Chemistry and Performance of SCMs for Wisconsin Concrete Pavement

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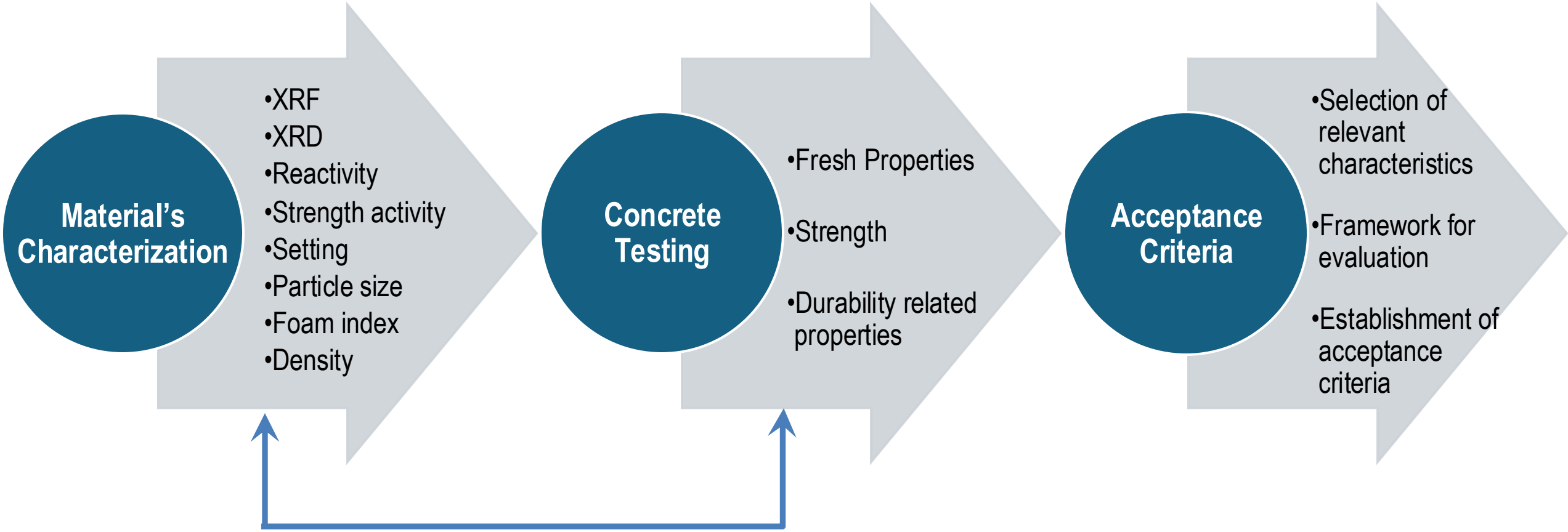
BACKGROUND

- Increasing number of new materials and technologies
- They need to be properly evaluated
- ASTM C1709 is a guide with a laundry list of tests

OBJECTIVES

- Establish appropriate testing methodologies for SCM, ASCMs, as well as concrete containing SCM and ASCMs
- Establish acceptable test results ranges
- Propose revisions to WisDOT manuals, specifications, standards, and policies related to SCMs and ASCMs

Overview


Material's Characterization
•XRF
•XRD
•Reactivity
•Strength activity
•Setting
•Particle size
•Foam index
•Density
Concrete Testing
•Fresh Properties
•Strength
•Durability related properties
Acceptance Criteria
•Selection of relevant characteristics
•Framework for evaluation
•Establishment of acceptance criteria

MATERIALS

Traditional Materials

Material	Source	Cement Replacement
Class C	Holcim from Elm Road Oak Creek, WI	30%
	Holcim, from Weston Plant at Wausau, WI	30%
Class F	Eco Material Technologies, from Coal Creek at Underwood, ND[1]	30%
	Eco Material Technologies, from Prairie State Generating Station at Marissa, IL[2]	30%
Slag Cement	Votorantim from St. Mary's, MI	30%

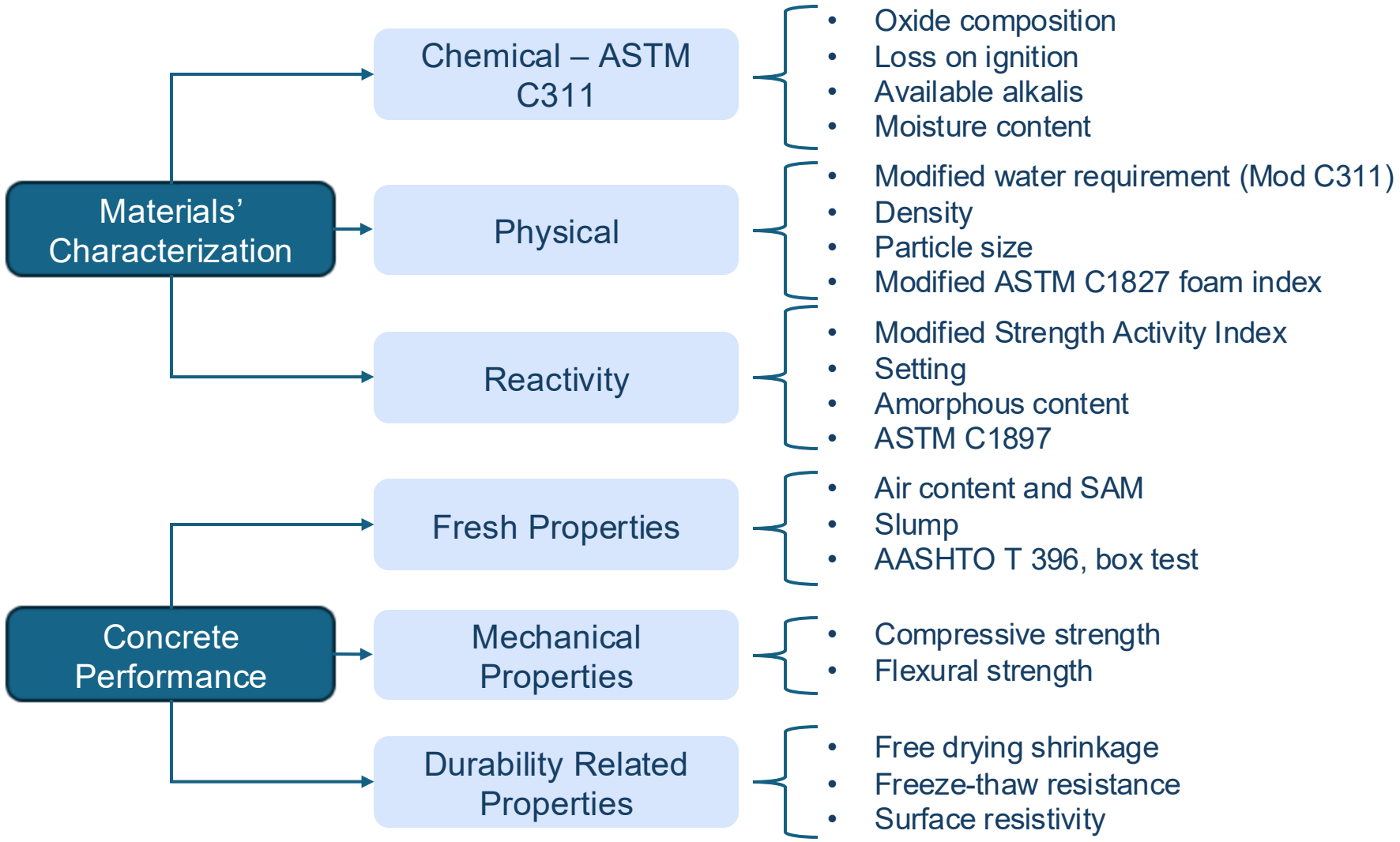
[1] Approved by other states, such as CO, IA, KS, MN, MT, NV, ND, OR, SD, TX, UT, and WY.

[2] Already part of the APL.

New Technologies

Material	Material type	Cement Replacement/Dose
Reclaimed Ash from Ottumwa, IA	Landfilled, Class C	30%
Terra CO_2, OPUS SCM™	Marketed to meet C618 Class F	30%
Eco Material Technologies, PozzoSlag™	Marketed to meet C618 Class F and C989	30%

TESTING PLAN



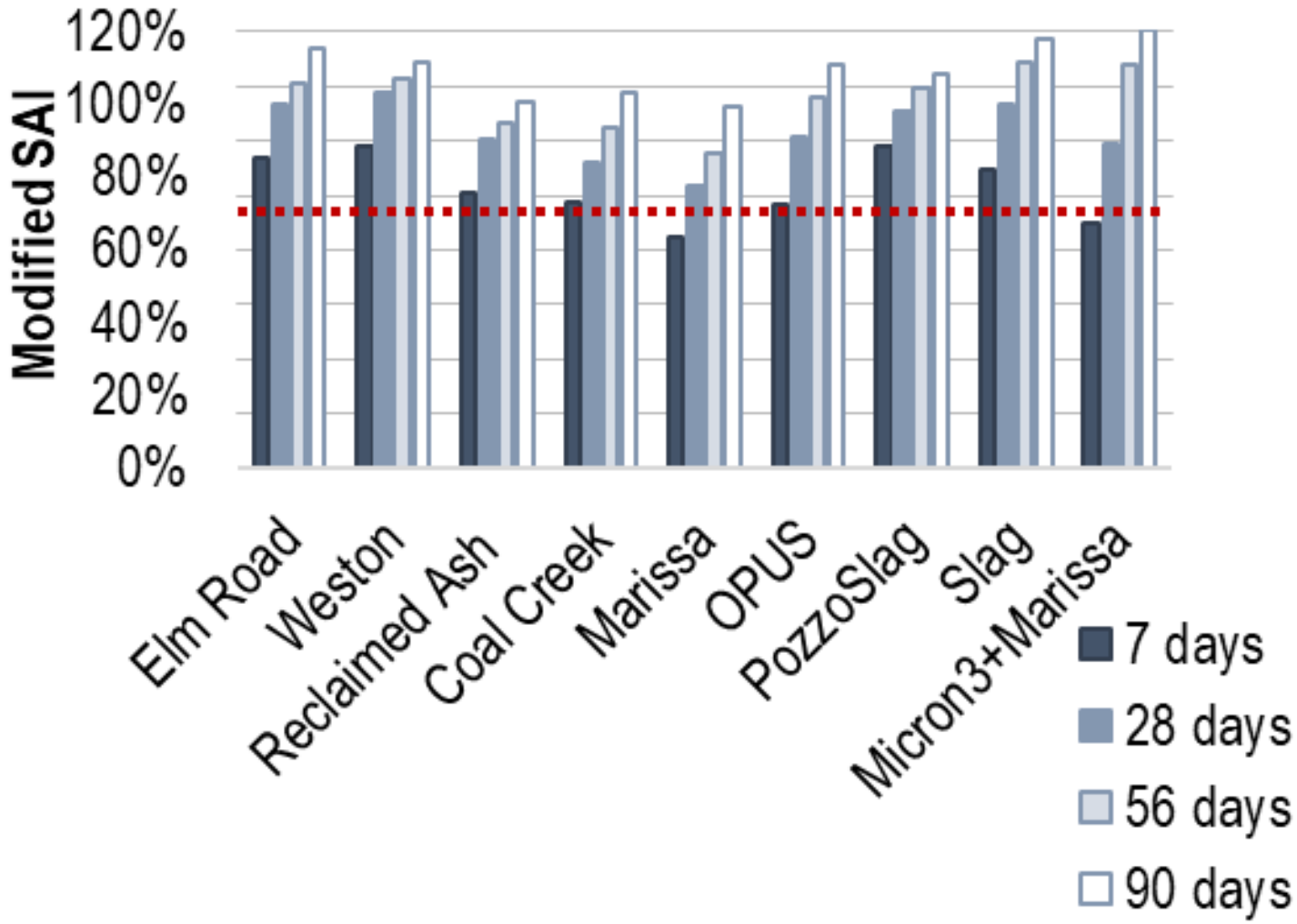
Test Results - Materials Characterization

Chemical Composition, % mass	Marketed as Class F Fly Ash				
	Coal Creek	Marissa	OPUS	Micron[3]	ASTM C618 requirements
Silicon as (SiO_2)	50.96	56.21	61.88	49.93	-
Aluminum as (Al_2O_3)	15.69	18.69	14.78	15.73	-
Iron as (Fe_2O_3)	5.74	9.72	8.48	5.30	-
SUM (SiO_2+ Al_2O_3+ Fe_2O_3)	72.39	84.62	85.14	70.96	≥ 50.0
Sulfur as (SO_3)	0.78	0.91	0.12	1.14	≤ 5.0
Calcium as (CaO)	14.64	6.23	5.24	13.62	≤ 18.0
Magnesium as (MgO)	4.20	1.49	3.15	4.09	-
Sodium as (Na_2O)	4.03	1.29	2.66	4.18	-
Potassium as (K_2O)	2.18	2.67	3.21	2.72	-
Total Alkali as (Na_2O_e)	5.46	3.05	4.77	5.97	-
Moisture Content	0.09	0.04	0.09	-	≤ 3.0
Loss on Ignition (LOI)	0.27	0.70	0.07	0.41	≤ 6.0

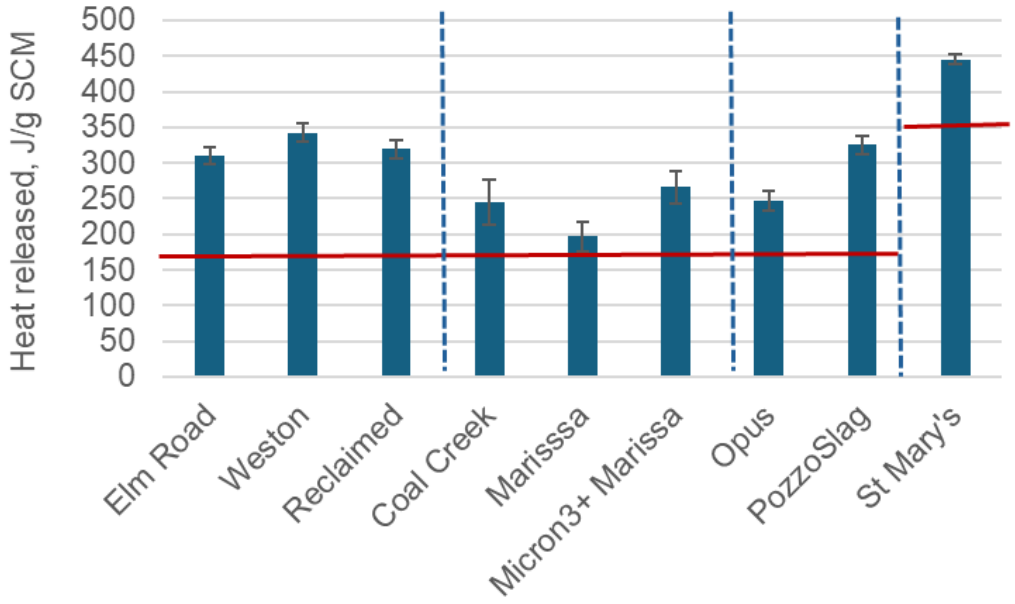
Test Results - Materials Characterization

Chemical Composition, % mass	Marketed as Class C Fly Ashes					Slag	
	Elm Road	Weston	Reclaimed Ash	PozzoSlag	ASTM C618 Requirements	St Mary's Slag	ASTM C989 Requirements
Silicon as (SiO_2)	39.46	38.14	33.83	44.31	-	33.25	-
Aluminum as (Al_2O_3)	19.69	19.43	19.27	19.58	-	13.53	-
Iron as (Fe_2O_3)	9.54	6.23	5.52	7.04	-	0.82	-
SUM (SiO_2+ Al_2O_3+ Fe_2O_3)	68.69	63.80	58.62	70.93	≥ 50.0	-	-
Sulfur as (SO_3)	2.16	1.33	1.56	2.24	≤ 5.0	1.80	-
Calcium as (CaO)	18.21	23.65	22.40	20.42	> 18.0	42.90	-
Sulfide Sulfur (S)	-	-	-		-	0.47	≤ 2.5
Magnesium as (MgO)	4.20	5.74	4.10	4.35	-	6.12	-
Sodium as (Na_2O)	1.37	1.94	2.62	1.11	-	0.22	-
Potassium as (K_2O)	0.89	0.57	0.48	0.70	-	0.41	-
Total Alkali as (Na_2O_e)	1.96	2.32	2.94	1.57	-	-	-
Moisture Content	0.06	0.11	2.53	0.38	≤ 3.0	-	-
Loss on Ignition (LOI)	0.65	0.37	5.38	0.53	≤ 6.0	0.62	-

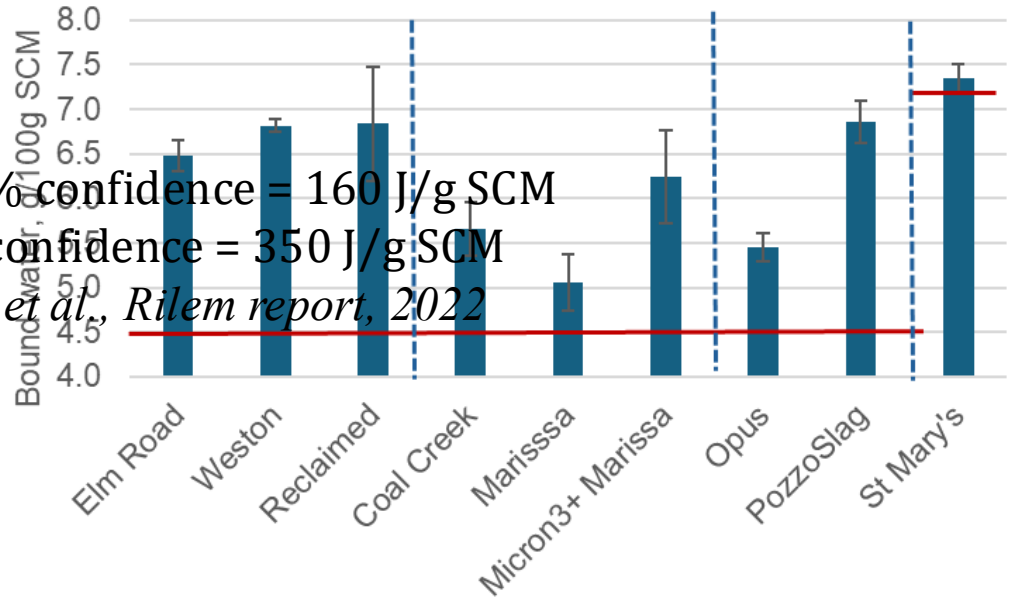
Test Results - Materials Characterization

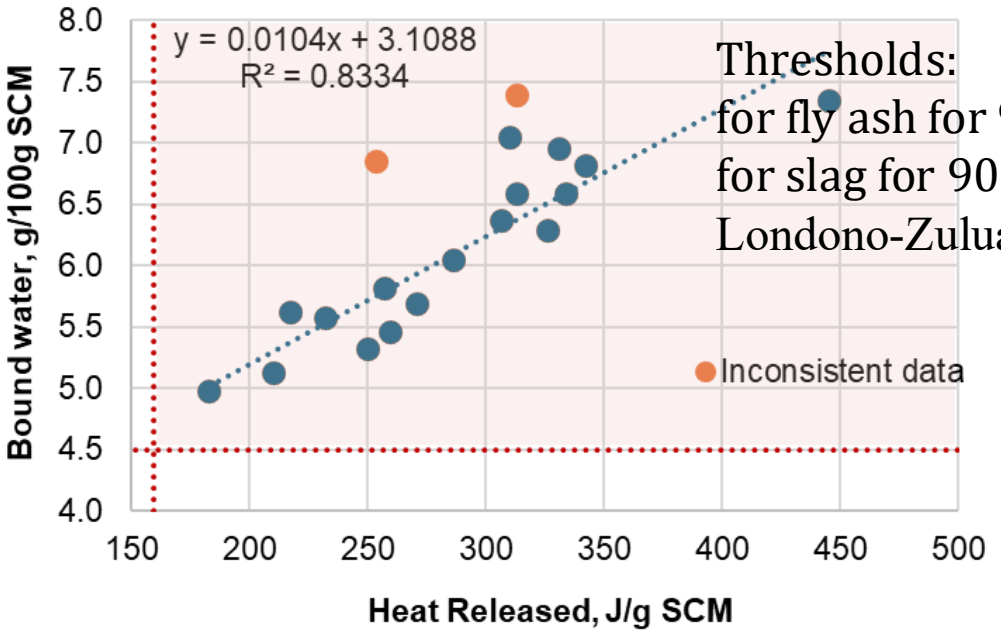


Test Results - Materials Characterization



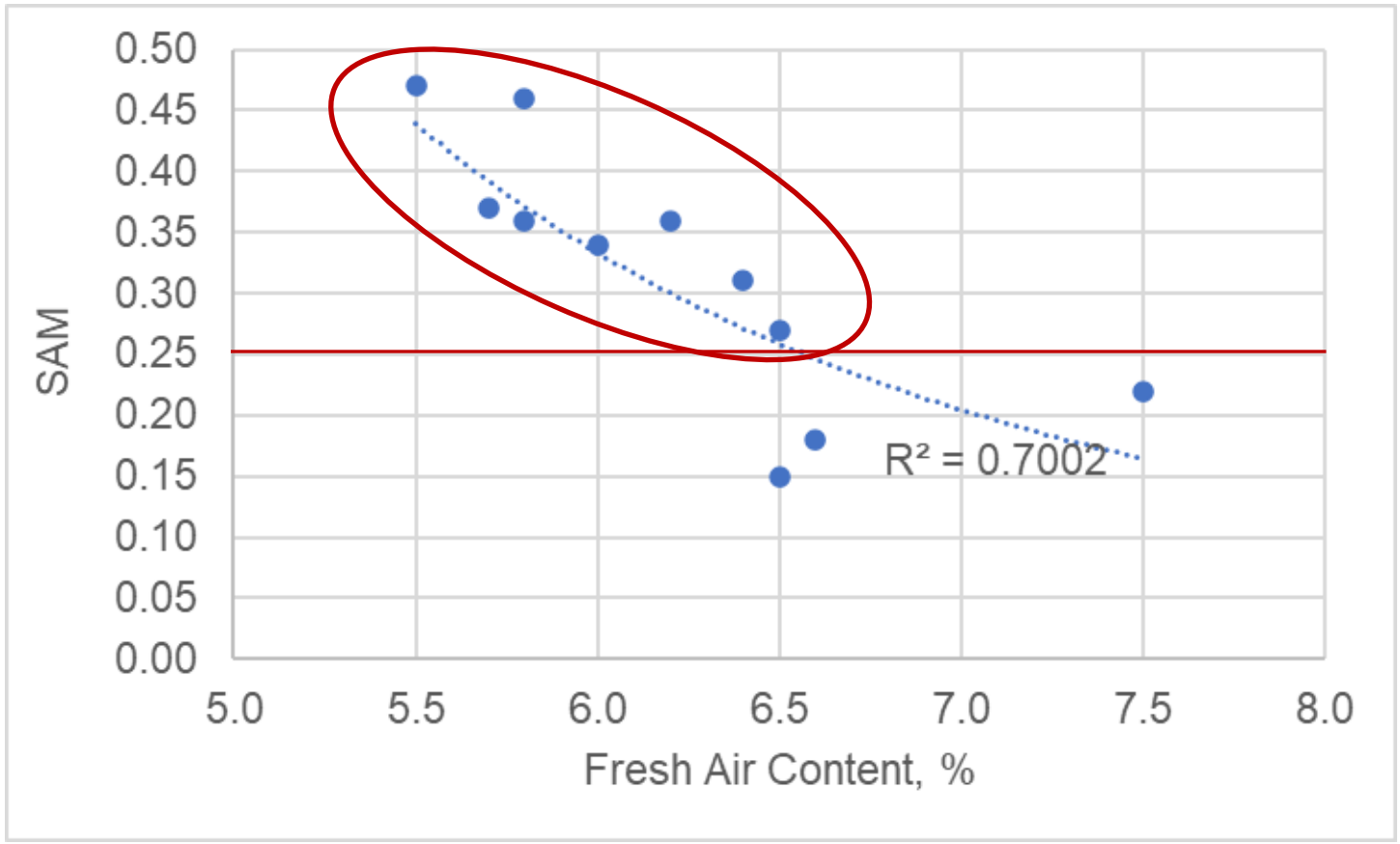
Thresholds:
for fly ash for 90% confidence = 160 J/g SCM
for slag for 90% confidence = 350 J/g SCM
Londono-Zuluaga *et al., Rilem report, 2022*





Thresholds:
for fly ash for 90% confidence = 4.5 g/100g SCM
for slag for 90% confidence = 7.2 g/100g SCM
Londono-Zuluaga *et al., Rilem report, 2022*

Test Results – Concrete Performance



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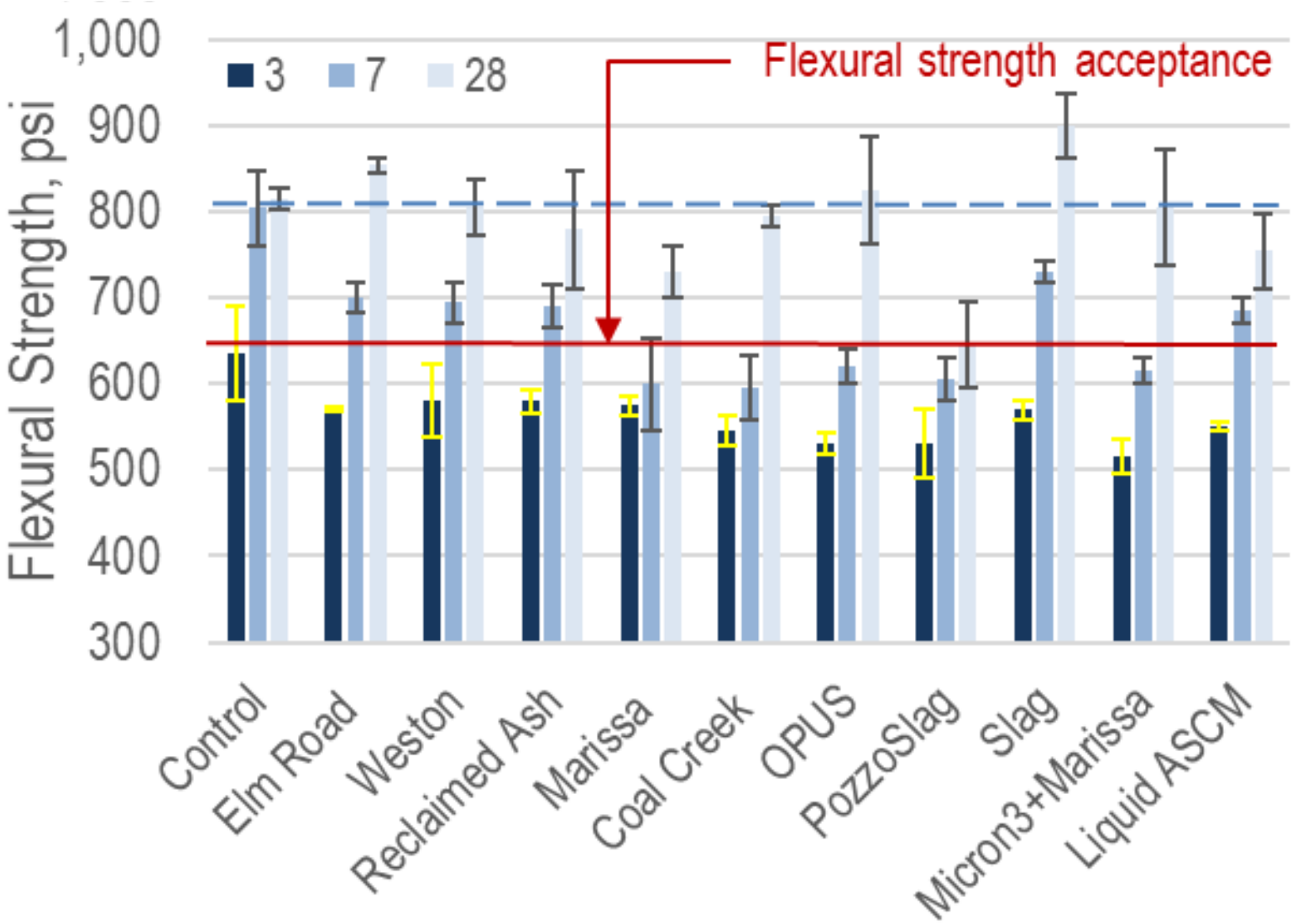

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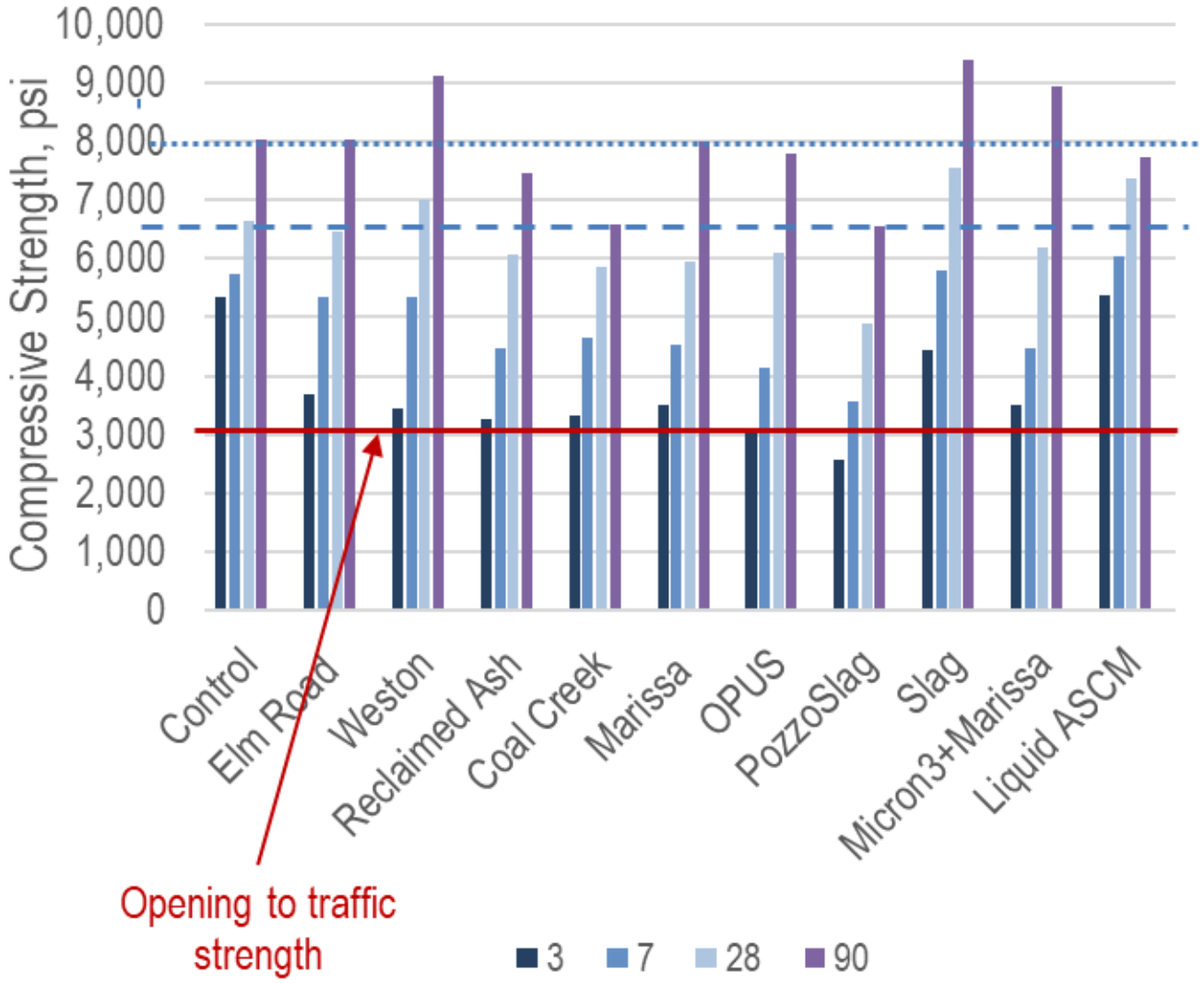
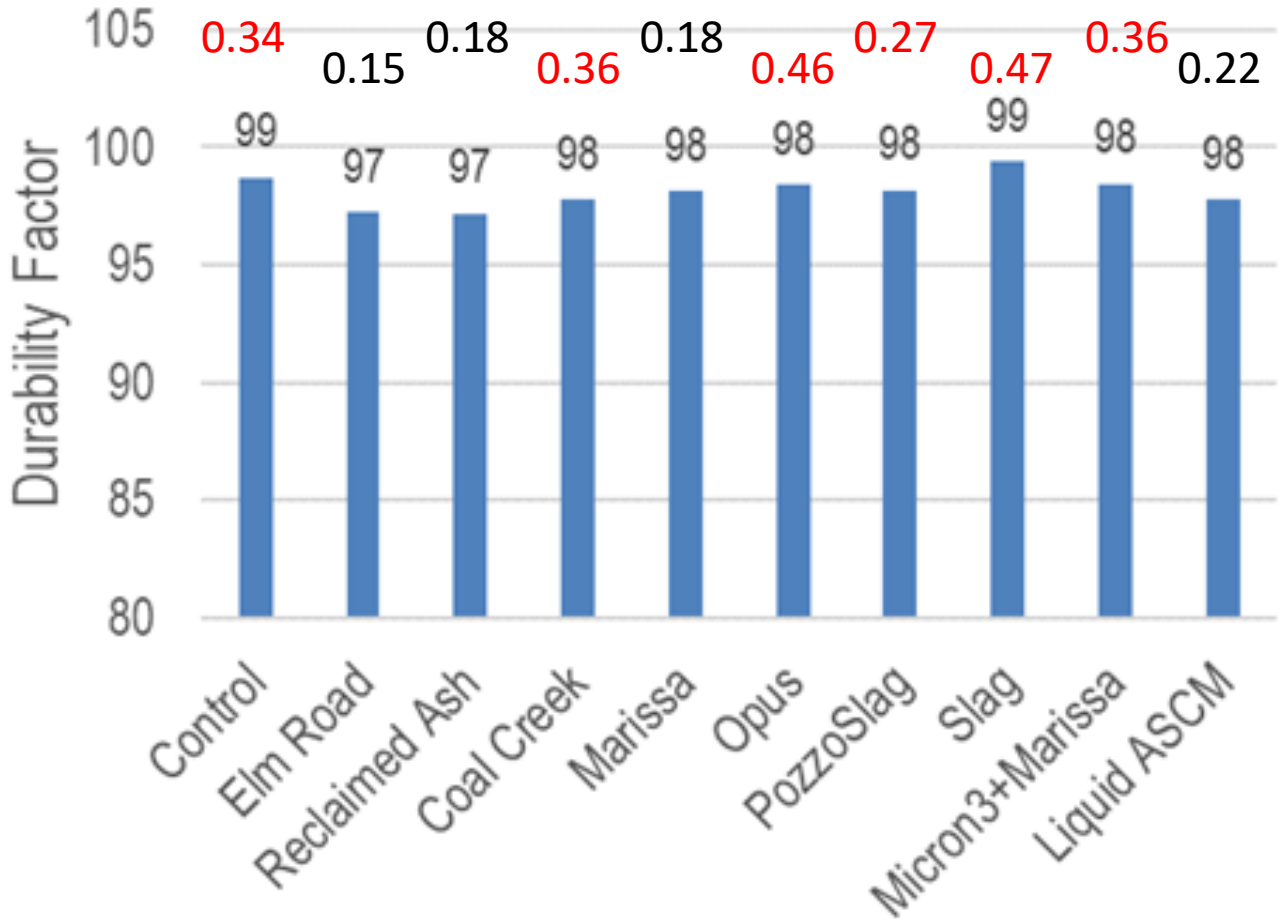


Test Results – Concrete Performance



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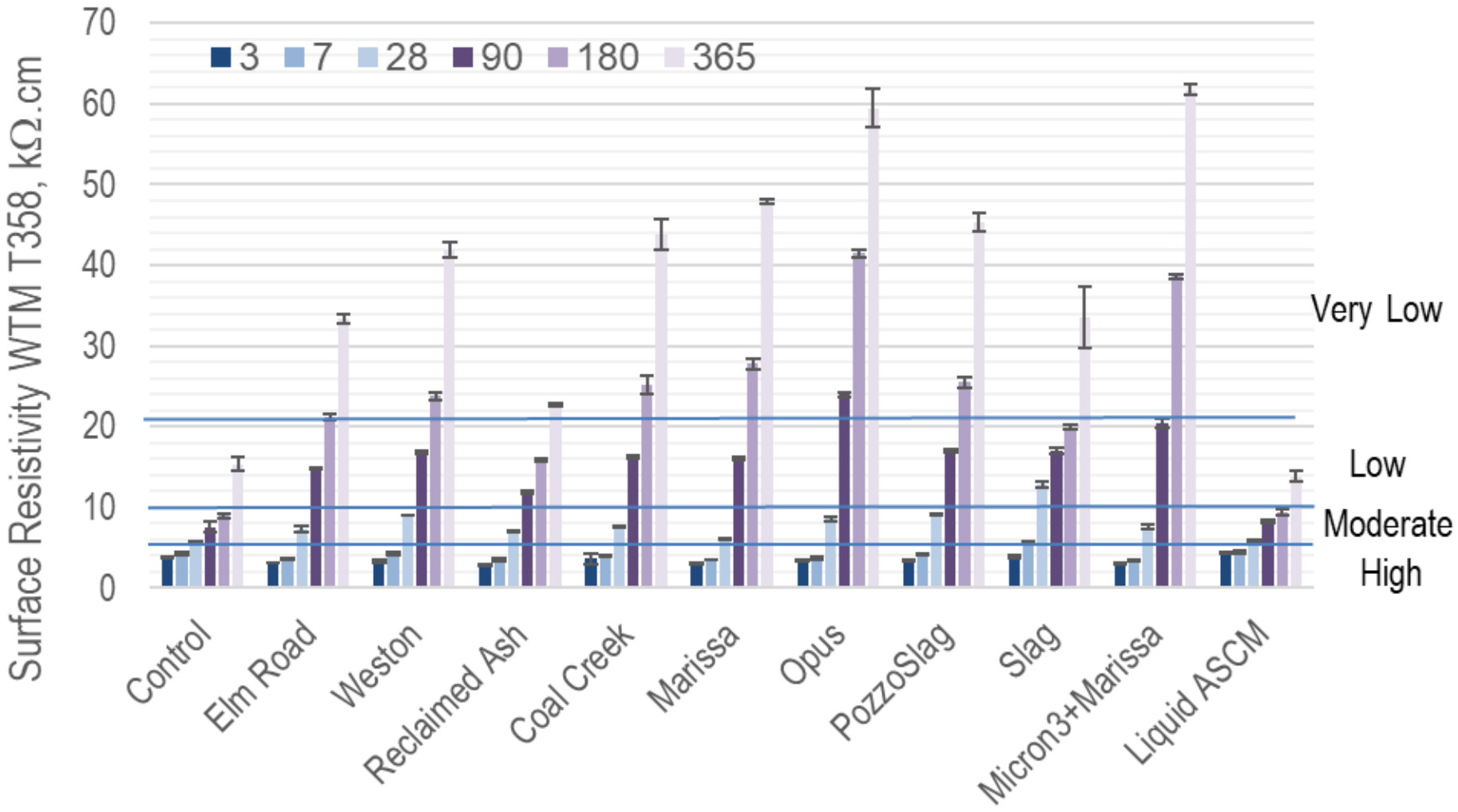

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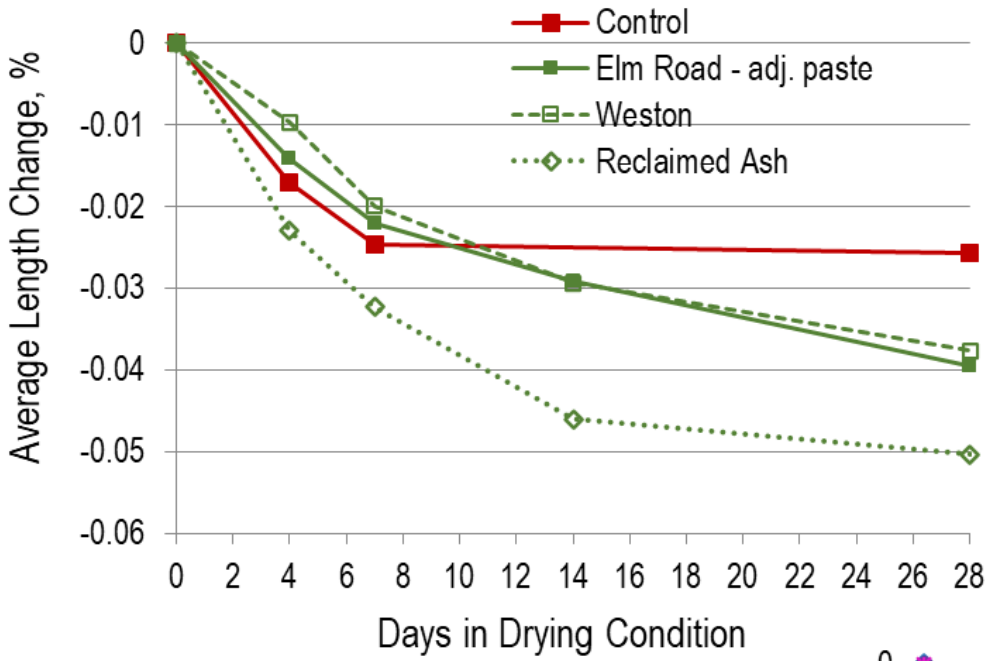
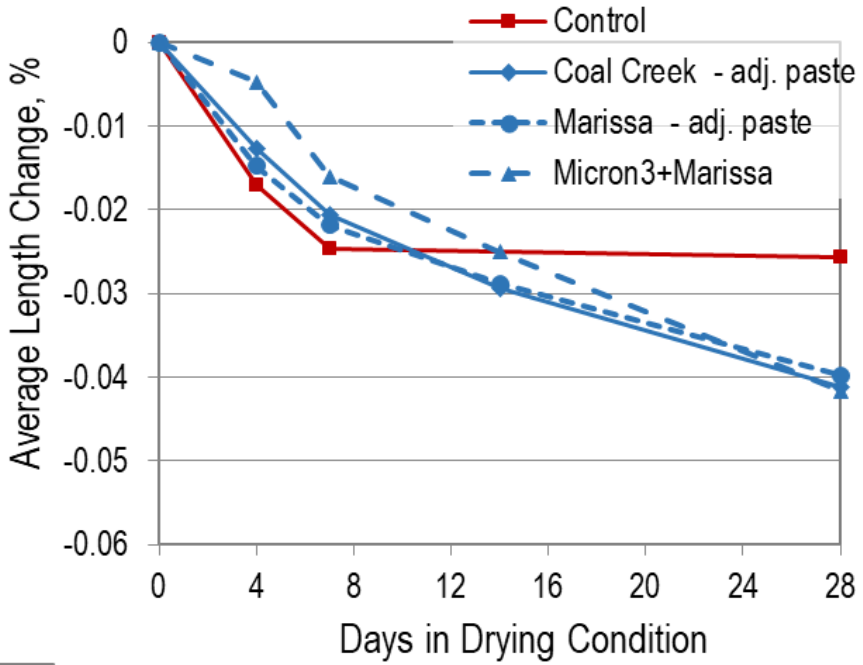
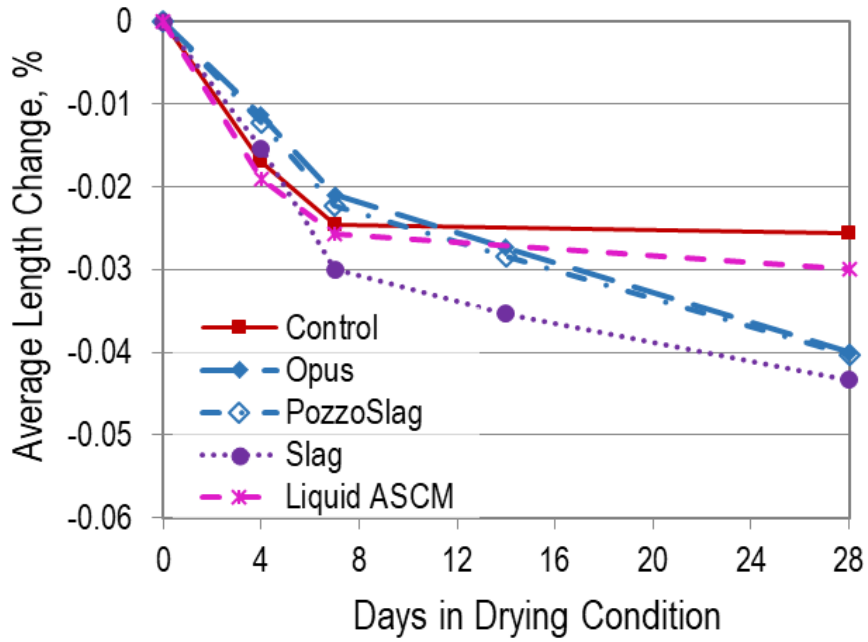
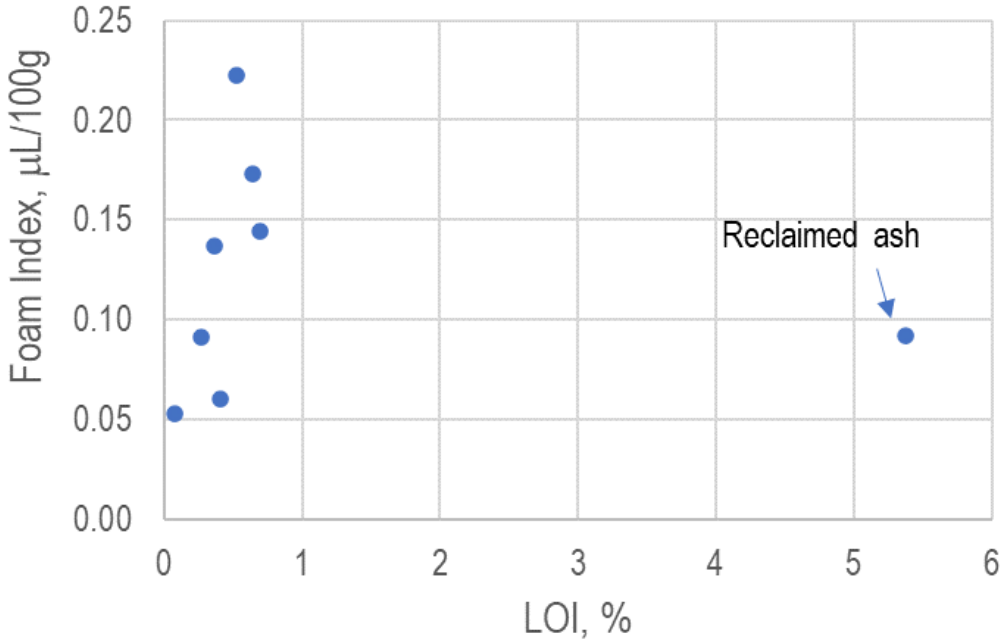
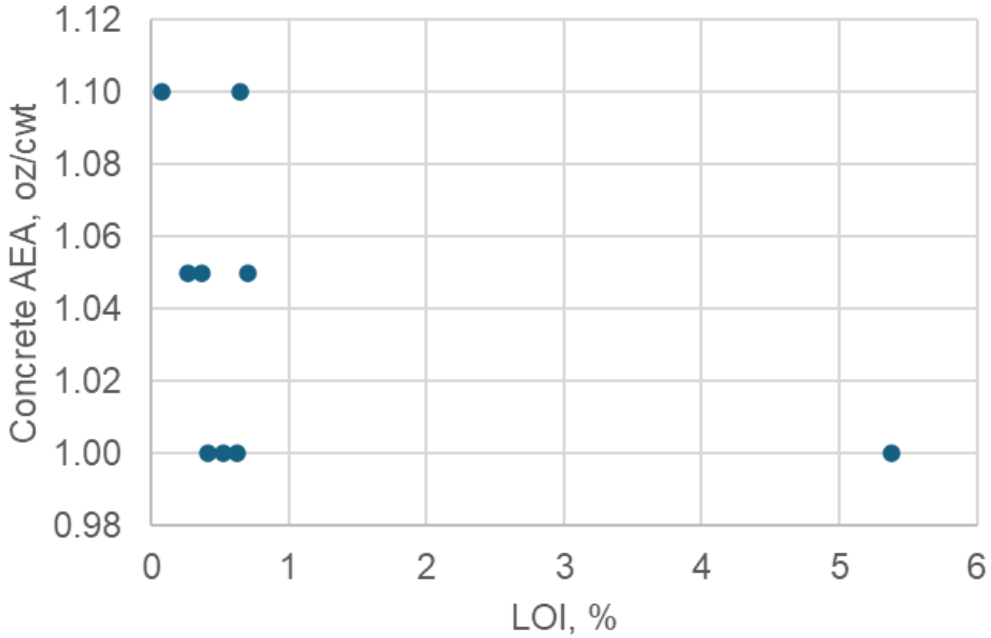




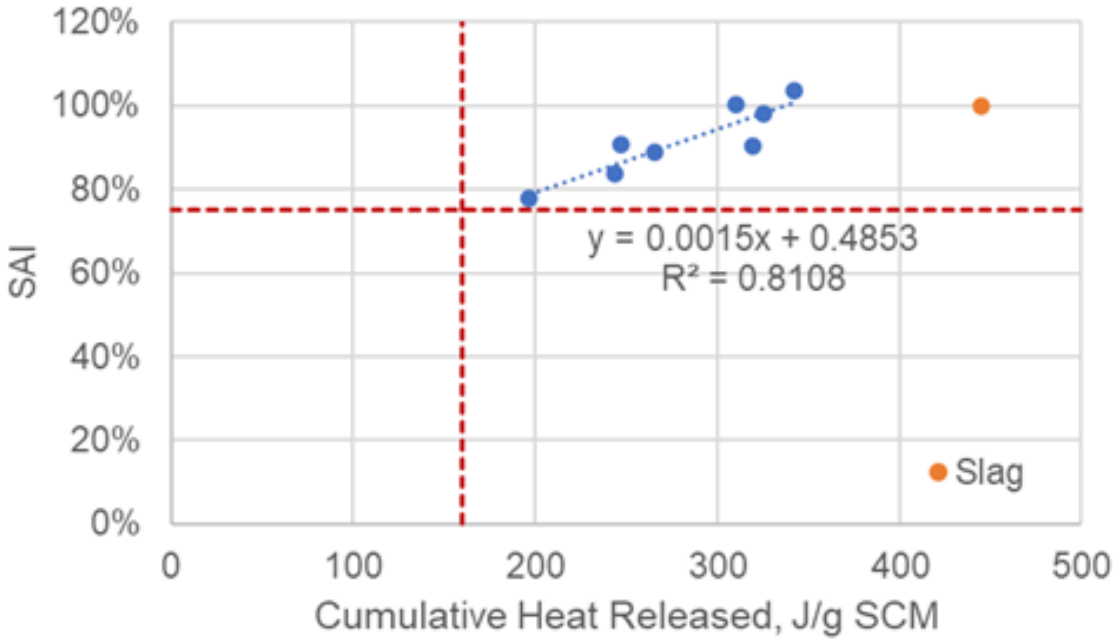


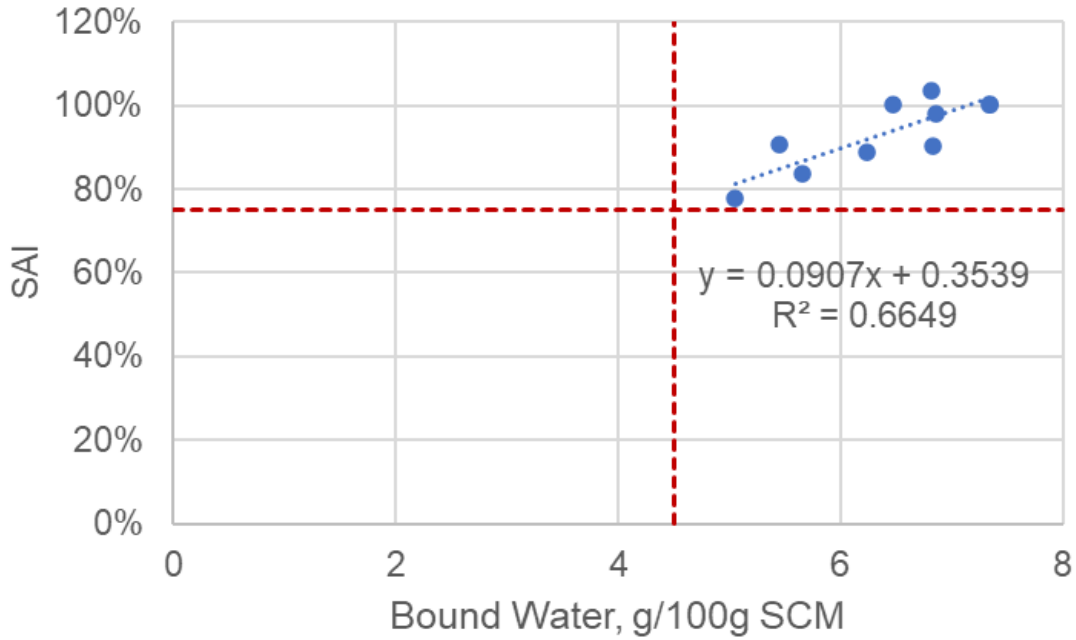
Test Results – LOI and Foam Index



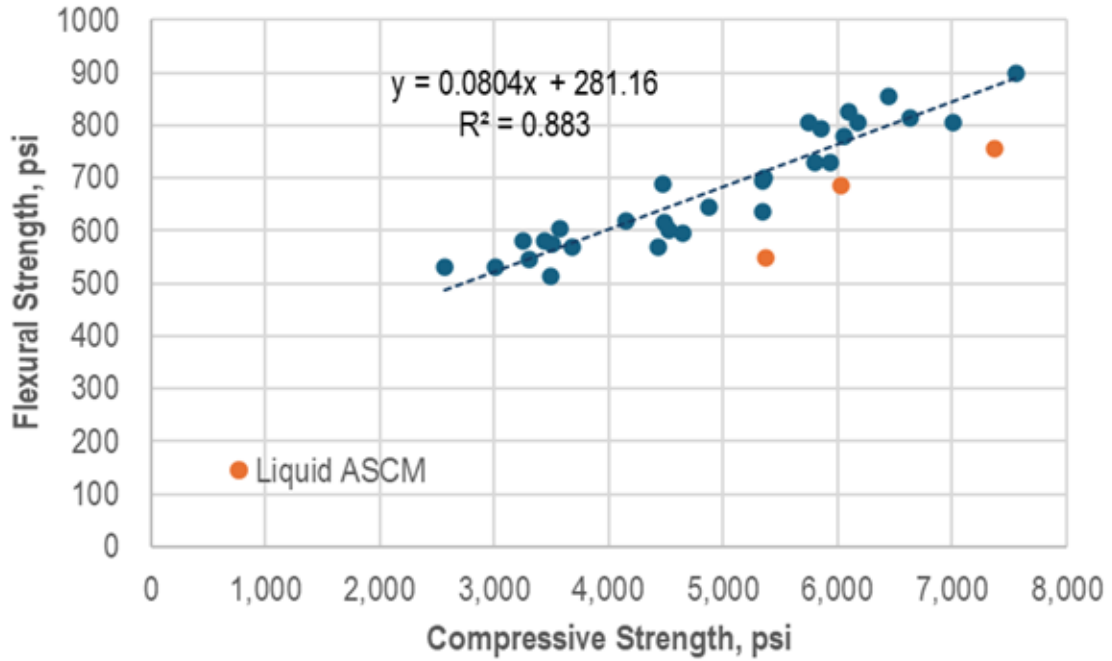


Test Results – Mod SAI vs Reactivity





Test Results – Concrete Compressive Strength vs Flexural Strength



RECOMMENDATIONS

1. LOI – Remove the requirement of maximum LOI of 2%
2. SAM – CMM refers to an acceptable SAM ≤ 0.25
    - It appears to be over conservative
    - Obtain more information to establish a reasonable SAM number
3. Class F Fly Ash:
    - Data did not substantiate the need of an APL for Class F
    - Allow for Class F that comply with C618 (except for SAI)
    - Use modified SAI

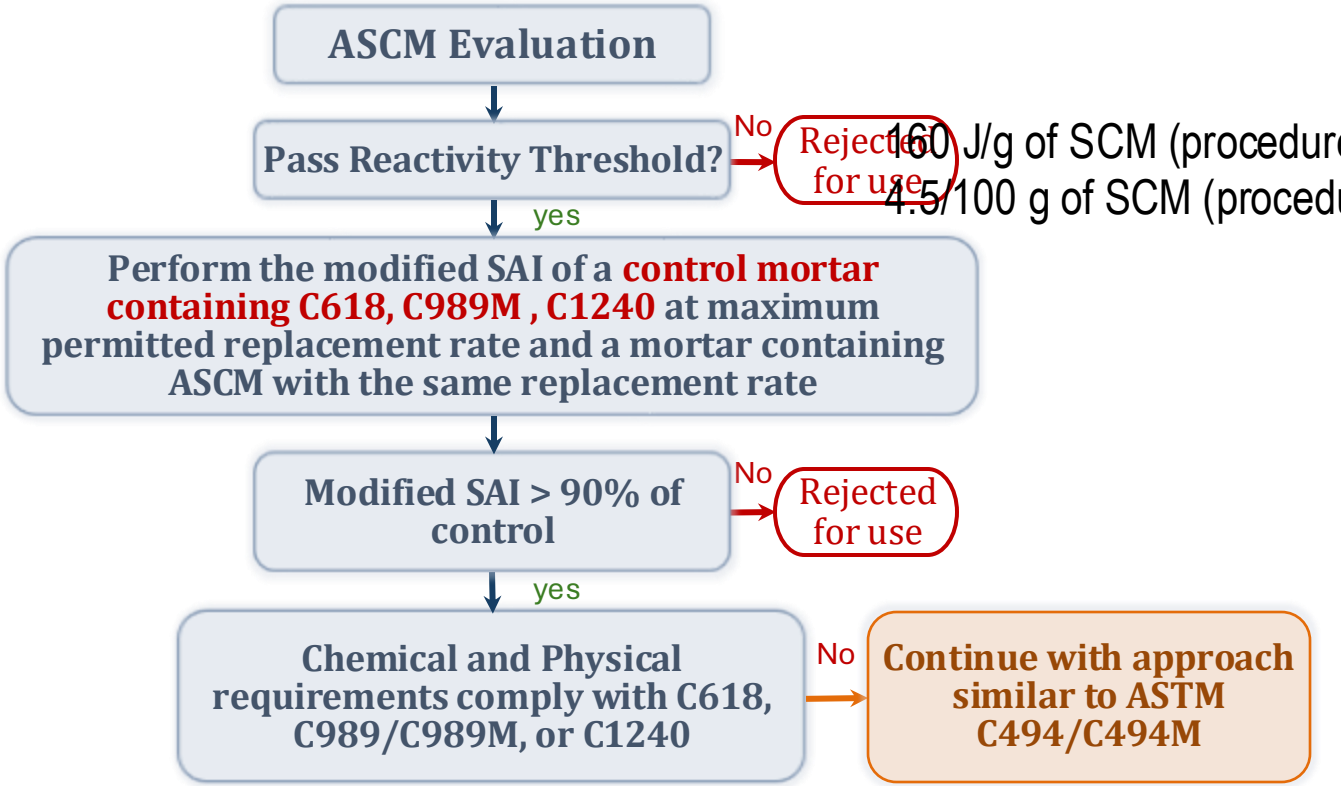
RECOMMENDATIONS

4. **Blended SCMs:**
    - **Remove the need for the individual components to comply with applicable specification (C1697)**
    - **Final product needs to comply with applicable specification (except for SAI)**
    - **Use modified SAI**
    - **Final product needs to comply with table 3 of C1697**

RECOMMENDATIONS

5. Alternative SCMs:

Use this framework



RECOMMENDATIONS

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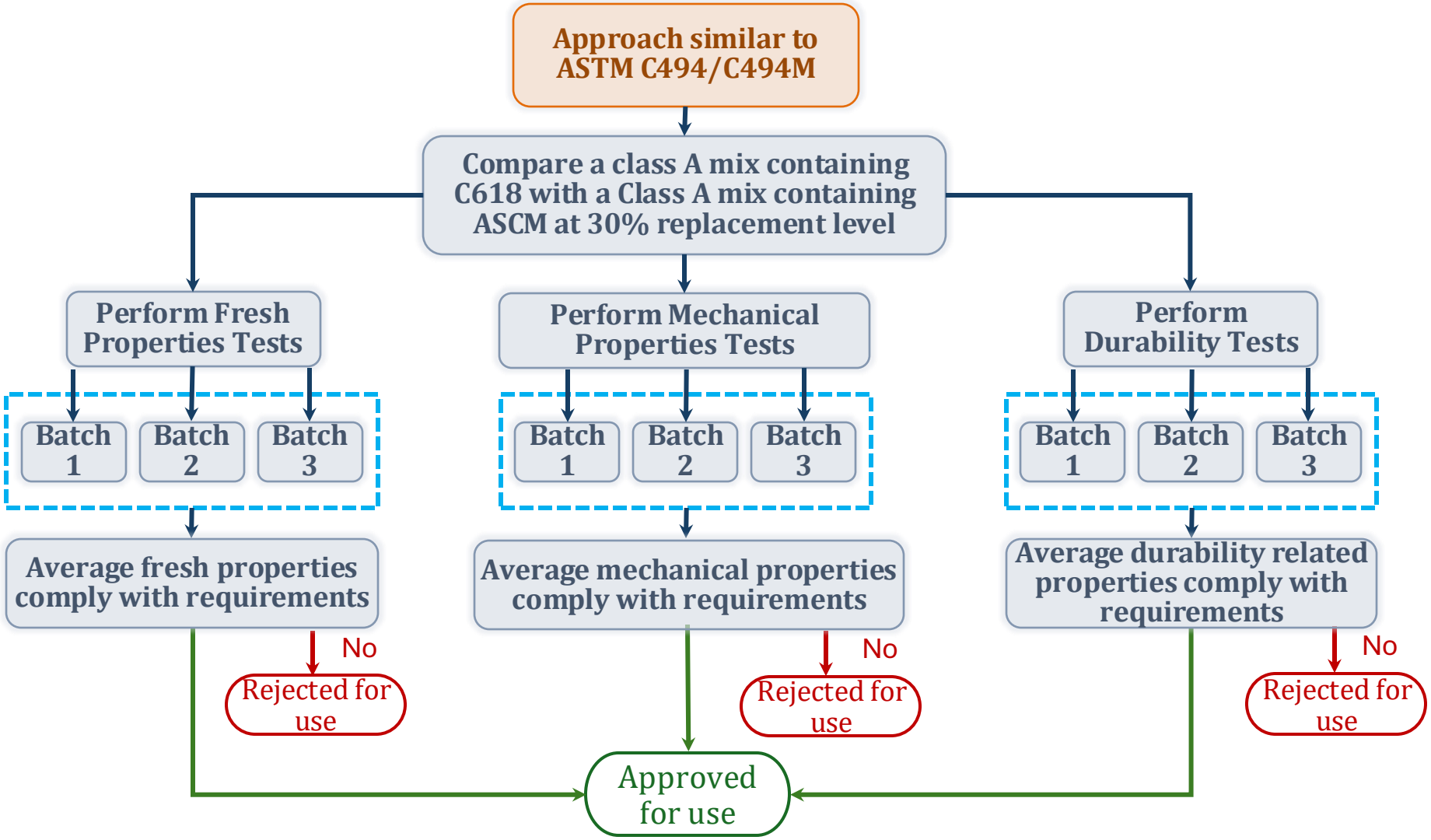
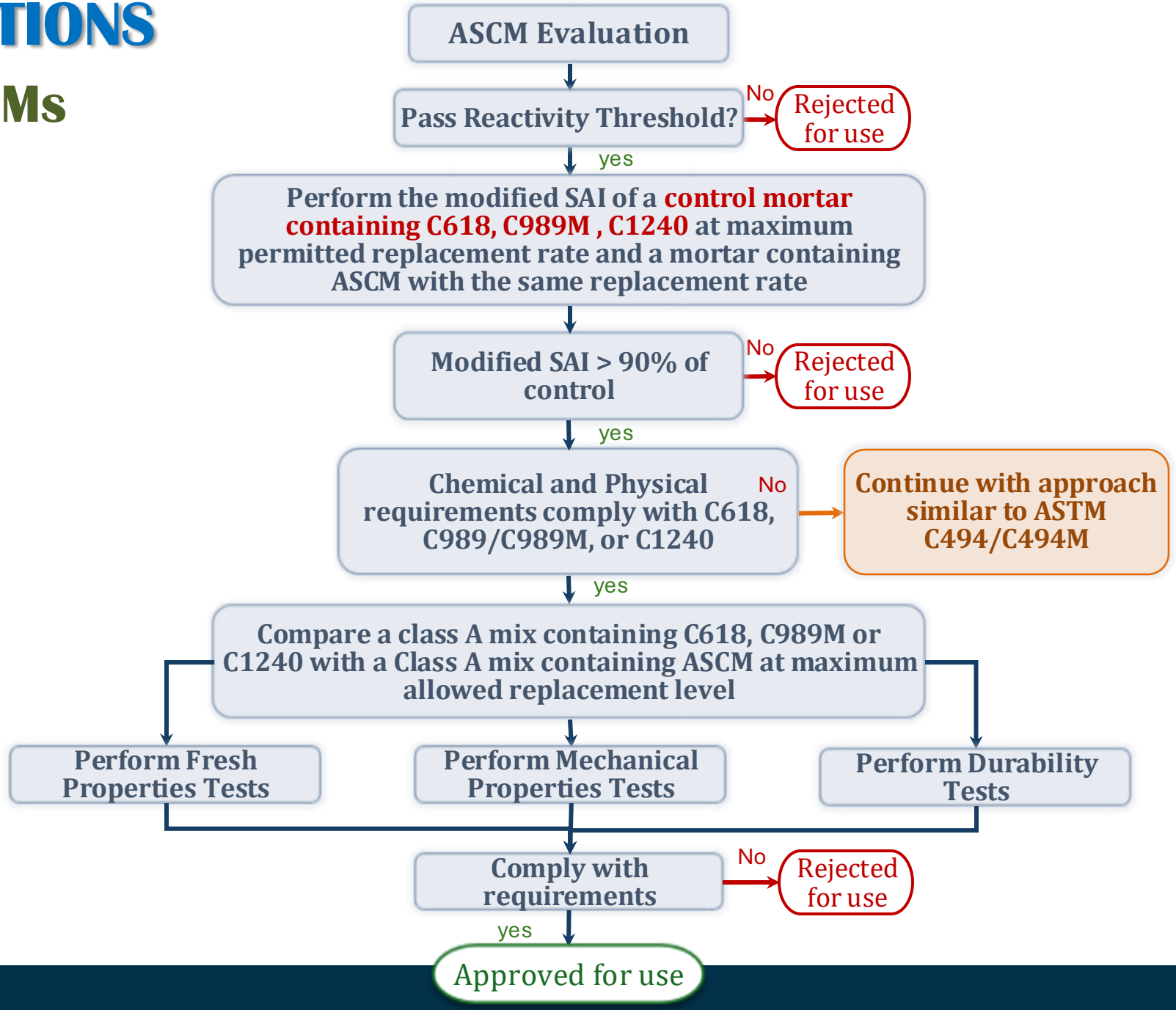


RECOMMENDATIONS

5. Alternative SCMs



RECOMMENDATIONS

5. Alternative SCMs

Property	Requirements
Slump (AASHTO T 119M/T 119)	1 to 2.5 in.
Air Content (AASHTO T 395)	7.0 ± 1.5 %, using manufacturer recommended dosage of AEA
Box Test (AASHTO T 396)	Average rate ≤ 2.5
Setting time (ASTM C403/C403M)	Not earlier than 1 h of control, not later than 1 h of control
SAM (AASHTO T 395)	Report only
Compressive strength at 7, 28, and 90 days (AASHTO T 22M/T 22)	90% of control
Flexural strength at 7, 28, and 90 days (AASHTO T 97M/T 97)	90% of control
Relative durability factor (AASHTO T 161, procedure A)	Min 80%
Length change (ASTM C157/C157M)	More research is needed
Surface resistivity at 90 days (WTM T 358)	Low penetrability at 90 days

RECOMMENDATIONS

6. **Acceptance Age – increase the qualification acceptance age to 90 days**
7. **Shrinkage – More research needed to establish a threshold**
8. **Resistivity – Add qualification requirement of low penetrability at 90 days**
9. **Expand research to include more ASCM and validate the proposed framework.**

https://wisconsindot.gov/documents2/research/0092-23-03-final-report.pdf

Thank you

Any Questions?