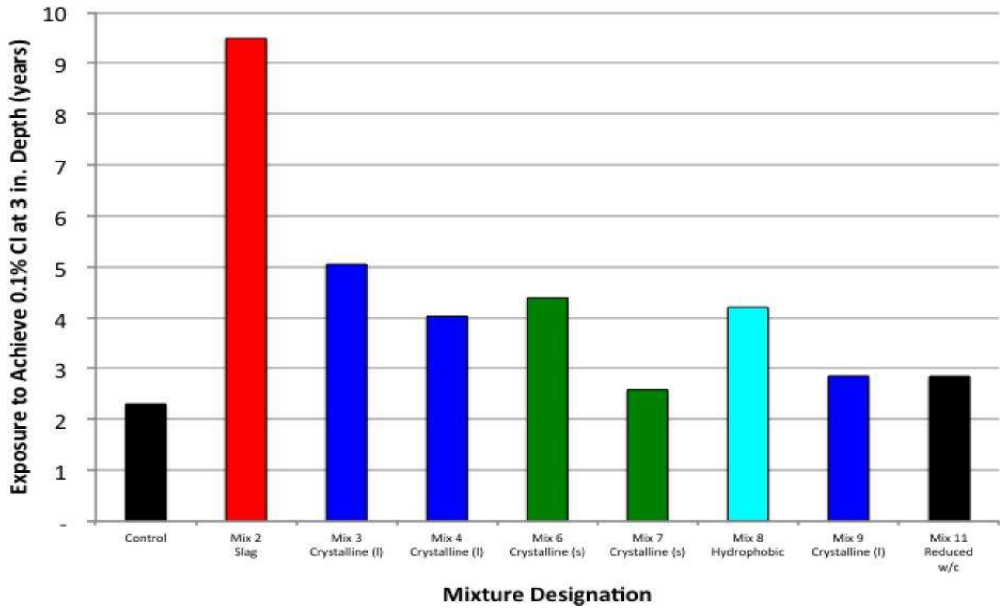
- Ten concrete mixes were made at MDOT that include Type I Portland cement control, 30% slag cement replacement, three liquid and three solid crystalline PRAs, one liquid hydrophobic PRA, and a crystalline PRA remix. Concrete mixes were tested at 0.45 w/c.

Mortar Sorptivity ASTM C1585

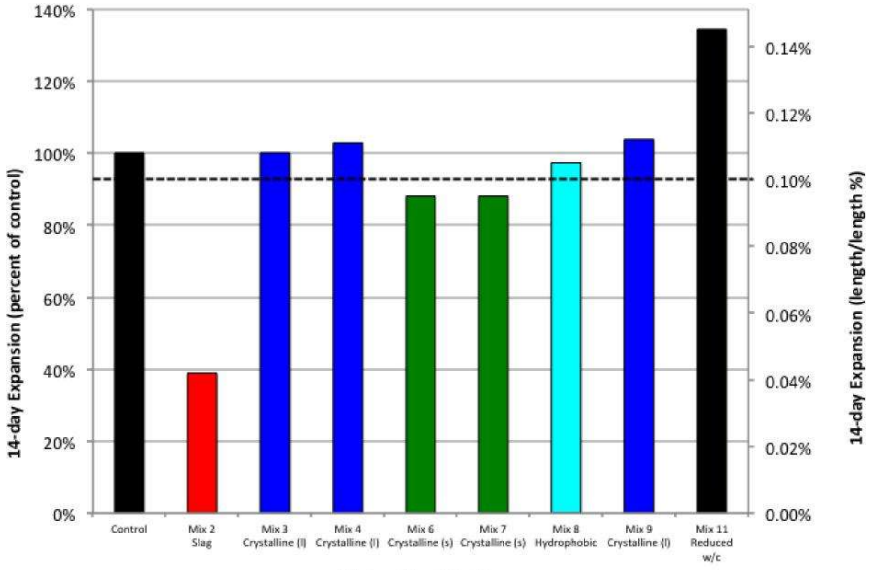


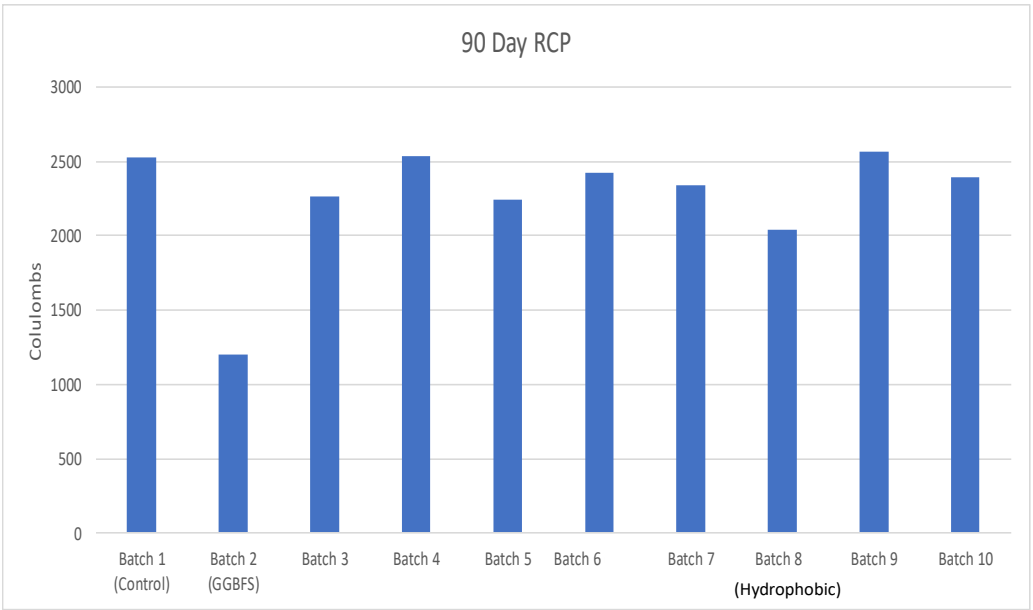


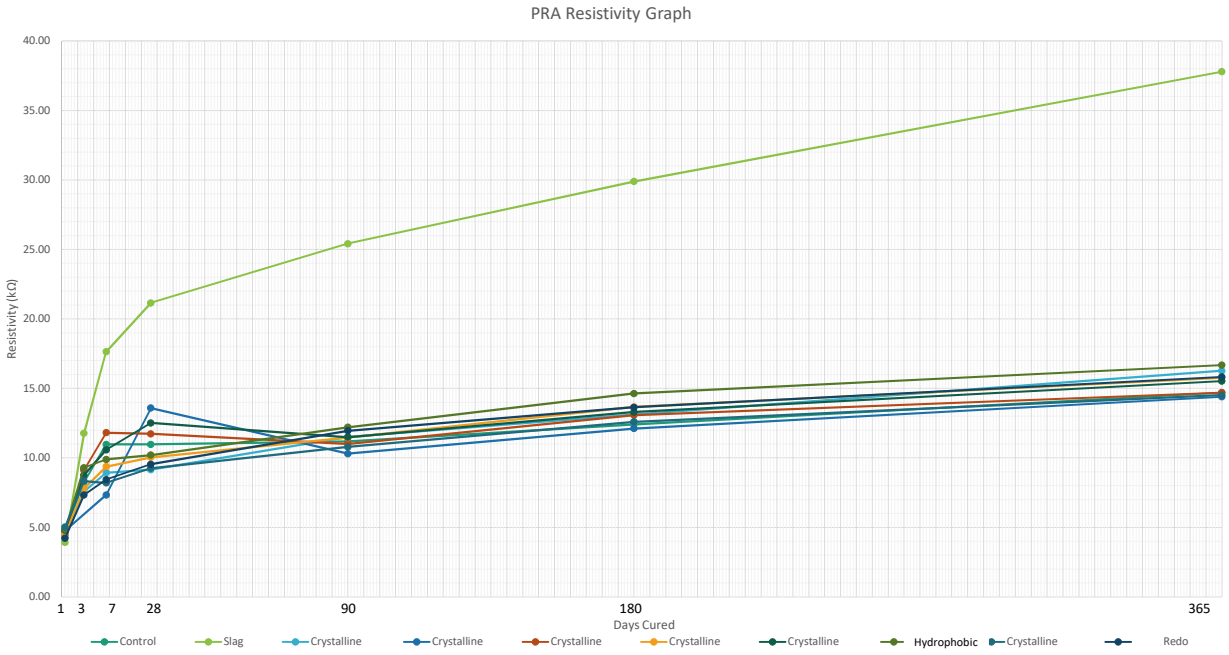
RILEM TC 176 F/T Testing



ASTM 1260 Mortar Bar Testing





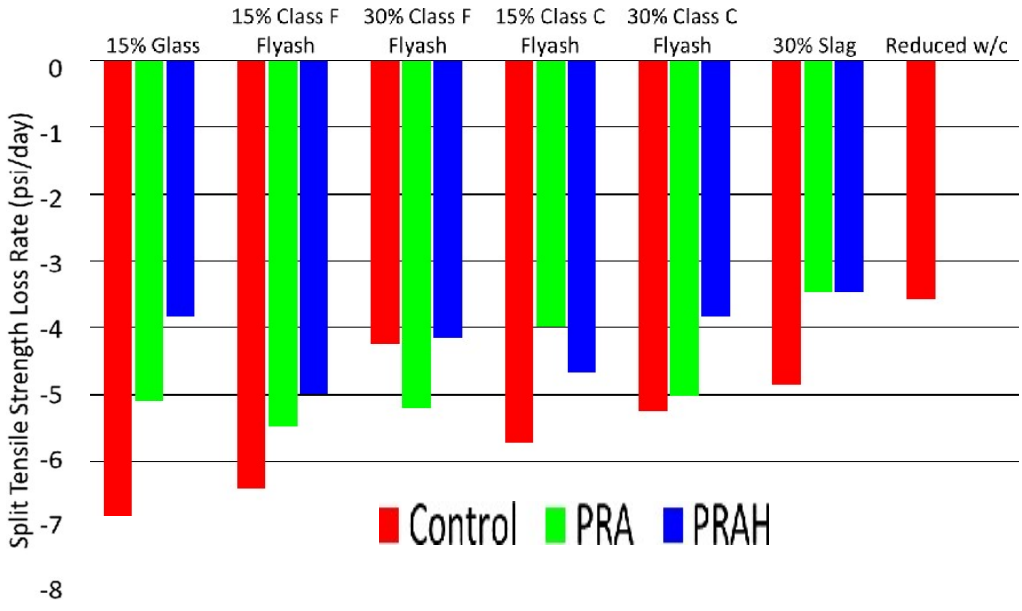


2017 Research Findings

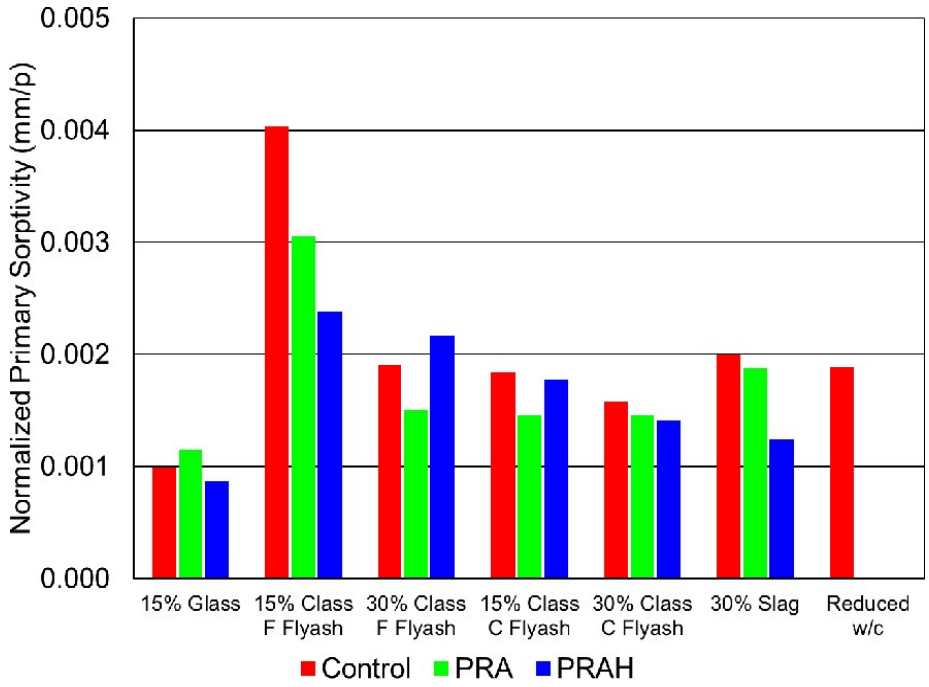
- Sorptivity and chloride penetration showed improvement with addition of PRA over the Type I control mix.
- Hydrophobic PRA performed better than other PRA's tested in sorptivity and salt frost scaling.
- Deicer resistance showed slight improvement with addition of PRA.
- 30% slag cement replacement mix outperformed all mixes tested.
- PRA mixes performed approximately equivalent to control in AMBT (C1260) .
- Resistivity and Rapid chloride permeability tests corelated well and show slight to no improvement over the control concrete.

2018 testing matrix included the combined effects of PRA's and SCM's

- 30% SCM replacement (slag cement, Class C and Class F Ash)mixes became control for 2018.
- One hydrophobic and one crystalline admixture that performed well in 2017 were tested with each combination of SCM.
- w/cm ratio was reduced from 0.45 in 2017 to 0.40 in 2018.
- MTU tested additional mortar samples with 15% ash and ground glass.
- Concrete testing also included one Portland Type I sample.



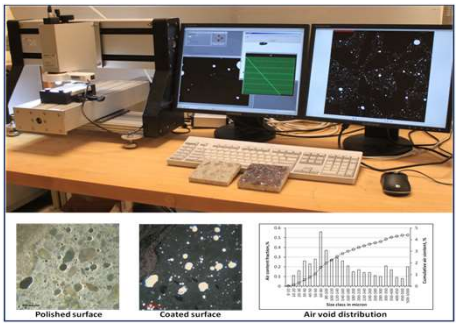
Deicer resistance results; split tensile strength loss rate after soaking in 17% CaCl2 at 40 F

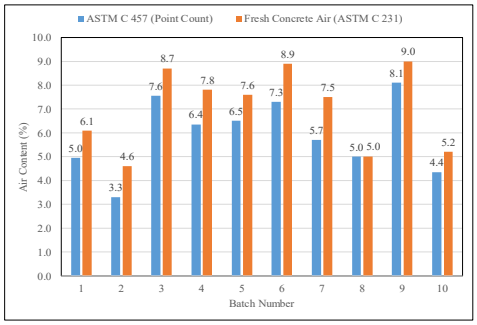


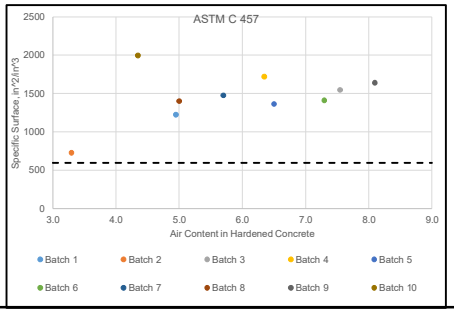
MDOT Concrete Mix Proportions (lb/cyd)-SSD

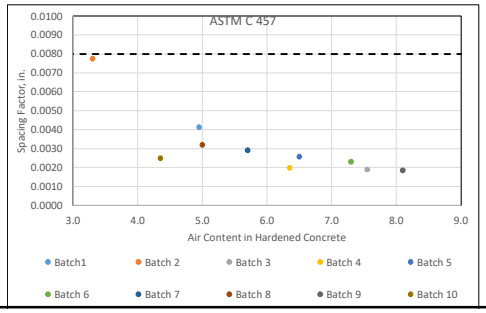
Batch No.	1	2	3	4
ID	Slag Cement Control	Slag Cement w. PRA	Slag Cement w. PRA	Portland Cement Control
Materials				
Type I Cement	395	395	395	564
Slag Cement	169	169	169	0
Class C Flyash	0	0	0	0
Class F Flyash	0	0	0	0
Total Cementitious	564	564	564	564
Total Water	226	226	226	226
C. Agg.	1779	1779	1779	1779
F. Agg.	1250	1250	1250	1250
Liquid PRA (gal/cyd)	0	2	0	0
Dry PRA (% cwt)	0	0	2	0
MR WR (oz/cwt)	12.48	24	0	0
HR WR (oz/cwt)	0	0	12	3.5
% Air	6.1	4.6	8.7	7.8
Slump (in.)	2	6.75	7	2.5
Temperature (0F)	73.4	70	69	76

Concrete Specimen Air-Void System



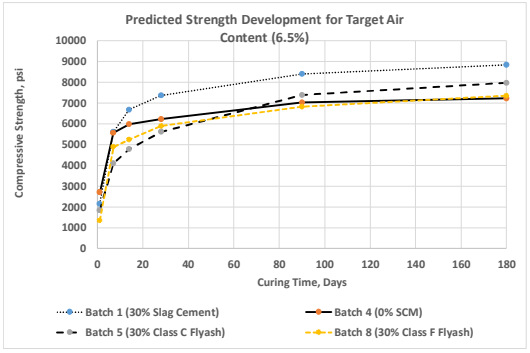


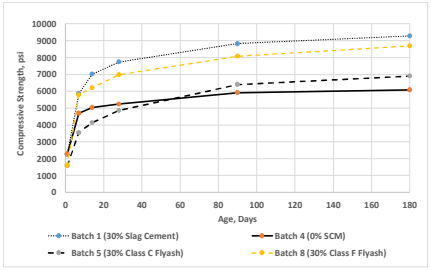


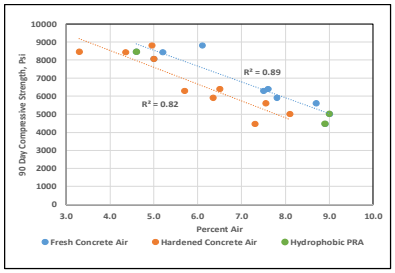


Pozzolanic Effectiveness and Air Content for Compressive Strength

Four Control Concretes







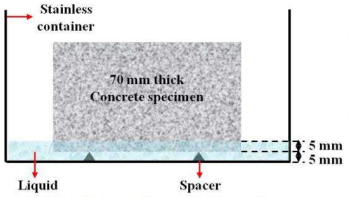
UM Freeze-Thaw Testing for Internal Crack Resistance and Salt Scaling (i.e. 3% NaCl solution)

Concrete Containing SCM Cured 90 days:

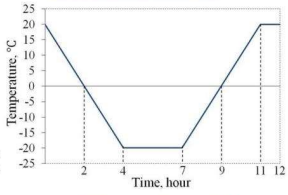
- cut specimens (4 by 4 by 2.75 inch thick)
- Drying at 50C for 2 weeks
- 1 week water sorption (ASTM C 1585)
- Then, F-T testing from 20 C to -20 C

(a) Salt frost test machine

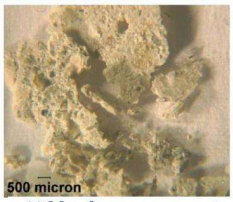
(b) Specimen container



(c) Detailed specimen configuration



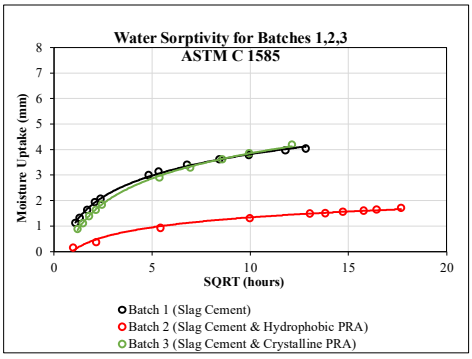
(d) Temperature profile

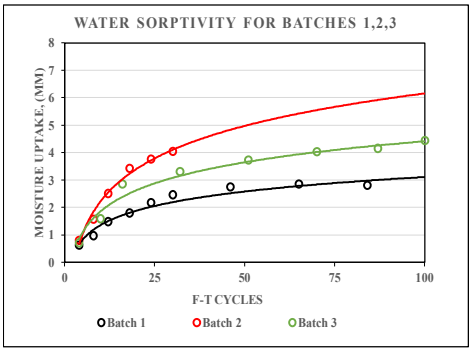


(e) Mass loss measurement

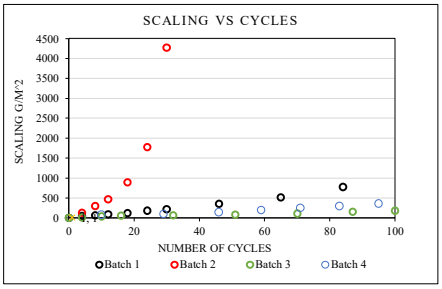
(f) Internal cracking measurement

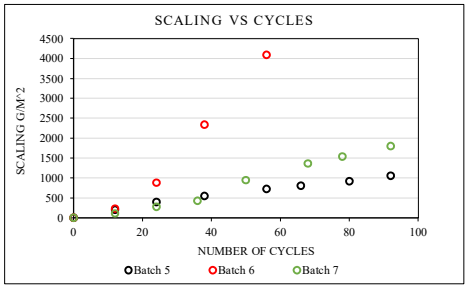
Water Sorptivity before and after Freeze-Thaw Exposure

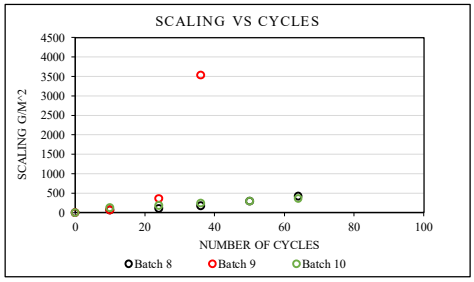




Salt-Frost Scaling







Specimen Exposure Surface Following F-T Testing

2018 Research Summary

- Addition of PRA to mortar mixes containing SCM resulted in negligible or no change in paste properties under conditions tested.
- Comparisons to 2017 research indicate the addition of just an SCM and lower w/c ratio has a greater positive impact on the properties of the cement paste.
- PRA type (hydrophobic or crystalline) had little effect on permeability based on concrete RCP and resistivity measurements.
- The hydrophobic PRA showed a 50% reduction in concrete sorptivity after one week while the crystalline PRA showed no change
- Hydrophobic PRA concrete mixes had poor salt-scaling resistance after 90 day curing, irrespective of air content (4.6% to 9.0 %) and SCM type. All other concrete mixes tested performed well.

How does this research apply to MDOT and Industry partners?

- We are on the right track with current P1Mod and DM concrete mix specifications that require the use of SCM for pavements and bridges.
- The same mix design concept should be extended to all concrete in Michigan that is exposed to deicing salts (FDR's, Barriers, Curb).
- Supply of quality SCM is important to providing an economical way to make concrete that is less permeable and more durable.
- Lower water to cementitious ratio specifications should also be considered as an economical mechanism to achieve better durability.

Acknowledgements

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