

Early Age Properties of Internally Cured Concrete for Pavement and Bridge Decks

Jose Pacheco, PhD, PE, PEng

March 26, 2024



Outline

- Internal Curing (IC) Basics
- IC Bridge Survey
- IC Materials Characterization
- IC Mortar & Concrete
- Acknowledgements

Internal Curing of Bridge Decks and Concrete Pavement to Reduce Cracking

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Construction Technology Laboratories, Inc.
CTLGroup

WisDOT ID no. 0092-19-02
October, 2021

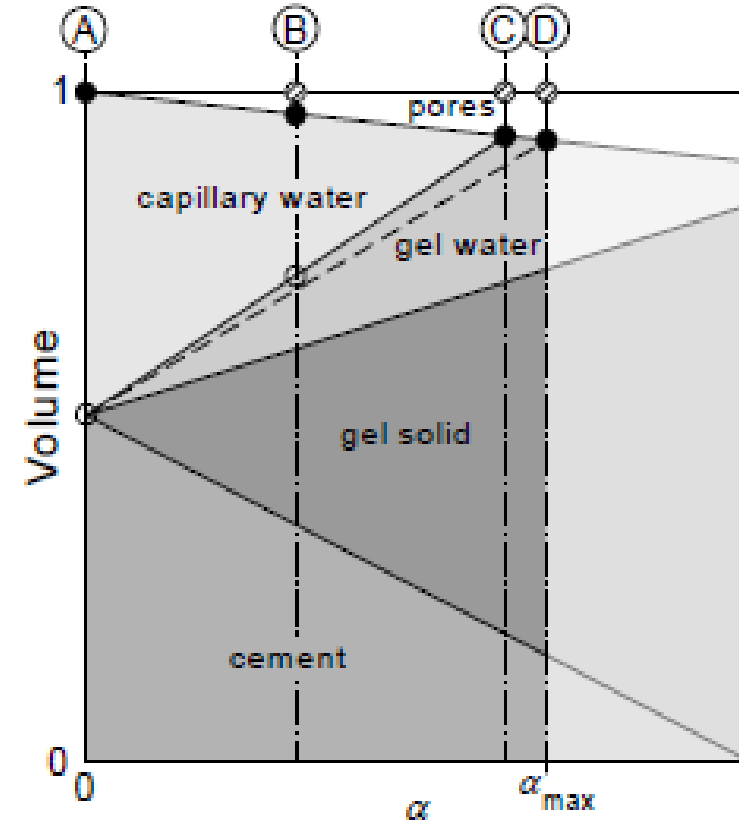
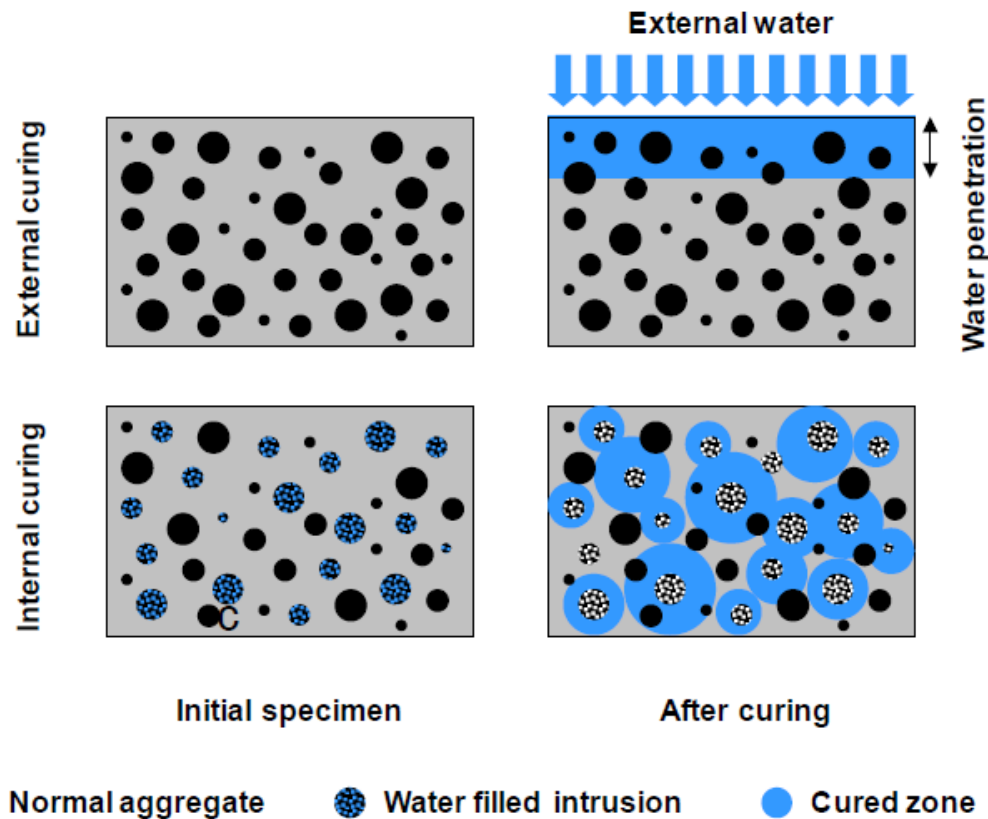


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WISCONSIN HIGHWAY RESEARCH PROGRAM

Internal Curing (IC)



D. P. Bentz and W. J. Weiss, "Internal Curing: A 2010 state of the art review," Natl. NISTIR 7765, p. 82, 2011, doi: 10.1016/j.jvcir.2009.09.004.

Internal Curing (IC)

Self-desiccation

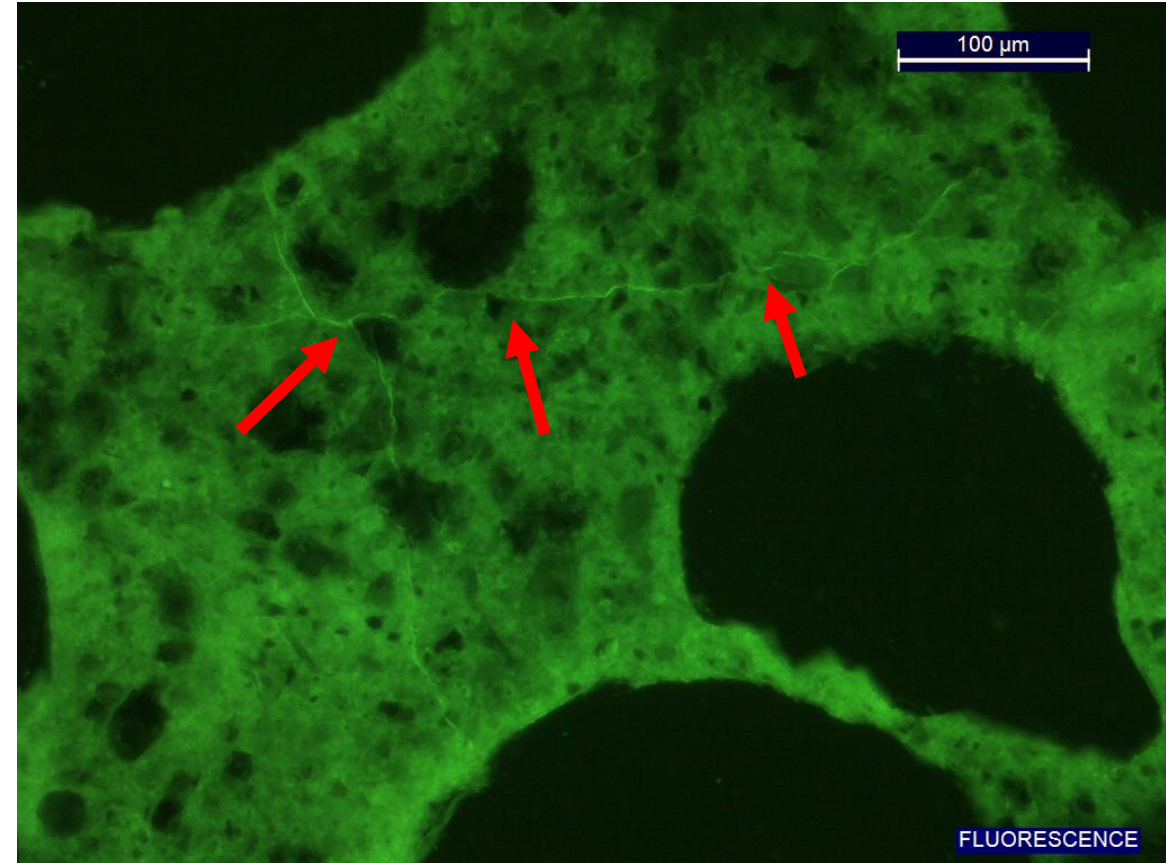
The consumption of free water by the chemical reaction so as to leave insufficient water to cover the solid surfaces and cause a decrease in the relative humidity of the system.

Autogenous shrinkage

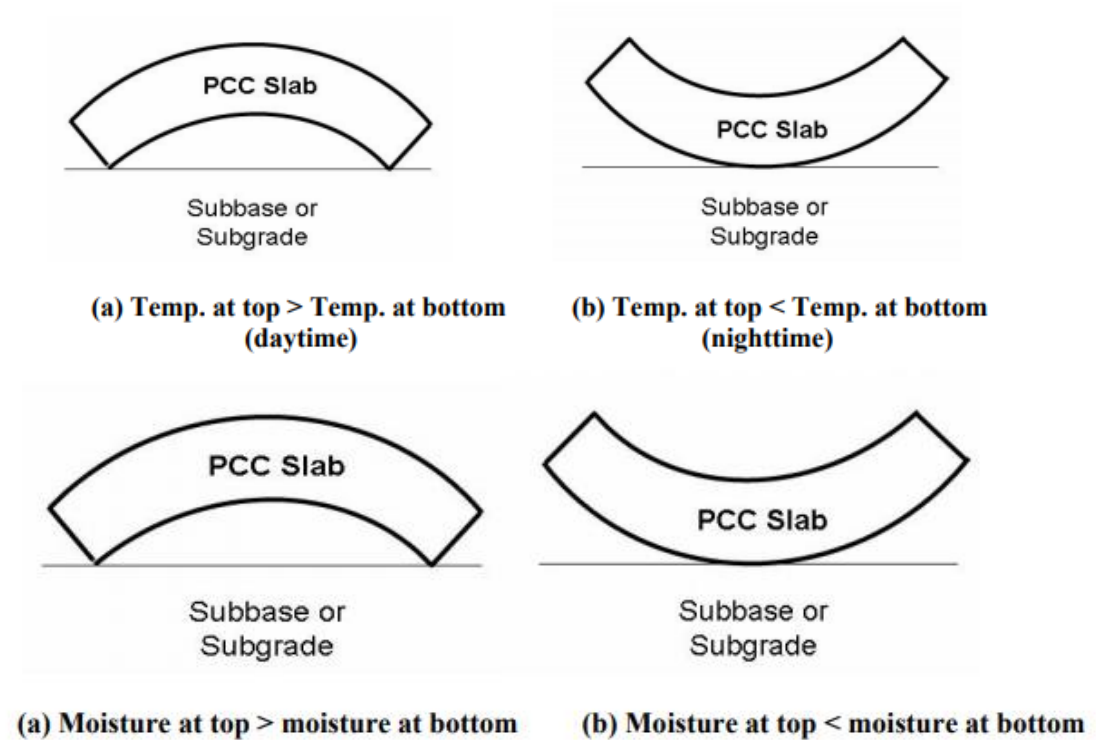
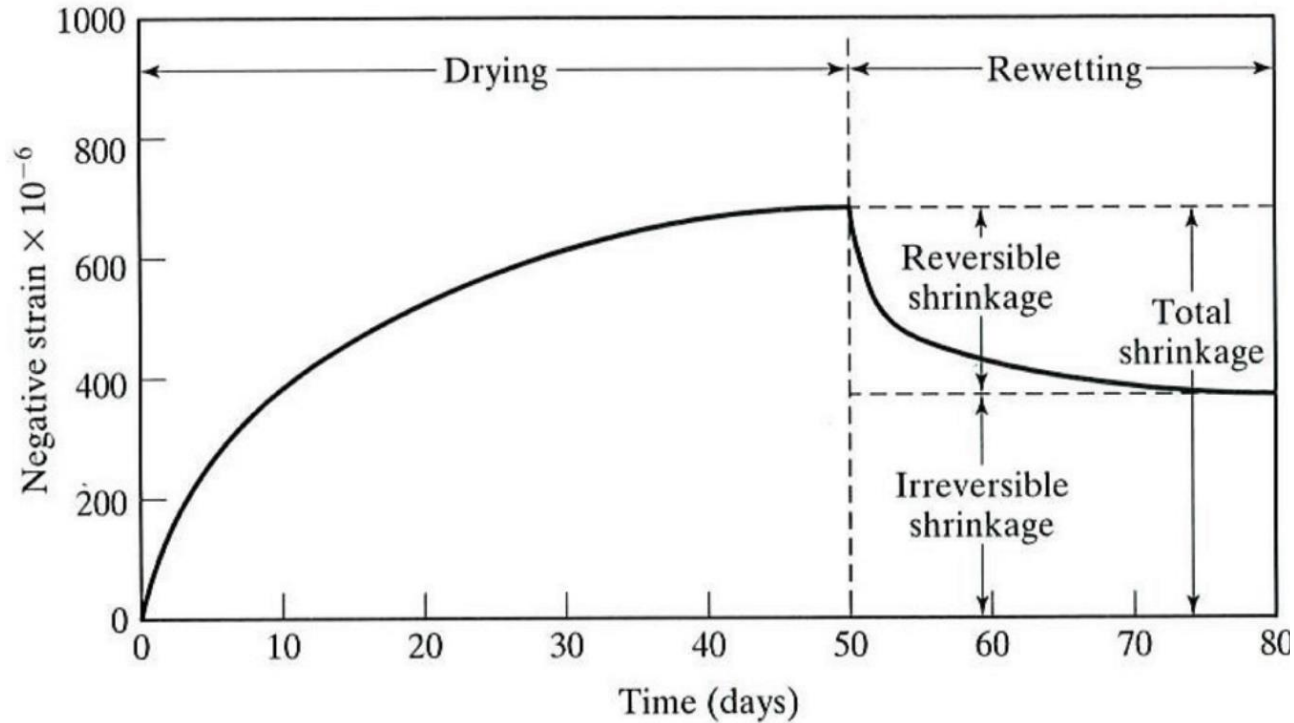
The change in volume due to the chemical process of hydration of cement, exclusive of effects of applied load and change in either thermal condition or moisture content

Chemical shrinkage

The internal-microscopic volume reduction, which is the result of the fact that the absolute volume of the hydration products is smaller than that of the reacting constituents

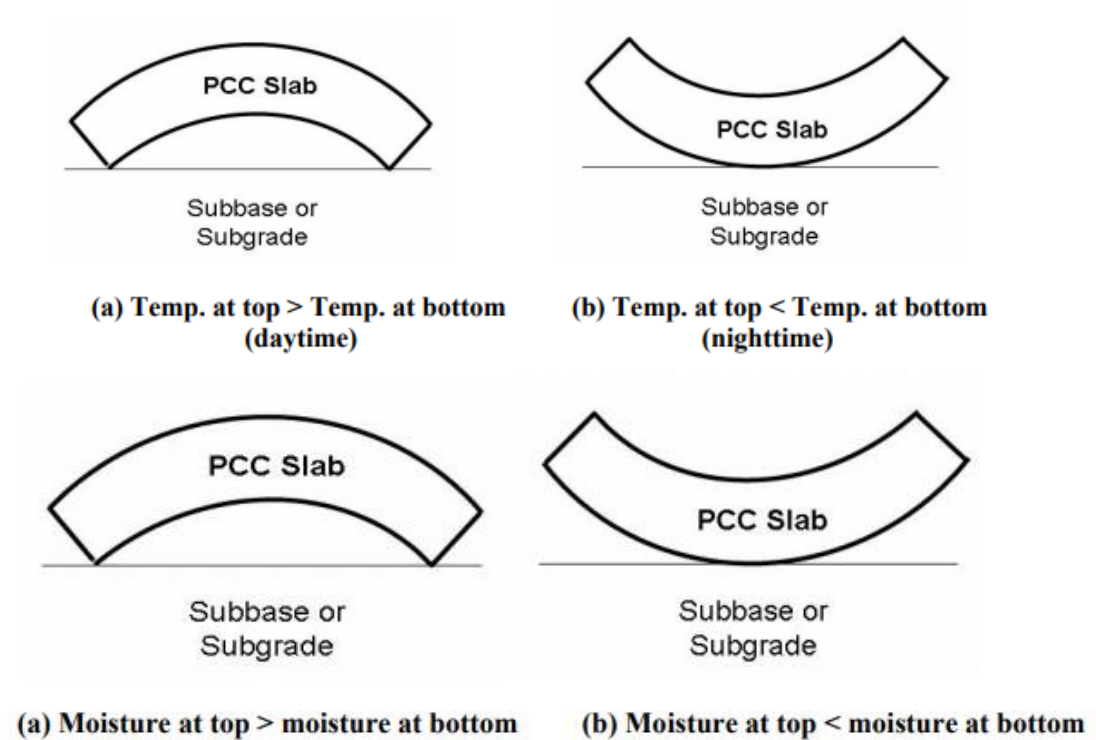
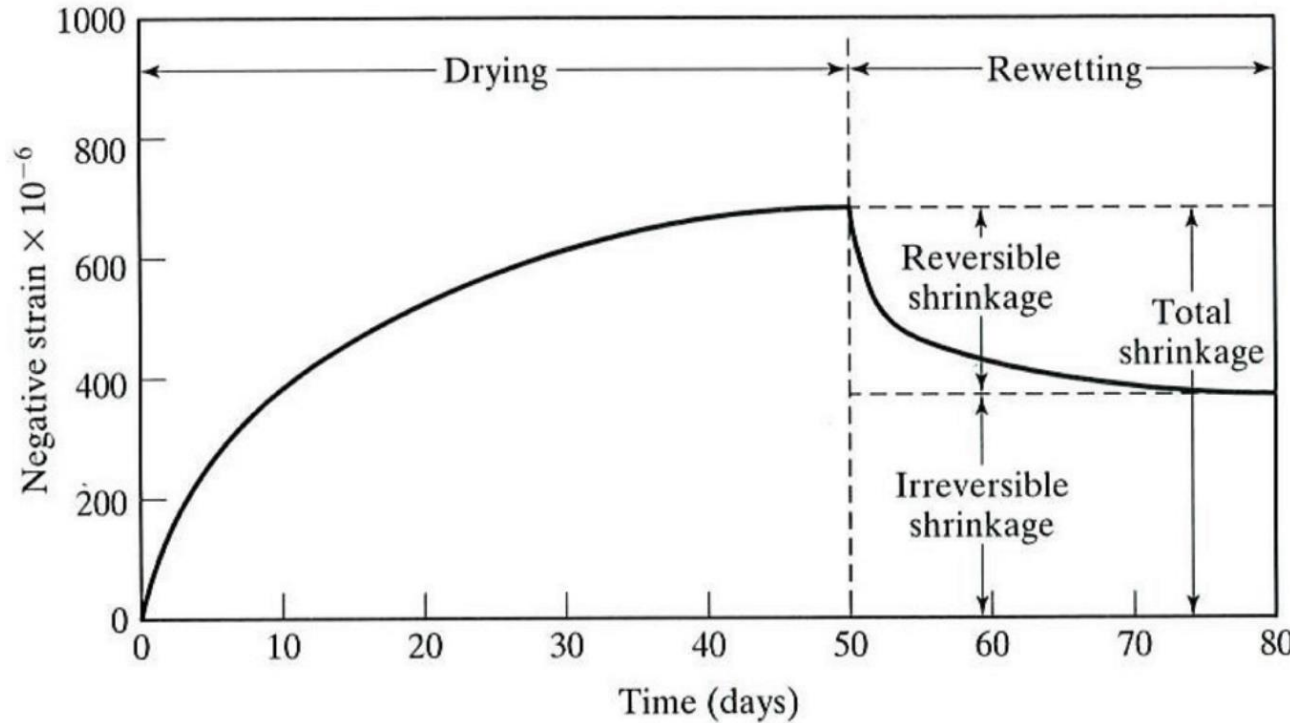


Internal Curing (IC)



O. M. Jensen, "Chapter 3 - Mechanisms of Internal Water Curing," *Intern. Curing Concr. RILEM TC 196-ICC State-of-the-Art Rep.*, no. June, pp. 15–27, 2007

Internal Curing (IC)



O. M. Jensen, "Chapter 3 - Mechanisms of Internal Water Curing," *Intern. Curing Concr. RILEM TC 196-ICC State-of-the-Art Rep.*, no. June, pp. 15–27, 2007

IC Bridge Survey

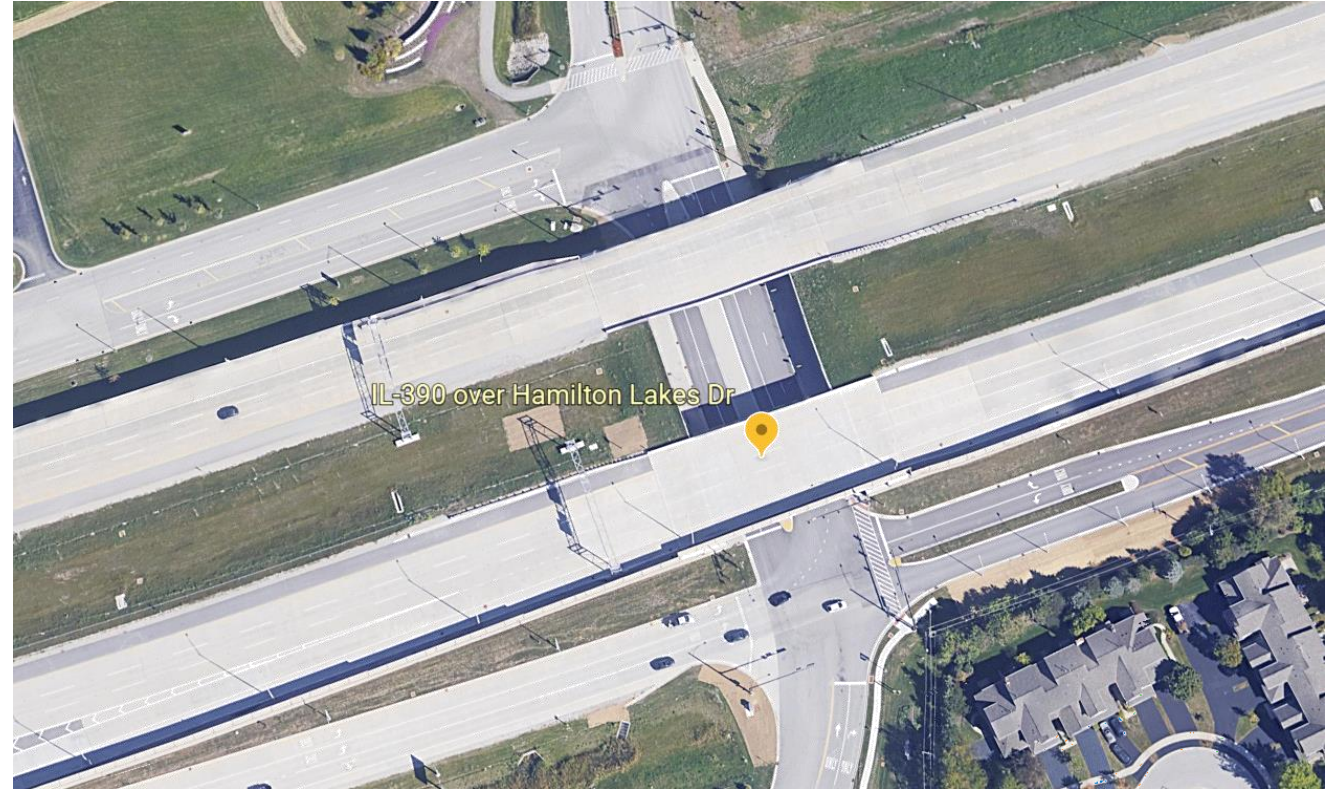


THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE



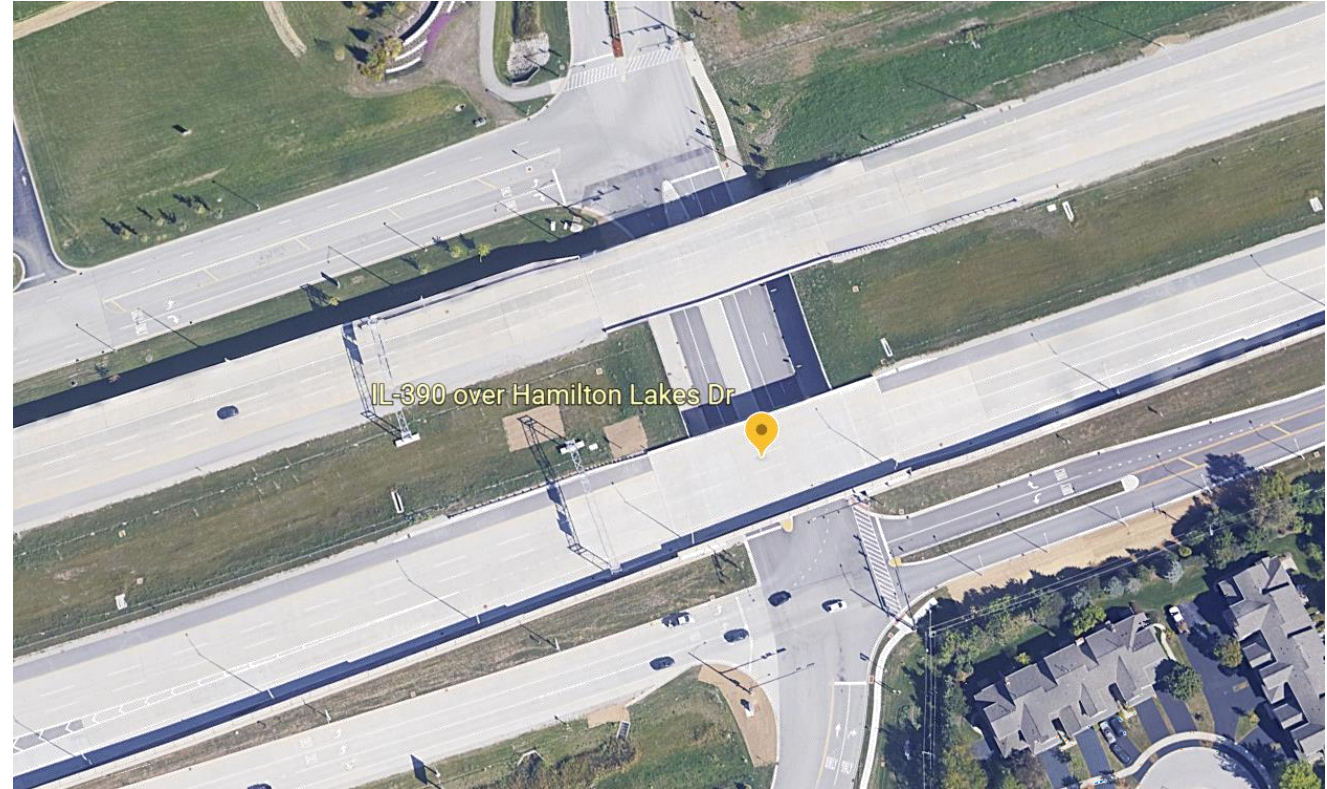
IC Bridge Survey

- IL Tollway Bridges:
 - IL 390 over Hamilton Lakes Dr
 - IL 390 over N Arlington Heights Rd
 - IL 390 over N Prospect Ave
 - IL 390 over Salt Creek
 - IL 390 over Mittel Dr
 - IL 390 over Lively Blvd

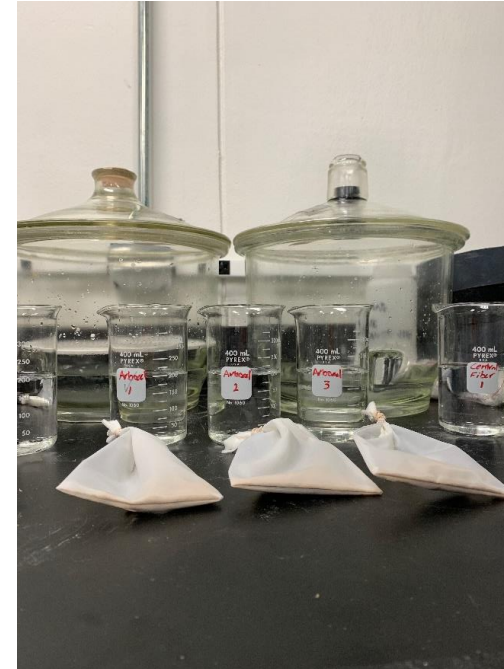


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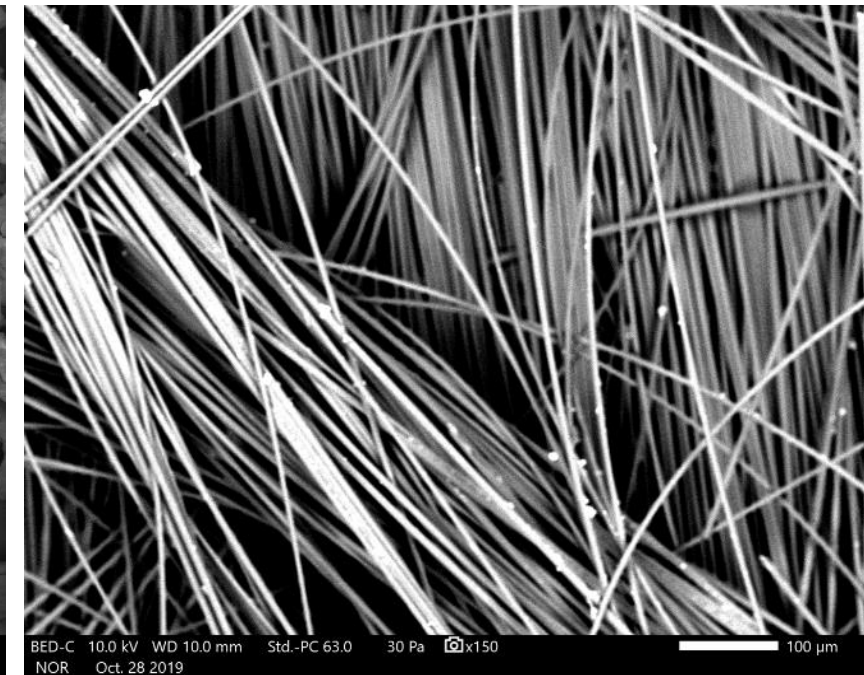
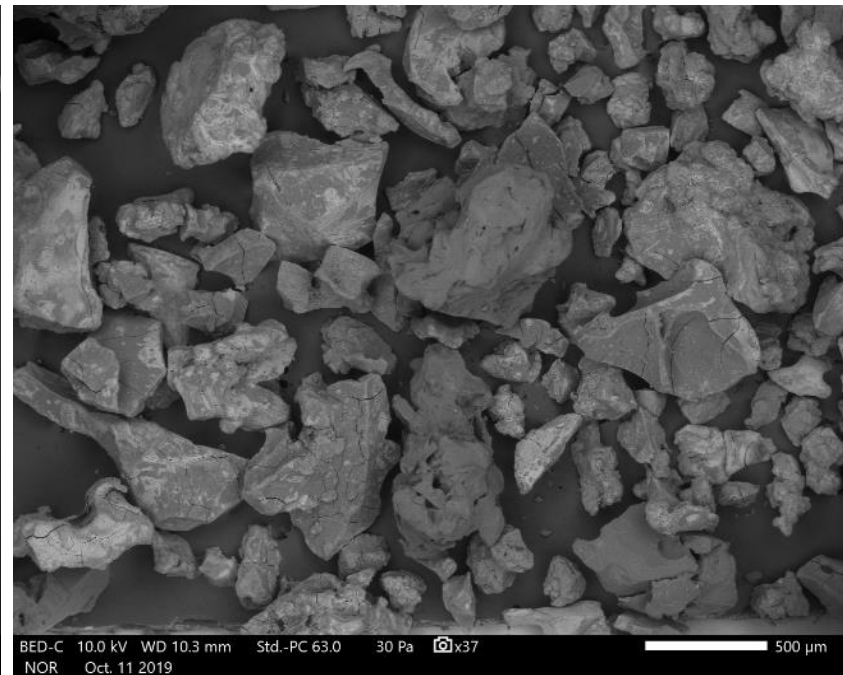
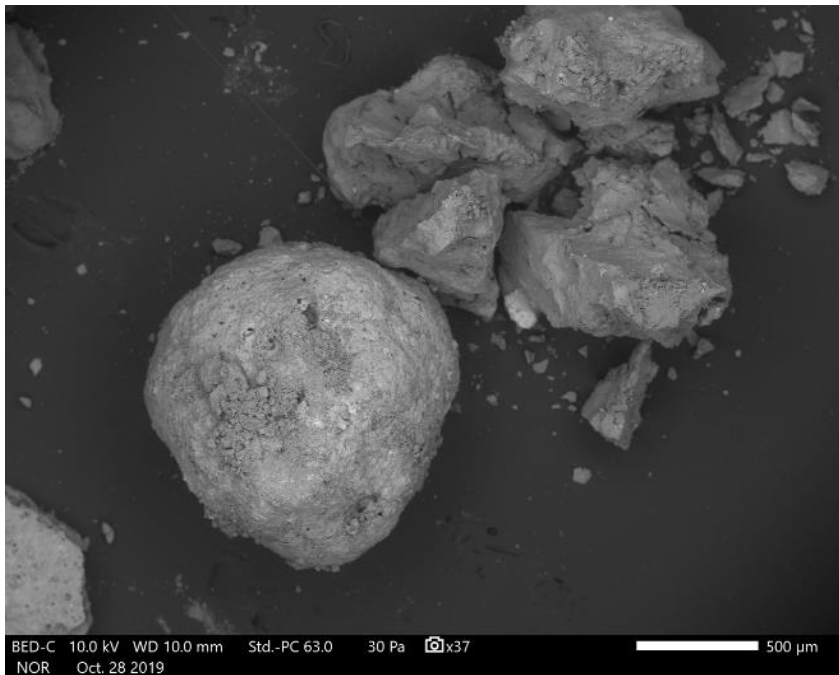
IC Materials Characterization — Absorption



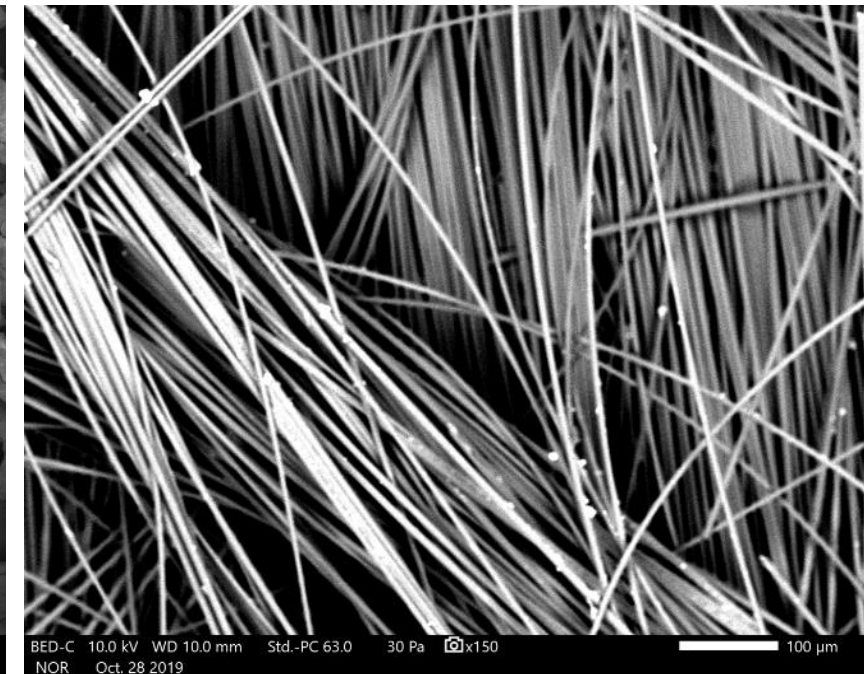
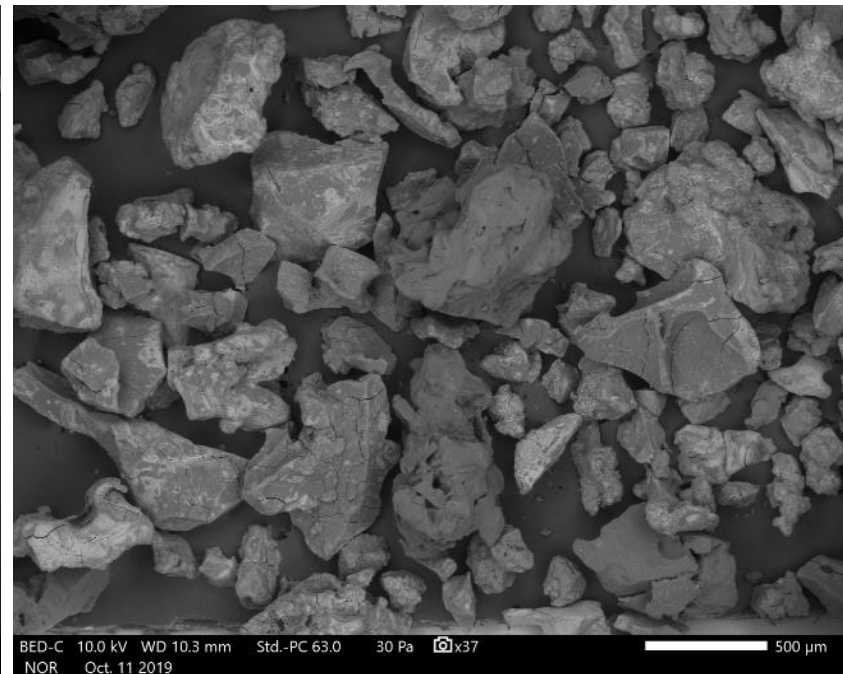
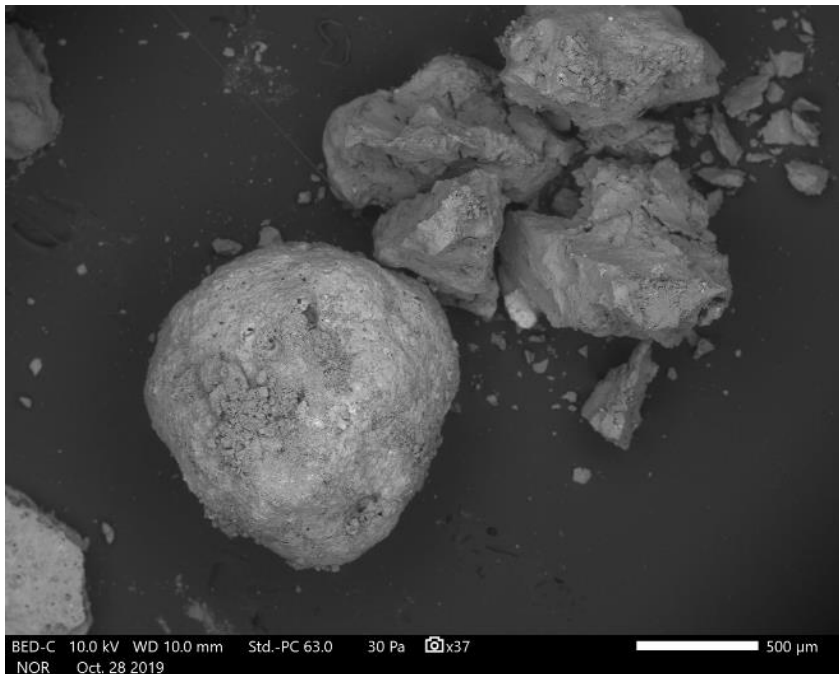
IC Materials Characterization — Desorption



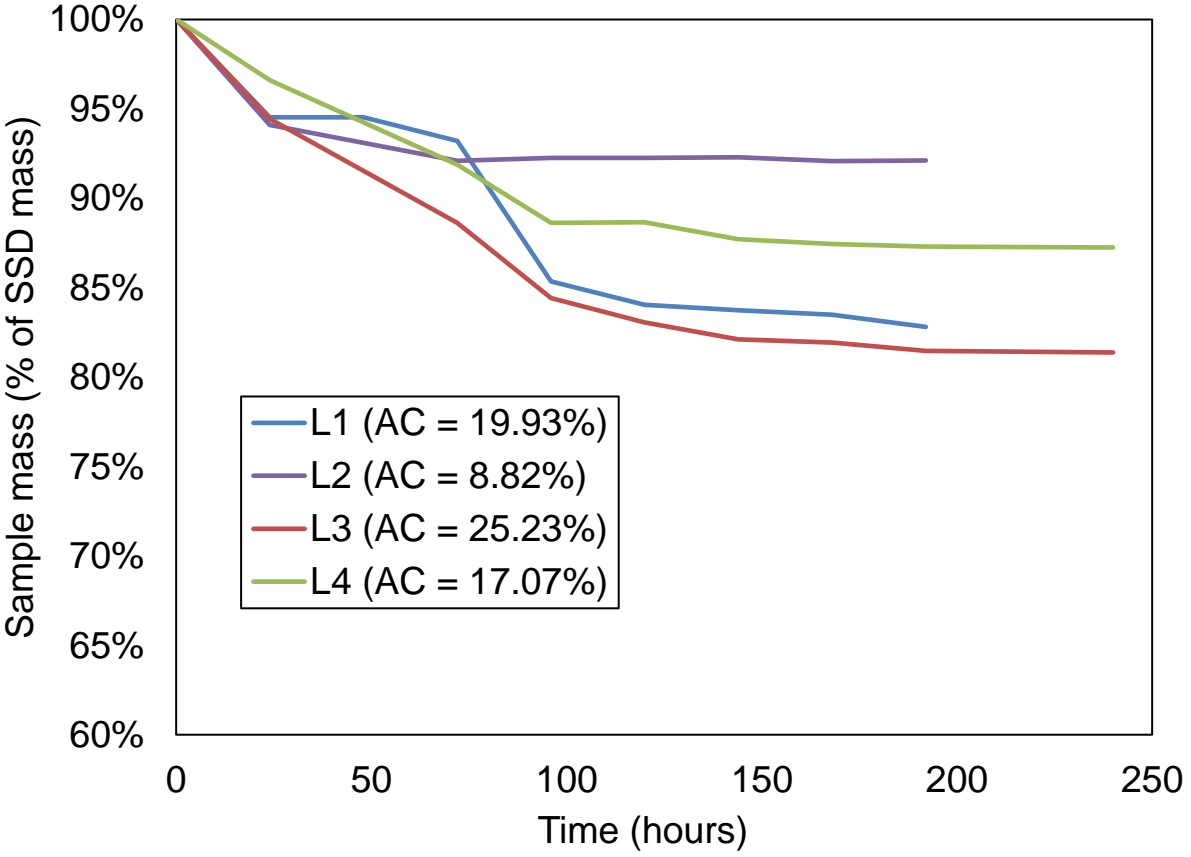
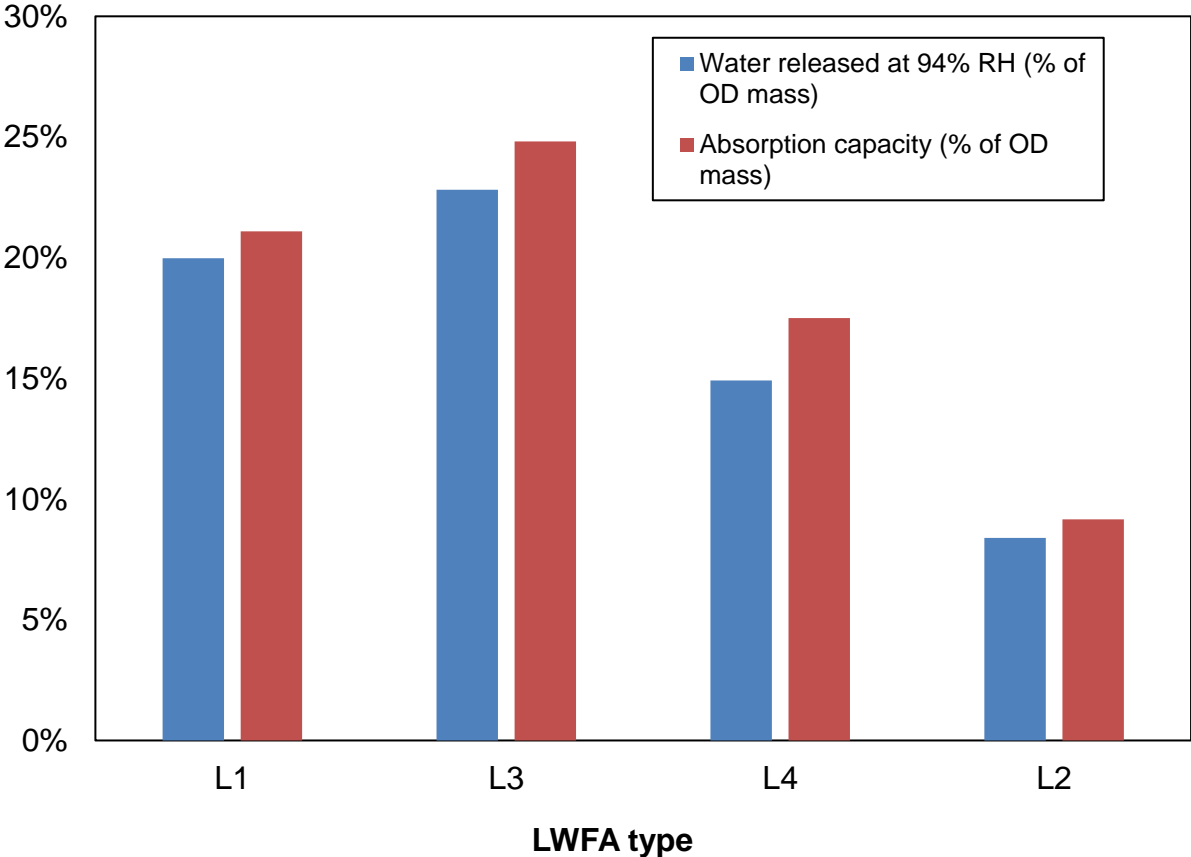
IC Materials Characterization — Morphology



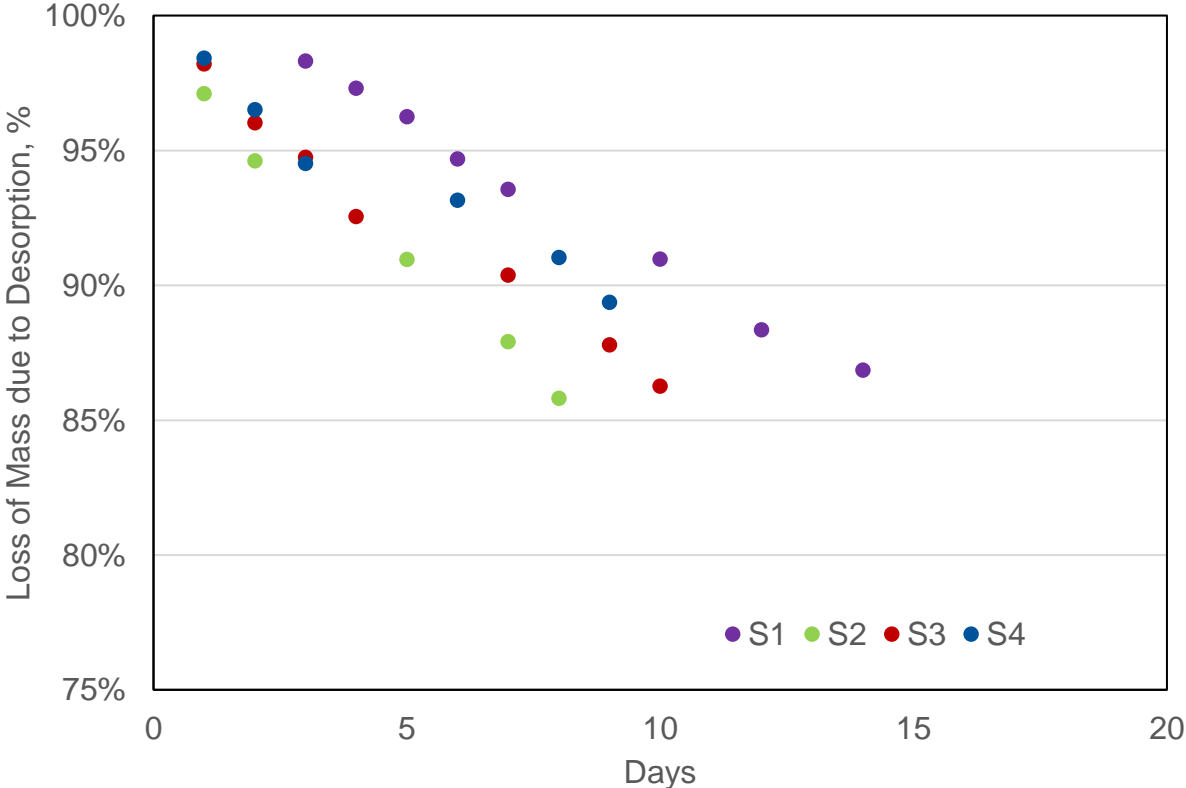
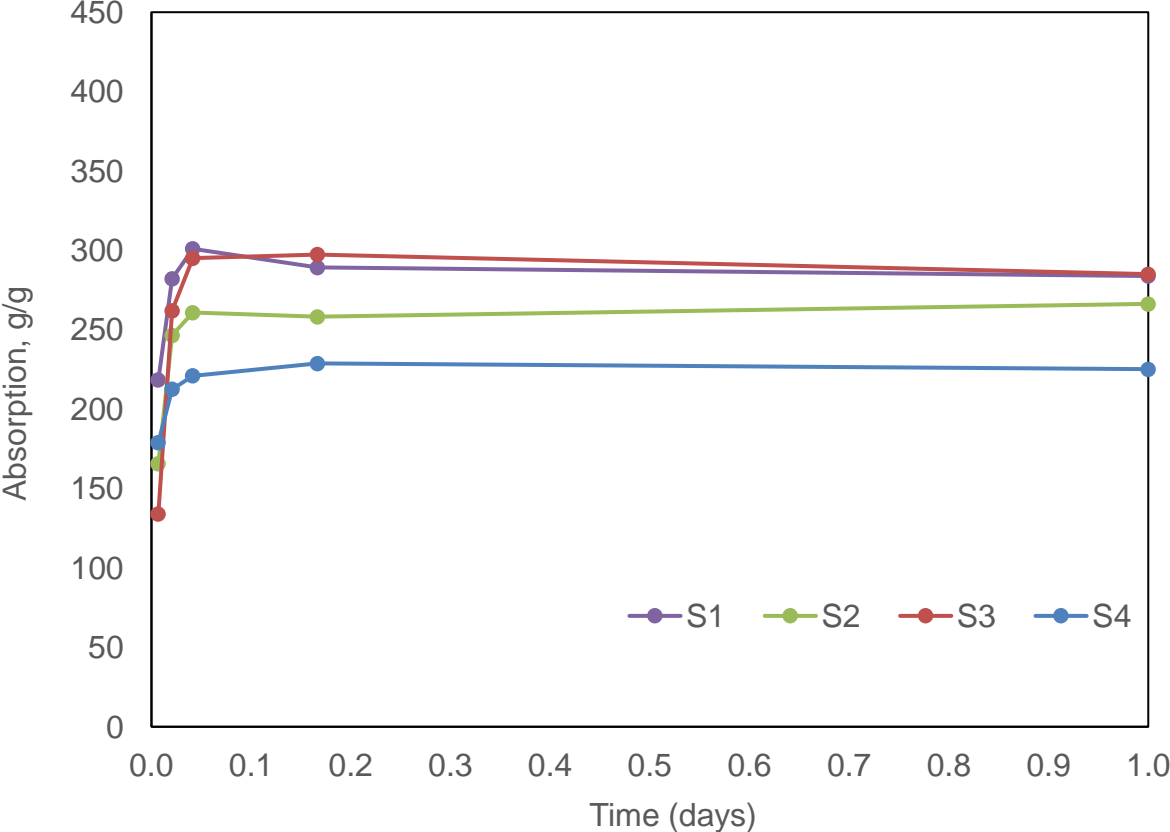
IC Materials Characterization — Morphology



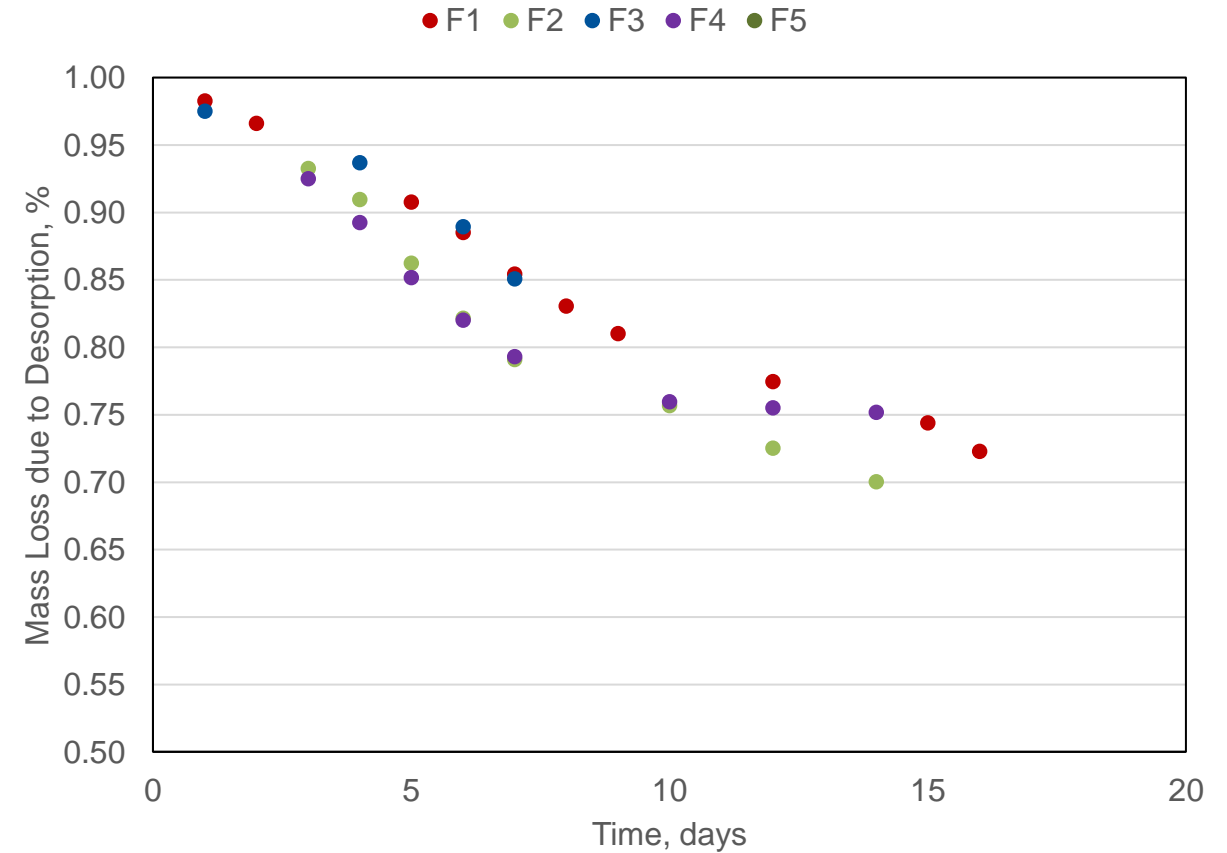
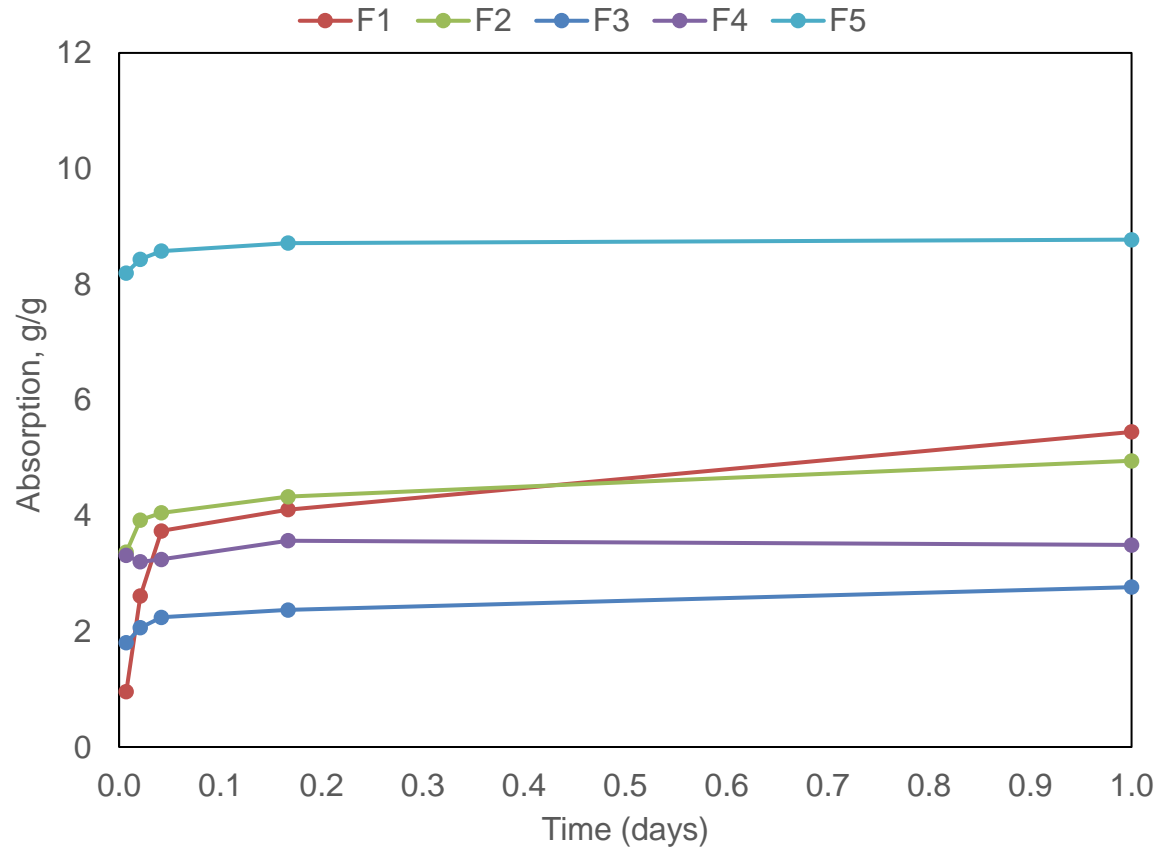
IC Materials Characterization — Results



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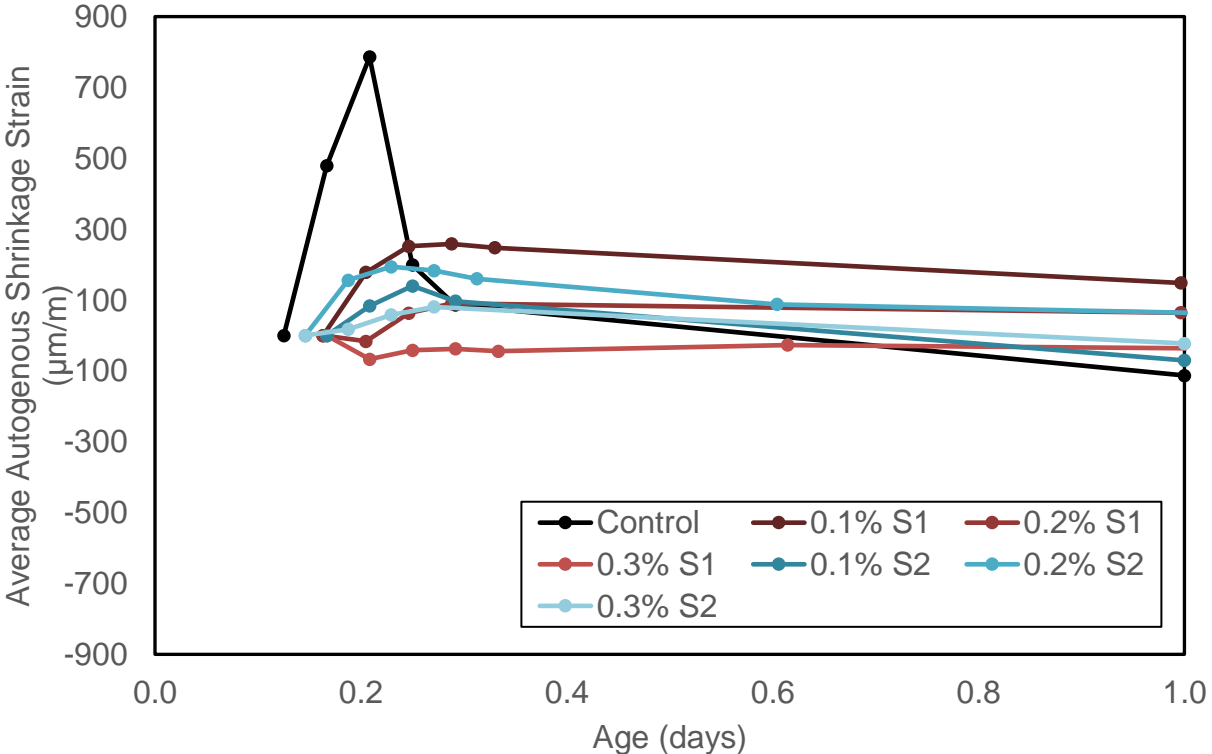
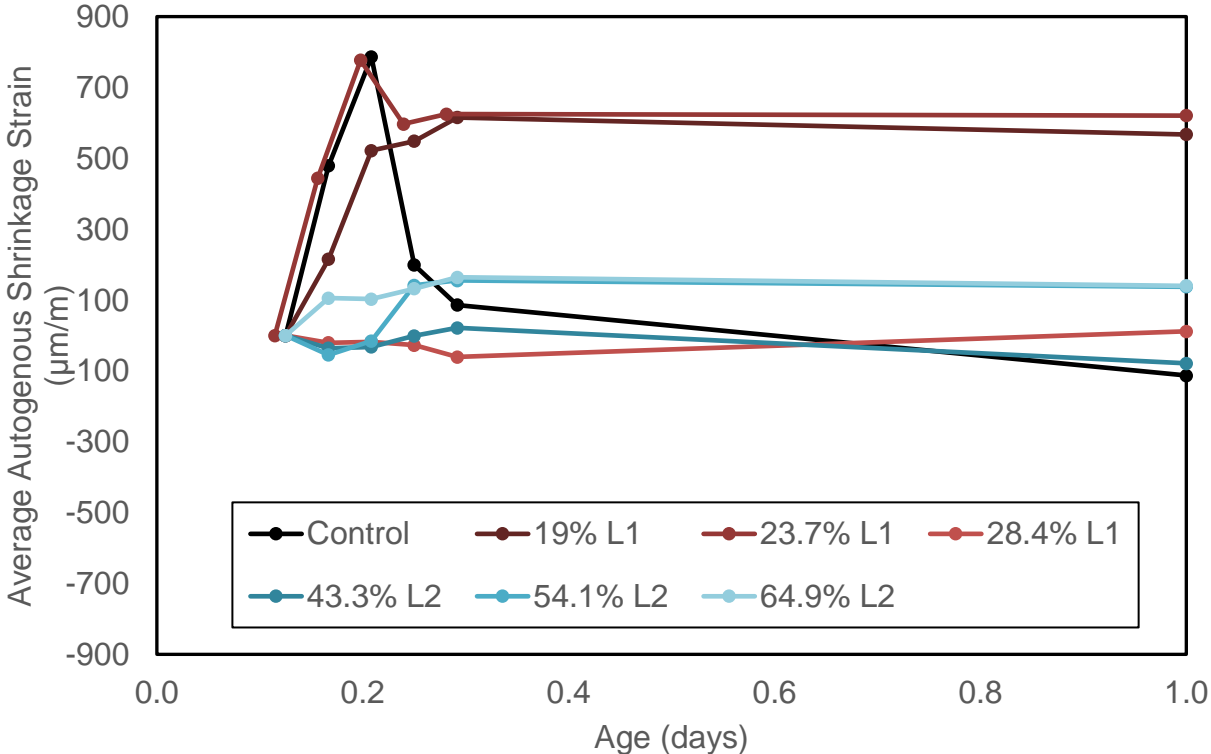


IC Mortar & Concrete — ASTM C1698

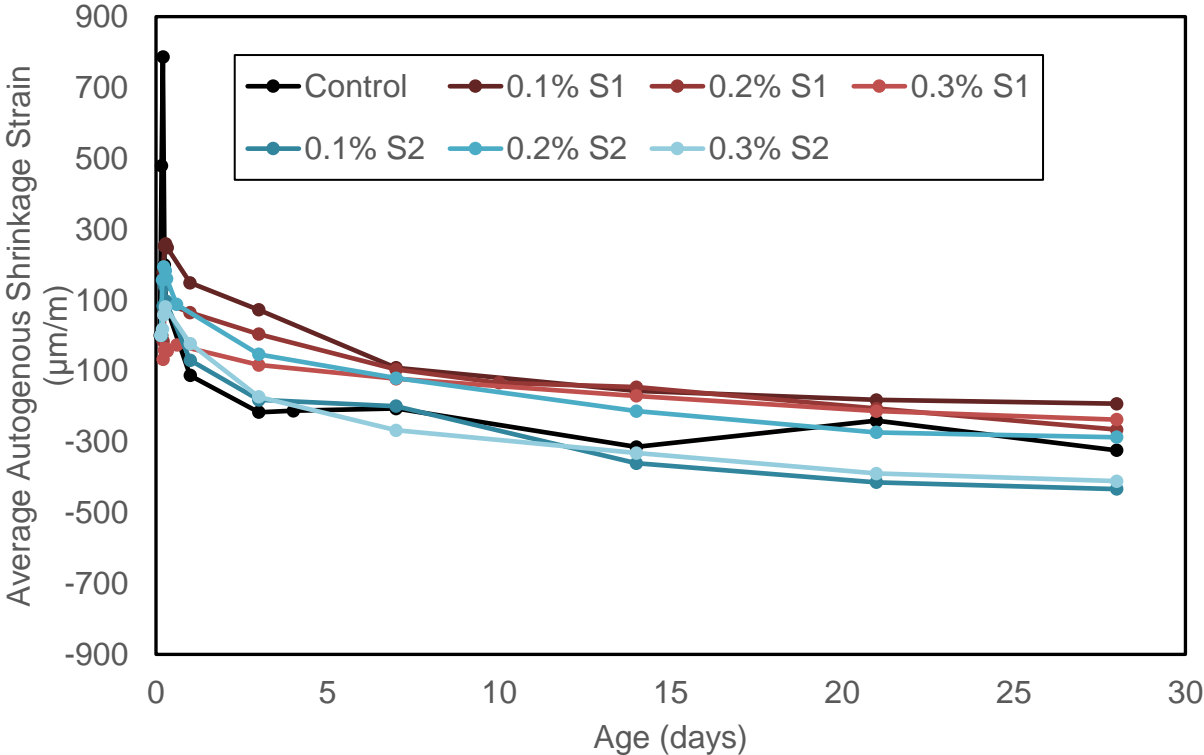
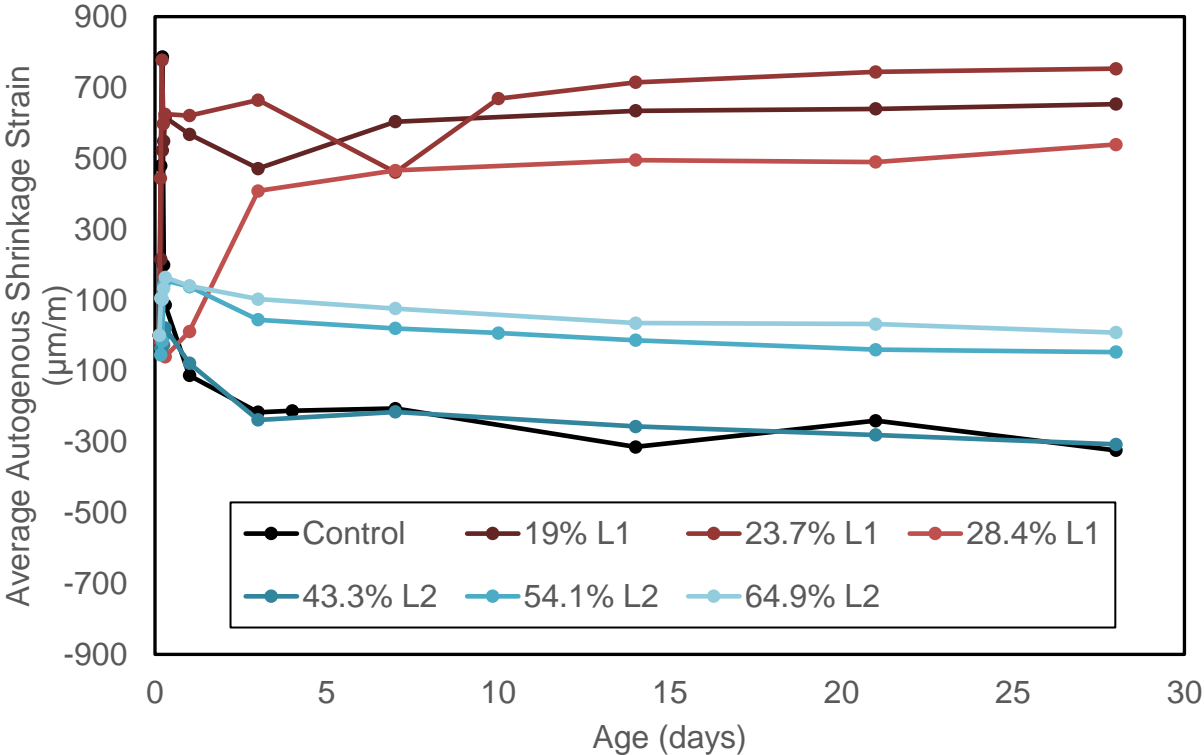
Mixture no.	Mixture ID	w/cm	LWFA type	Oven-dry LWFA replacement level (% total oven-dry sand mass)	SAP type	SAP admixed level (% cement mass)
1	W1-C	0.35	--	--	--	--
2	W1-L1-IC1	0.35	L1	19	--	--
3	W1-L1-IC2	0.35	L1	23.7	--	--
4	W1-L1-IC3	0.35	L1	28.4	--	--
5	W1-L2-IC1	0.35	L2	43.3	--	--
6	W1-L2-IC2	0.35	L2	54.1	--	--
7	W1-L2-IC3	0.35	L2	64.9	--	--
8	W1-S1-0.1	0.35	--	--	S1	0.1
9	W1-S1-0.2	0.35	--	--	S1	0.2
10	W1-S1-0.3	0.35	--	--	S1	0.3
11	W1-S2-0.1	0.35	--	--	S2	0.1
12	W1-S2-0.2	0.35	--	--	S2	0.2
13	W1-S2-0.3	0.35	--	--	S2	0.3



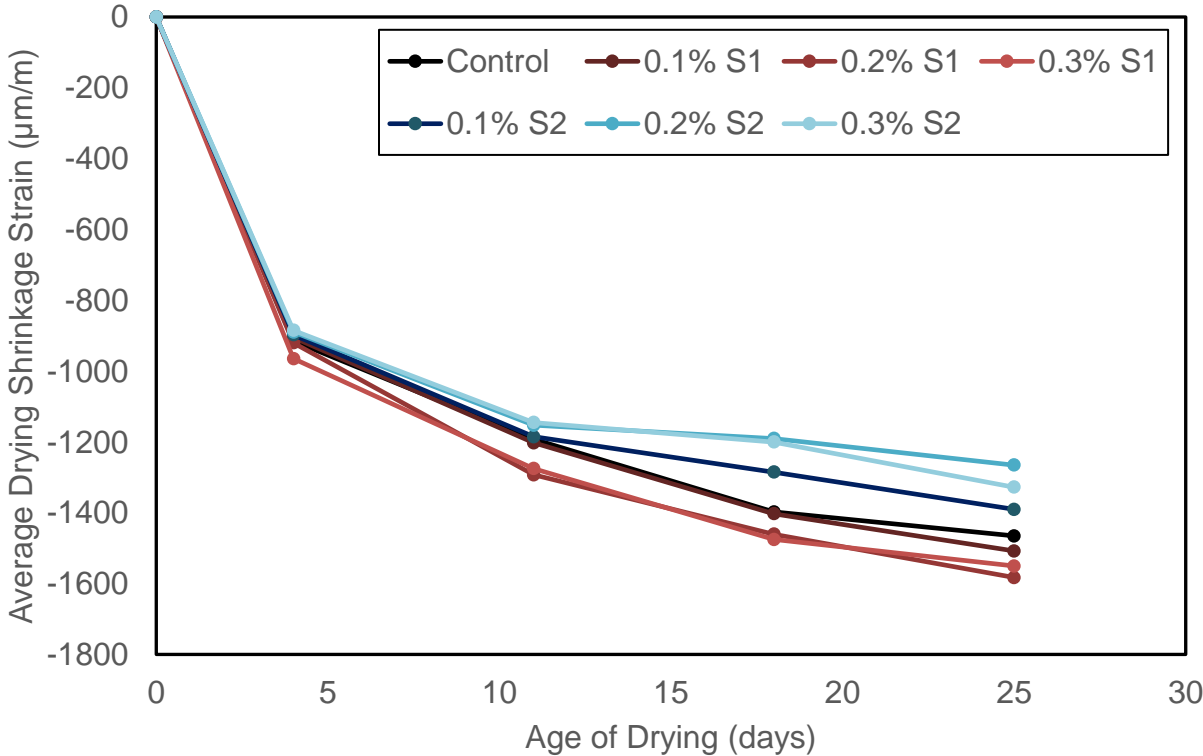
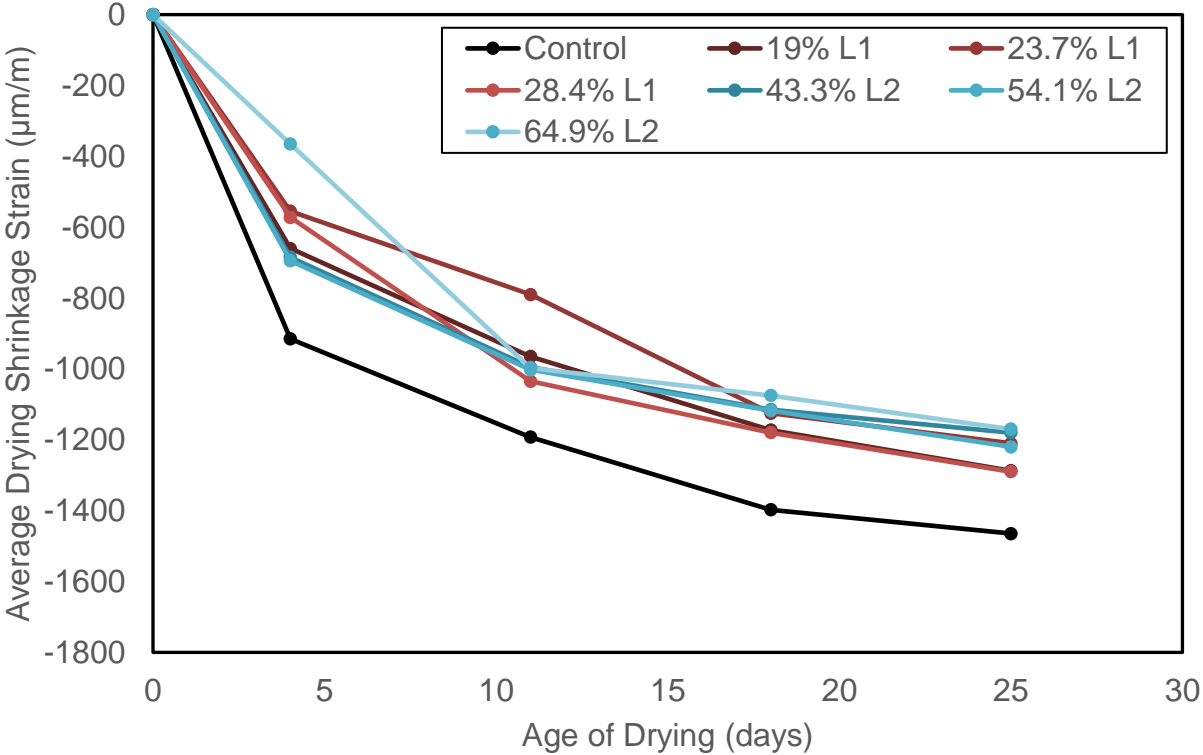
IC Mortar & Concrete — ASTM C1698 & ASTM C596



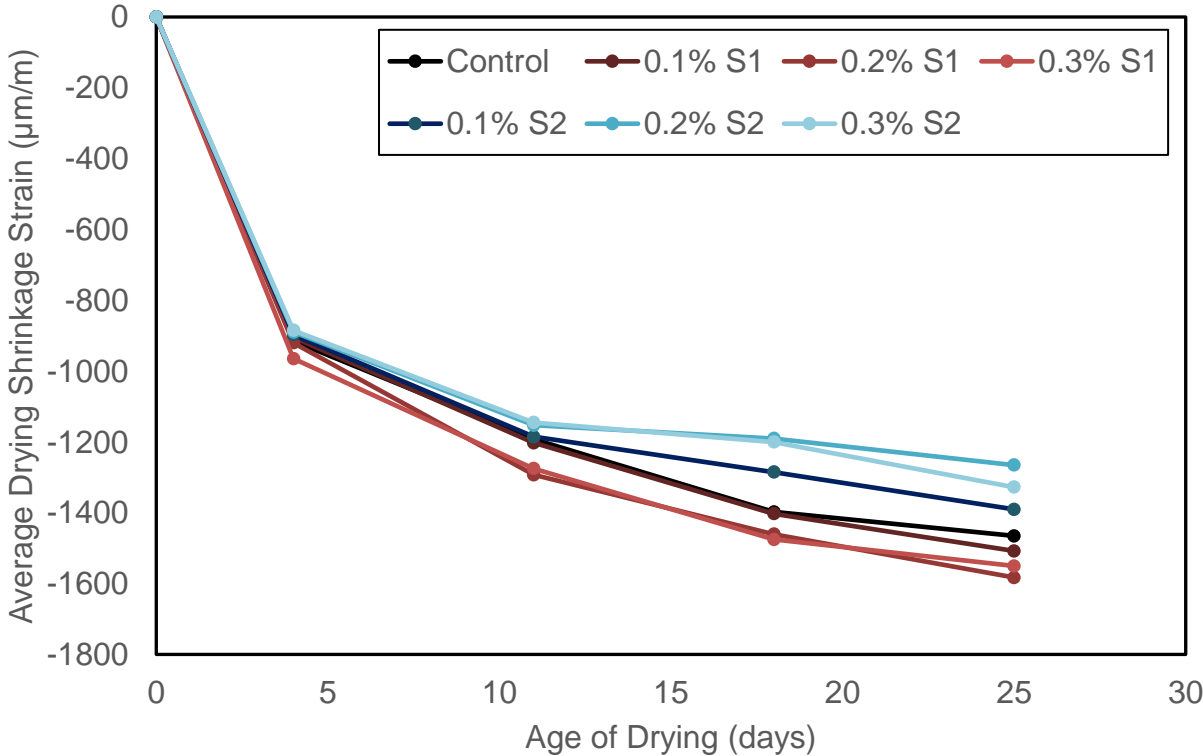
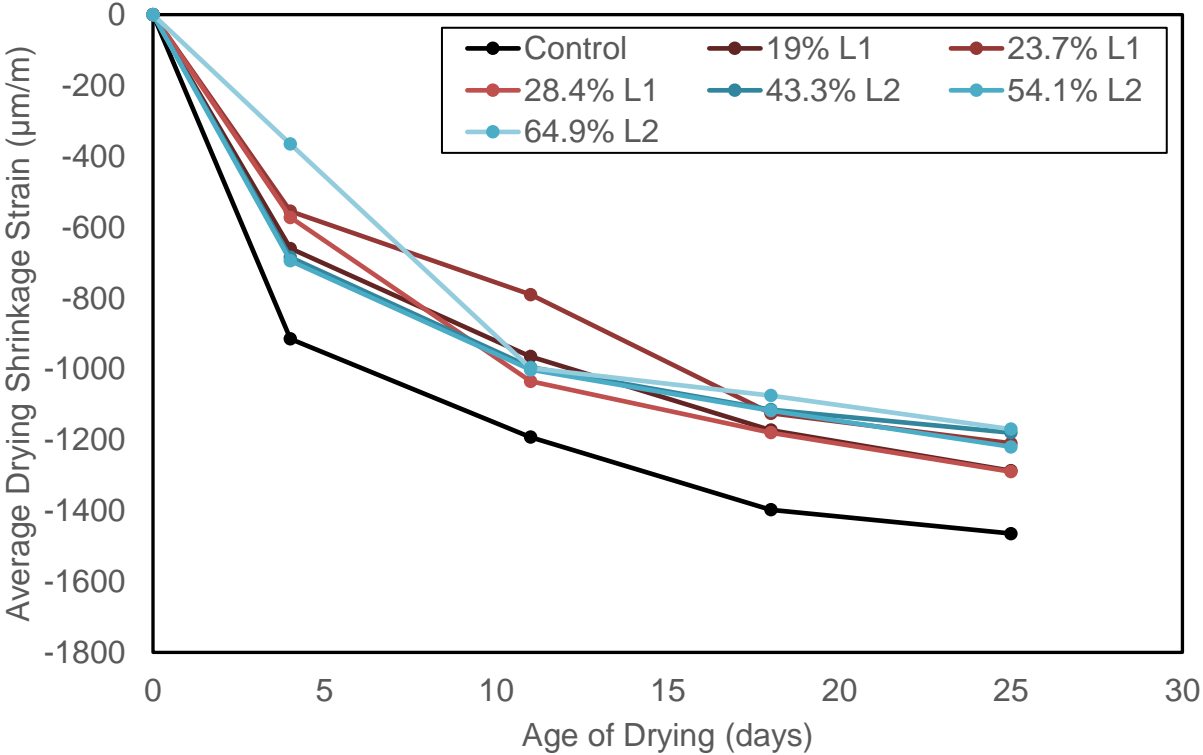
IC Mortar & Concrete — ASTM C1698 & ASTM C596



IC Mortar & Concrete — ASTM C1698 & ASTM C596

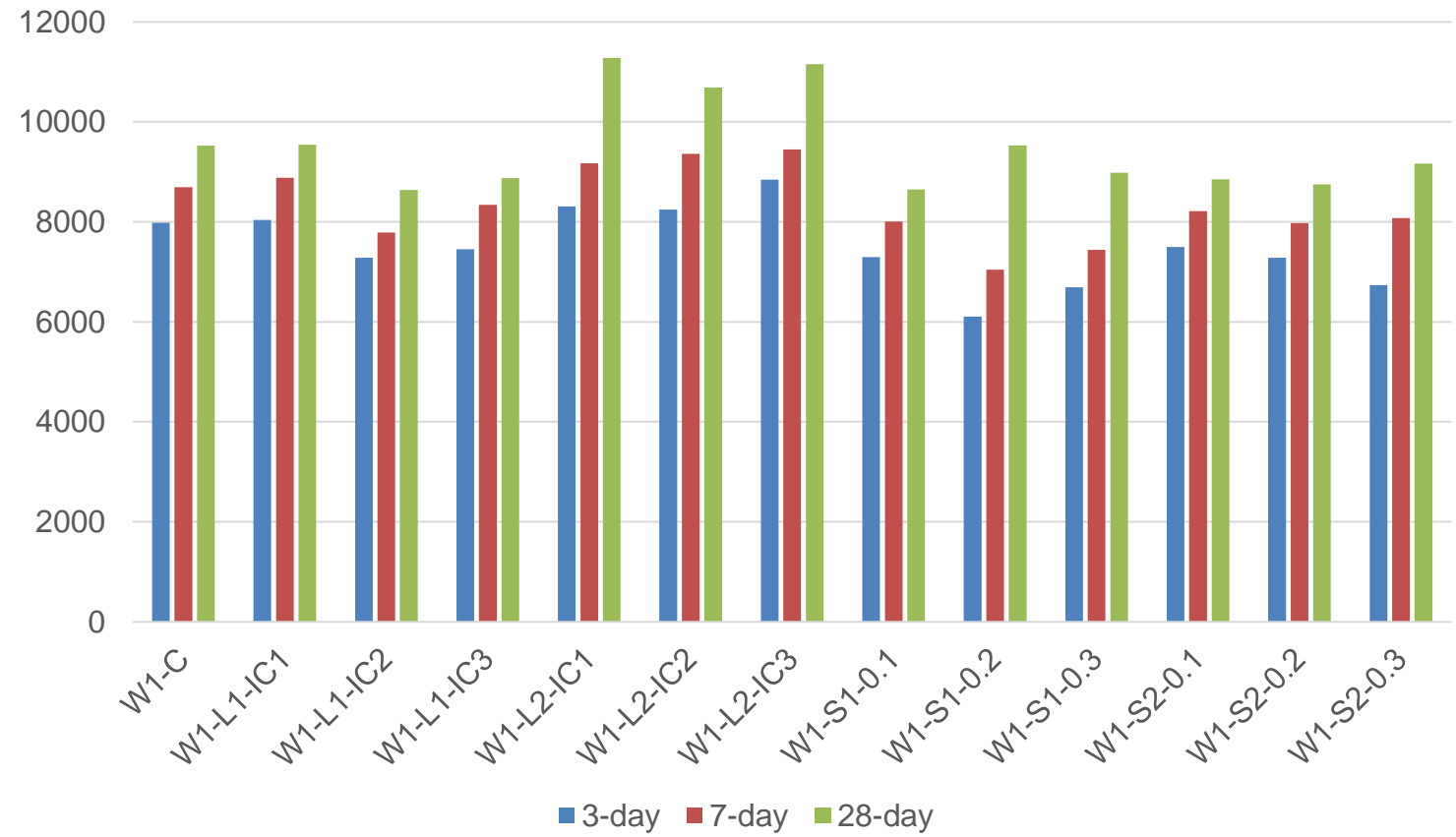


IC Mortar & Concrete — ASTM C1698 & ASTM C596



IC Mortar & Concrete — Setting & Compressive Str.

Mixture ID	Flow (%) / No. of blows	Unit Weight (lb/ft ³)	Final Set Time (h:mm)
W1-C	150 / 25	136	2:45
W1-L1-IC1	148.5 / 25	123	3:15
W1-L1-IC2	150 / 25	121	2:45
W1-L1-IC3	150 / 25	116	3:25
W1-L2-IC1	150 / 25	126	3:25
W1-L2-IC2	150 / 25	124	3:15
W1-L2-IC3	150 / 25	120	3:15
W1-S1-0.1	150 / 25	134	3:25
W1-S1-0.2	150 / 25	132	3:25
W1-S1-0.3	150 / 25	132	3:45
W1-S2-0.1	150 / 25	136	3:30
W1-S2-0.2	150 / 25	132	3:15
W1-S2-0.3	150 / 25	134	3:15



IC Mortar & Concrete — Pavement & Bridge Deck

Mixture Proportions (lbs/yd³)

Mixture ID	Type I/II cement	Fly Ash	Slag	Water	Coarse aggregate #4	Coarse aggregate #67	Concrete Sand	LWFA	SAP
PA-C-045	364	156	--	234	676	1216	1294	--	--
PA-LW-045	364	156	--	234	676	1216	843	238	--
PA-SAP-045	364	156	--	234	676	1216	1294	--	0.52
PA-C-036	364	156	--	187	676	1216	1419	--	--
PA-LW-036	364	156	--	187	676	1216	967	238	--
PA-SAP-036	364	156	--	187	676	1216	1419	--	0.52
BD-C-045	432	--	108	243	836	964	1324	--	--
BD-LW-045	432	--	108	243	836	964	855	247	--
BD-SAP-045	432	--	108	243	836	964	1324	--	0.54
BD-C-036	432	--	108	194	836	964	1453	--	--
BD-LW-036	432	--	108	194	836	964	984	247	--
BD-SAP-036	432	--	108	194	836	964	1453	--	0.54

Mixture ID Explanation: PA "Pavement"; BD "Bridge Deck"; LW "Lightweight Fine Aggregate"; SAP "Super Absorbent Polymer"; 045 "W/cm ratio of 0.45.

IC Mortar & Concrete — Pavement & Bridge Deck

Mixture Proportions (lbs/yd³)

Mixture ID	Type I/II cement	Fly Ash	Slag	Water	Coarse aggregate #4	Coarse aggregate #67	Concrete Sand	LWFA	SAP
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PA-LW-036	364	156	--	187	676	1216	967	238	--
PA-SAP-036	364	156	--	187	676	1216	1419	--	0.52
BD-C-045	432	--	108	243	836	964	1324	--	--
BD-LW-045	432	--	108	243	836	964	855	247	--
BD-SAP-045	432	--	108	243	836	964	1324	--	0.54
BD-C-036	432	--	108	194	836	964	1453	--	--
BD-LW-036	432	--	108	194	836	964	984	247	--
BD-SAP-036	432	--	108	194	836	964	1453	--	0.54

Mixture ID Explanation: PA "Pavement"; BD "Bridge Deck"; LW "Lightweight Fine Aggregate"; SAP "Super Absorbent Polymer"; 045 "W/cm ratio of 0.45.

IC Mortar & Concrete — Pavement

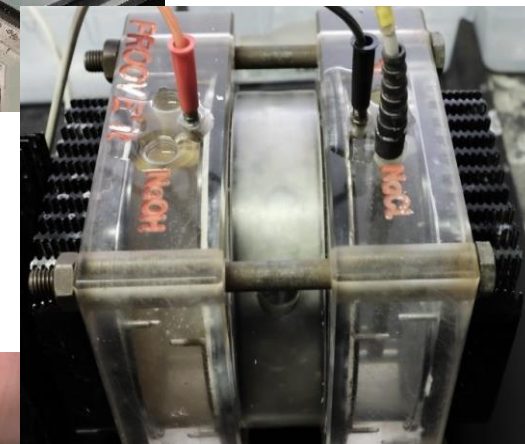
Property	Time	PA-C-045	PA-LW-045	PA-SAP-045	PA-C-036	PA-LW-036	PA-SAP-036
Slump, in.	Immediately after mixing	2.75	6.75	2.50	1.00	0.75	0.50
	45 min. after mixing	1.25	4.75	1.00	0.50	0.25	0.25
Air Content, %	Immediately after mixing	5.1	6.4	7.9	6.8	5.5	7.6
	45 min. after mixing	3.9	4.8	6.0	5.2	5.0	5.5
SAM Number	Immediately after mixing	0.34	0.52	0.36	0.27	0.54	0.25
Density, lbs/ft ³	Immediately after mixing	146.7	139.9	140.7	148.6	142.4	146.2
	45 min. after mixing	151.0	140.6	142.2	148.8	142.8	147.2
Temperature, °F	Immediately after mixing	65	68	67	67	68	68
Box Test Edge slump, in.	Immediately after mixing	0.31	Fail ^{\$}	0.44	0.13	0.22	0.21
Box Test Visual Rating	Immediately after mixing	2	Fail ^{\$}	2	2	2	2
V-Kelly index	Immediately after mixing	0.94	0.23	0.70	0.43	0.70	0.79
Yield Stress, Pa	Immediately after mixing	N/A	N/A	N/A	N/A	N/A	N/A
Plastic Viscosity, Pa.s	Immediately after mixing	N/A	N/A	N/A	N/A	N/A	N/A
	45 min. after mixing	N/A	N/A	N/A	N/A	N/A	N/A
Plastic Viscosity, Pa.s	45 min. after mixing	N/A	N/A	N/A	N/A	N/A	N/A



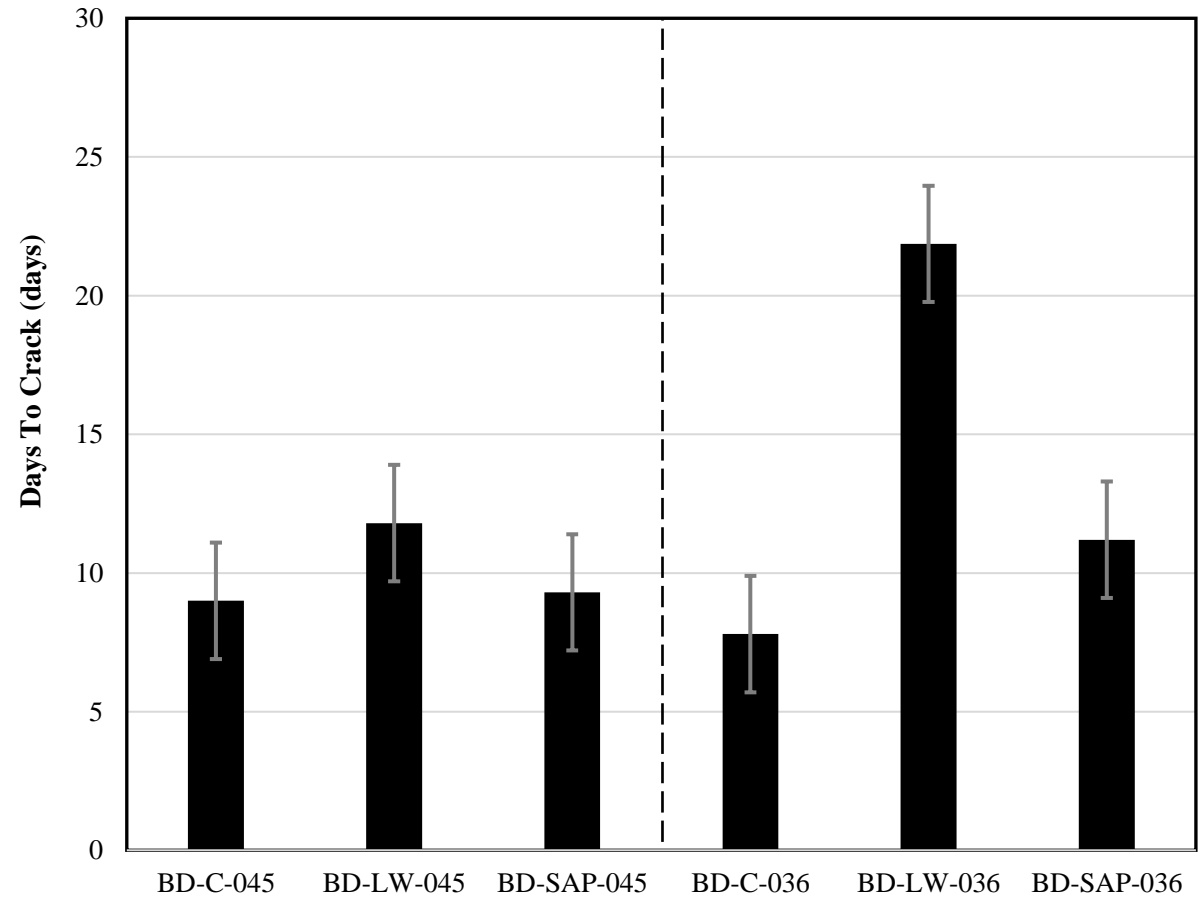
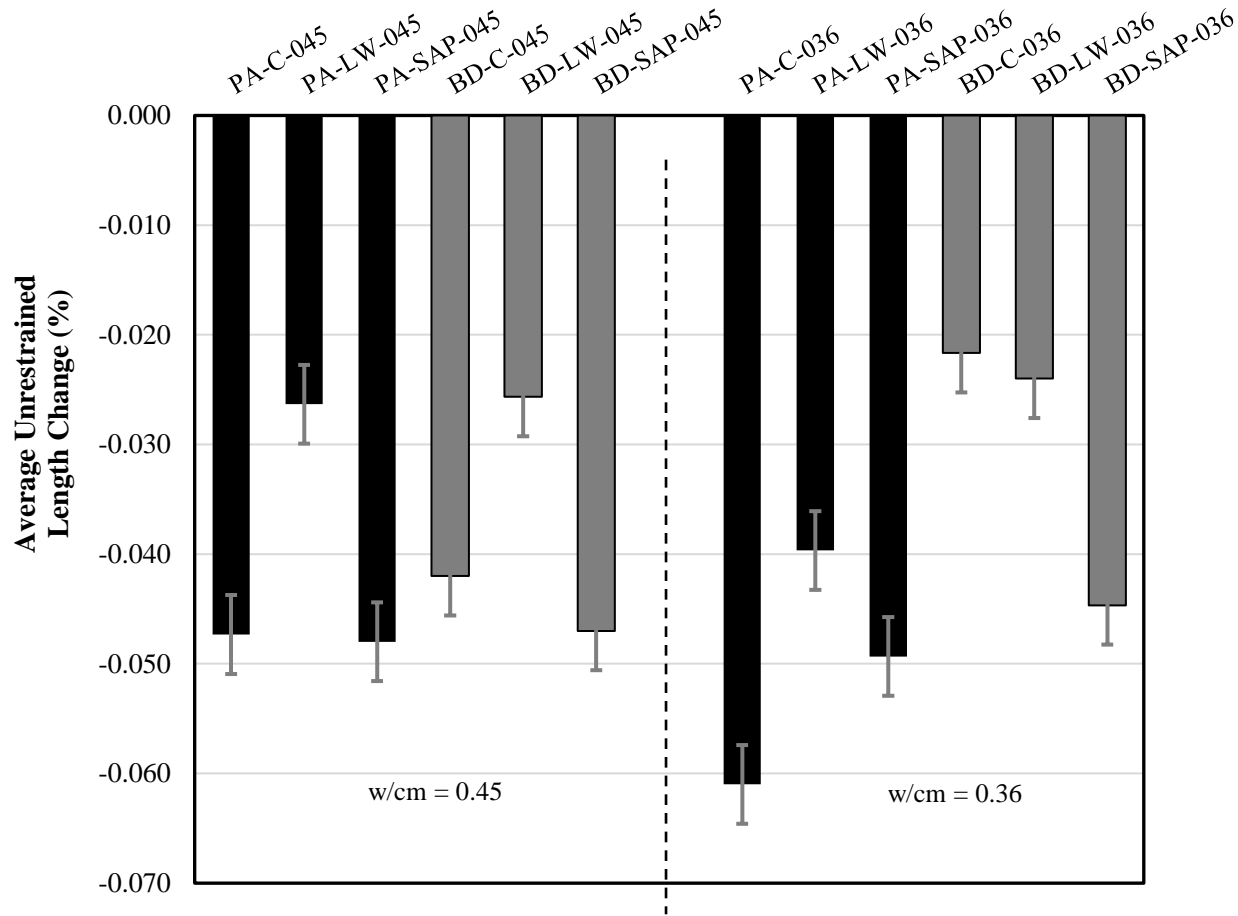
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IC Mortar & Concrete — Pavement & Bridge Deck

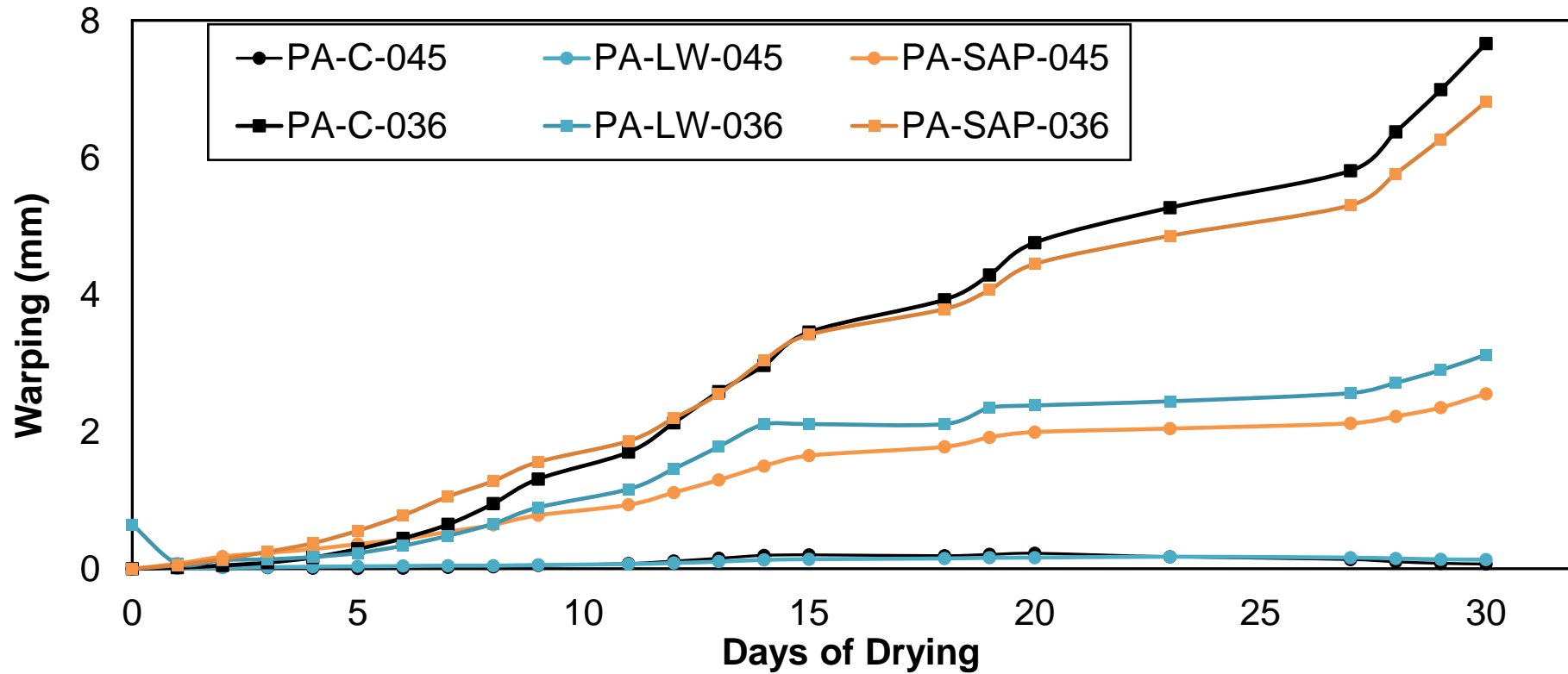
Property	Time	BD-C-045	BD-LW-045	BD-SAP-045	BD-C-036	BD-LW-036	BD-SAP-036
Slump, in.	Immediately after mixing	8.50	5.75	5.25	7.50	8.50	6.50
	45 min. after mixing	8.25	4.00	3.00	2.25	4.00	1.75
Air Content, %	Immediately after mixing	8.5	7.6	8.5	6.2	9.5	8.5
	45 min. after mixing	7.9	8.6	7.5	5.5	6.1	7.2
SAM Number	Immediately after mixing	0.05	0.31	0.15	0.09	0.25	0.10
	45 min. after mixing	141.7	137.1	140.2	148.4	137.9	145.2
Density, lbs/ft ³	Immediately after mixing	141.7	137.1	140.2	148.4	137.9	145.2
	45 min. after mixing	143.4	135.2	143.2	148.6	140.8	144.4
Temperature, °F	Immediately after mixing	67	73	69	68	70	68
Box Test Edge slump, in.	Immediately after mixing	N/A	N/A	N/A	N/A	N/A	N/A
Box Test Visual Rating	Immediately after mixing	N/A	N/A	N/A	N/A	N/A	N/A
V-Kelly index	Immediately after mixing	N/A	N/A	N/A	N/A	N/A	N/A
Yield Stress, Pa	Immediately after mixing	245.0	517.0	>1000	308.4	396.5	>1000
Plastic Viscosity, Pa.s	Immediately after mixing	32.2	18.8	42.3	39.1	46.4	87.2
	45 min. after mixing	392.5	712.3	>1000	555.8	695.1	>1000
Plastic Viscosity, Pa.s	45 min. after mixing	22.0	8.4	70.0	48.4	57.0	136.6



IC Mortar & Concrete — ASTM C157 & ASTM C1581



IC Mortar & Concrete — ASTM C157 & ASTM C1581



Acknowledgements

- Wisconsin Department of Transportation
– WisDOT No. 0092-19-02
- Jose Pacheco, Jan Vosahlik (MJ2 Consulting)
- Laboratory: CTLGroup

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WISCONSIN HIGHWAY RESEARCH PROGRAM

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March 26, 2024

