Optimizing Belitic Calcium Sulfoaluminate (BCSA) Overlay Concrete Integrated with Diverse Polymer Modification Strategies

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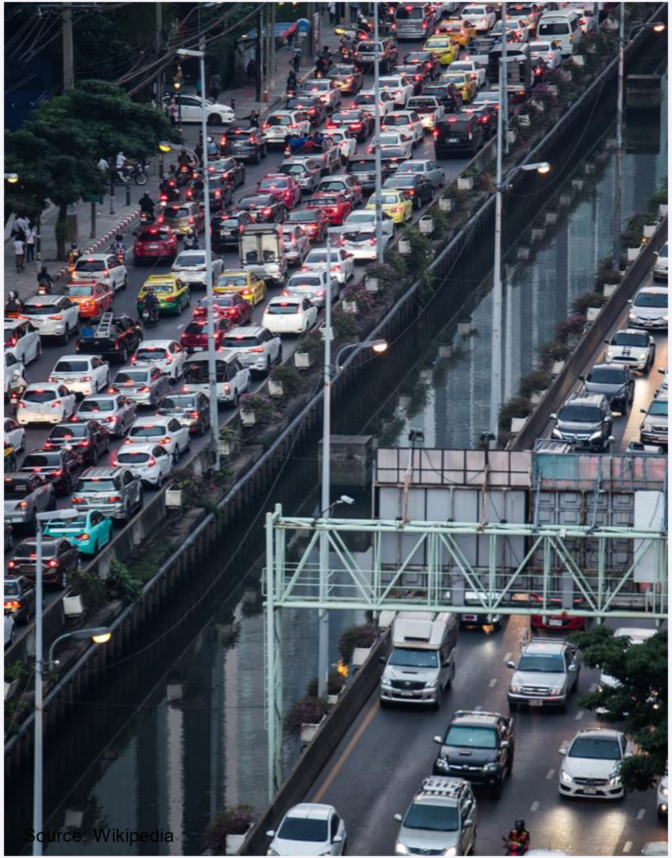
UNIVERSITY of WASHINGTON

Source: WSDOT

Problem Statement

- Aging infrastructure requiring urgent repair
- Cost (social distress inclusive) of road closures
- Environmental and mechanical distress
- Reduced construction time



Source: Wikipedia

Solution

CSA

BCSA

Ye'elimite → Ettringite, early-age strength

Belite ↑ → Strätlingite , later-age strength & durability

Calcium Sulfates

- Shrinkage-compensating
- Rapid setting
- Self-stressing
- Combination

Cements

<table>
<tr><th>Cement System</th><th>Polymer</th><th colspan="2">Form of Polymer Addition</th><th>Integrated HRWR</th></tr>
<tr><td>CSAP</td><td rowspan="2">Low-P™</td><td colspan="2">Interground powder</td><td>Yes</td></tr>
<tr><td>LLP</td><td rowspan="2">Liquid admixture</td><td>10 fl-oz / 100 lbs</td><td>None</td></tr>
<tr><td>LM (control)</td><td>Latex</td><td>3.5 gal / 94 lbs</td><td>None</td></tr>
</table>

Three Key Stages

01
Characterization

- Strength
- Workability
- Air content

02
Field Testing

- Field-scale application
- Substrate compatibility

03
Durability

- Sustainability
- Mechanical & Environmental Conditions

Characterization

Targets	
Air Content	**Slump**
5.5% ± 1.5%	4–6"

Characterization

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Phase I: Aggregates

- Size
  (3/8", 3/4")
- CA/FA Blend
  (48.9/51.1, 45/55, 35/65)

Characterization

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CSAP & LLP

Phase II: AEA Dosage
(1%, 1.75%, 2.5%)

Characterization

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CSAP & LLP

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(1%, 1.75%, 2.5%)

Phase III: AEA Type
(VR10, DA1000, AE90, AE200)

Characterization

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5.5% $\pm$ 1.5%	4–6"

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Size
(3/8", 3/4")

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(48.9/51.1, 45/55, 35/65)

CSAP & LLP

LM

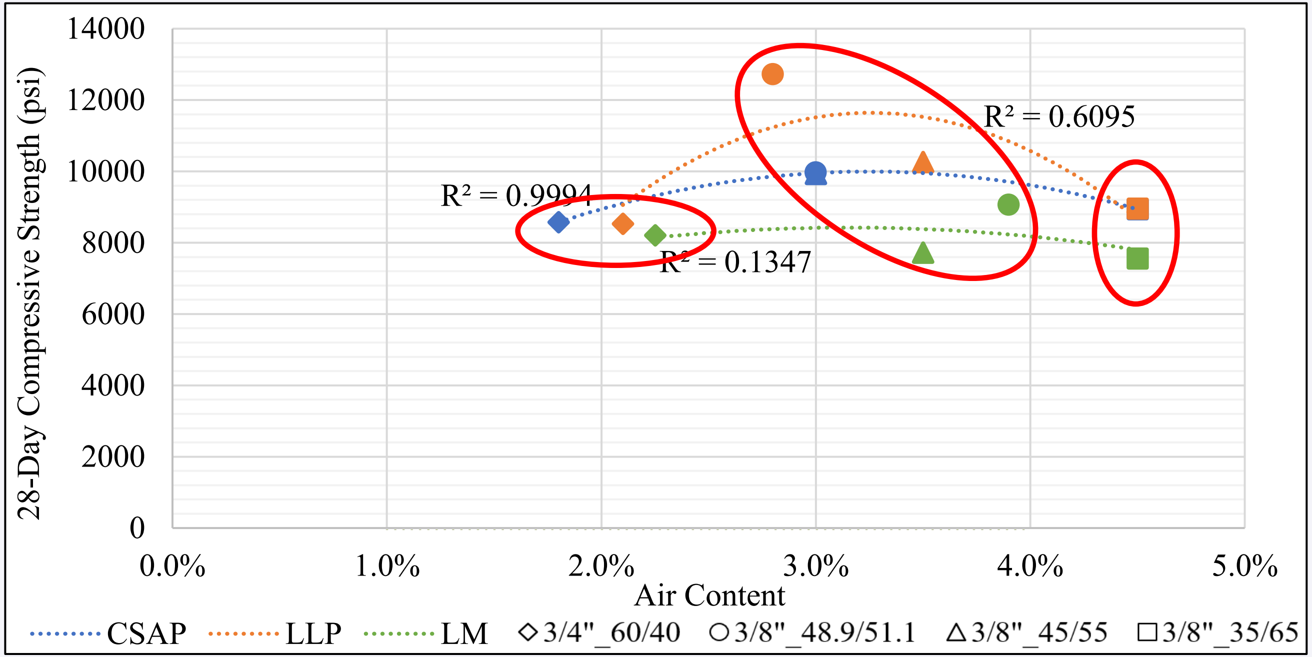
Phase II: AEA Dosage
(1%, 1.75%, 2.5%)

Phase III: AEA Type
(VR10, AE90, AE200, DA1000)

Phase IV: Latex Quantity
(100%, 50%, 25%)

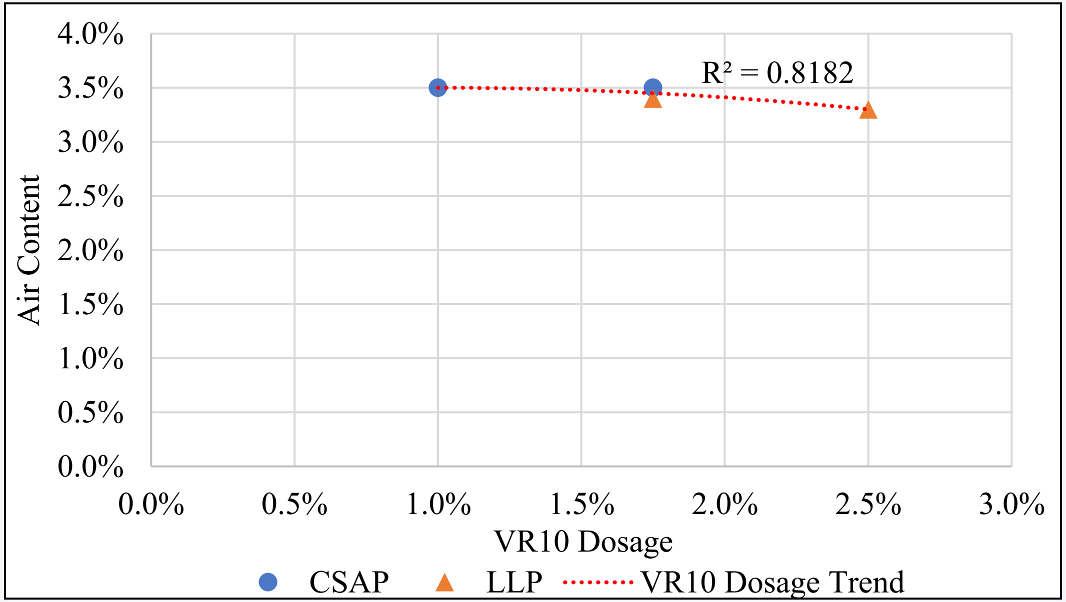
Results: Characterization

Phase I: Aggregates



- Higher FA ratio = ↑ air content, ↓ strength
- Larger NMSA = ↓ air content, ↓ strength
- Slight changes in blend impact long-term strength

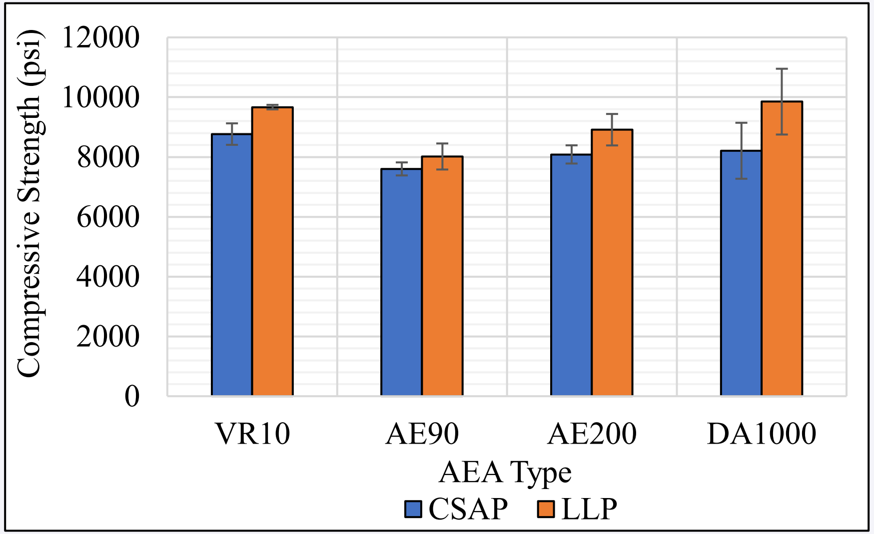
Phase II: AEA Dosage



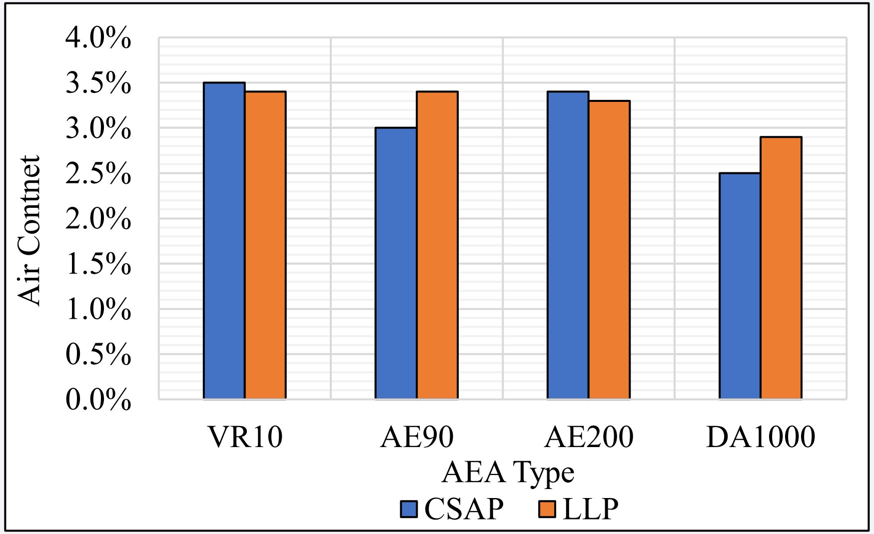
- Plateau or downward trend with increasing AEA

Phase III: AEA Type

28D Compressive Strength



Entrained Air Content



- The vinsol resin-based AEAs tended to result in higher strength
- DA1000 resulted in the lowest air content
- Overall, still below air content target

Characterization

Targets	
Air Content	**Slump**
5.5% $\pm$ 1.5%	4–6"

Phase I: Aggregates

Size
(**3/8"**, 3/4")

CA/FA Blend
(**48.9/51.1**, 45/55, 35/65)

CSAP & LLP

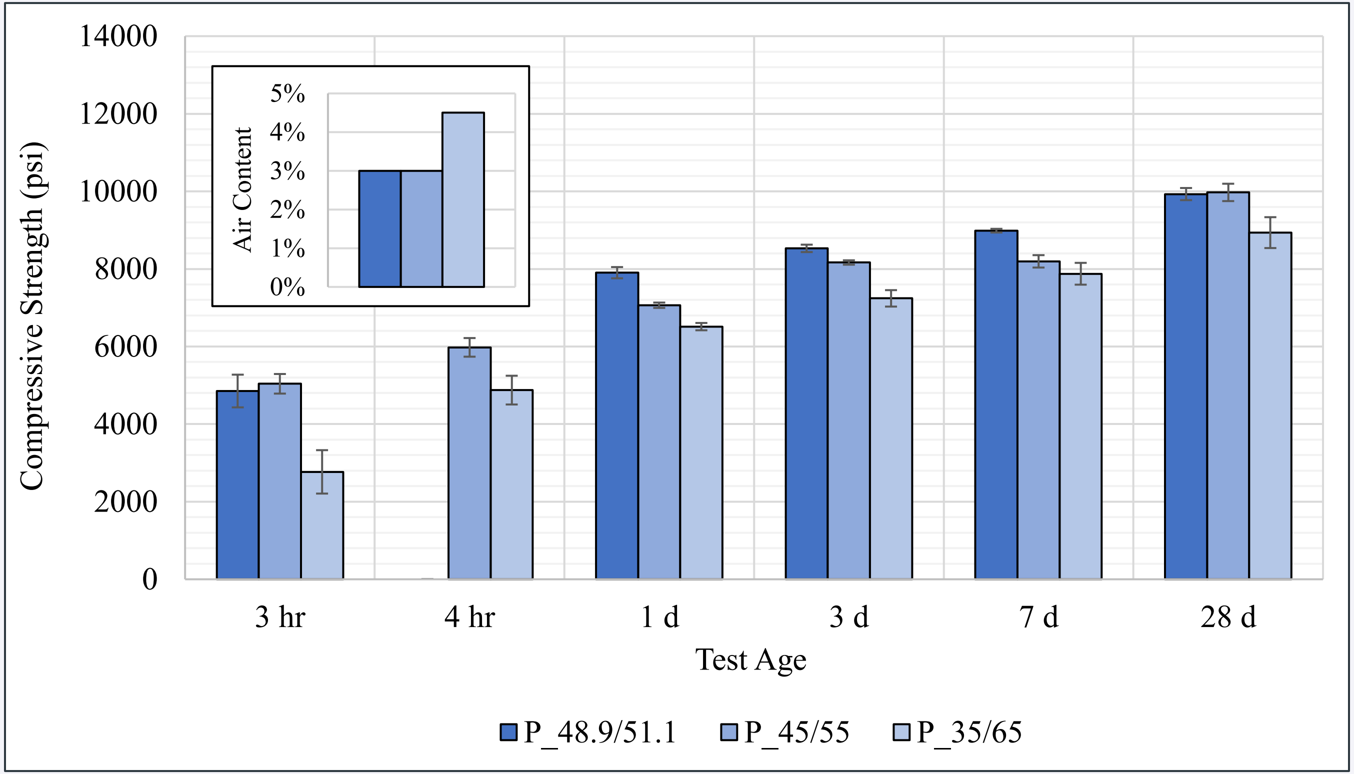
LM

Phase II: AEA Dosage
(1%, **1.75%**, 2.5%)

Phase III: AEA Type
(**VR10**, AE90, AE200, DA1000)

Phase IV: Latex Quantity
(**100%**, 50%, **25%**)

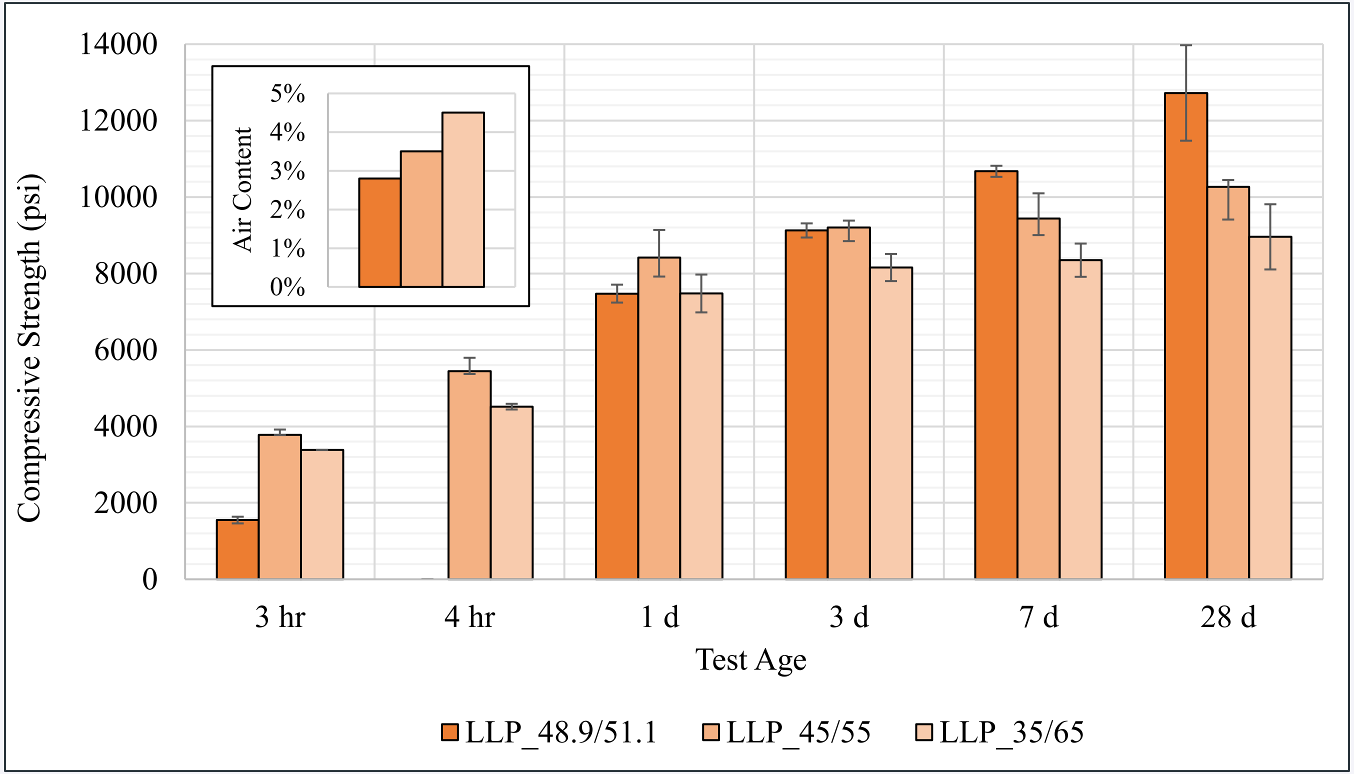
Phase I: CSAP CA/FA Blends



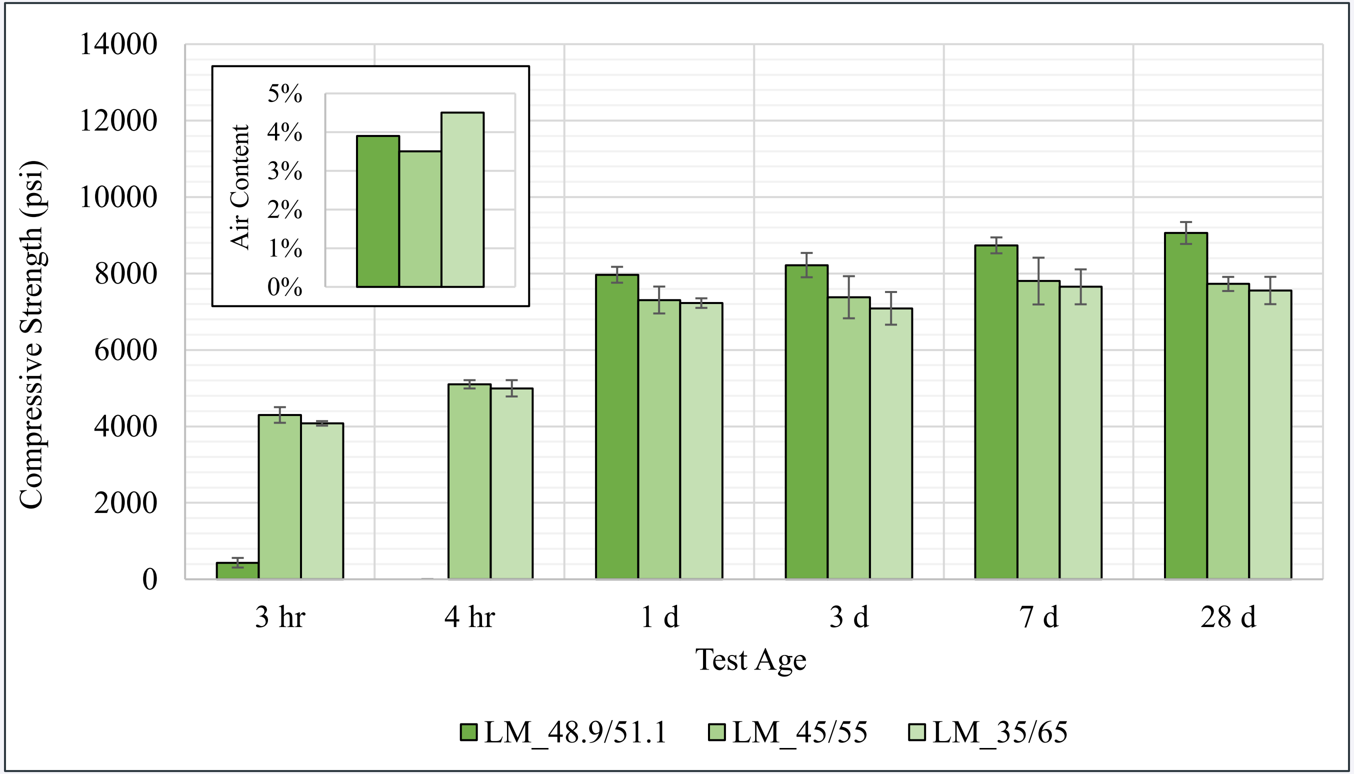
4,000 psi ≈ 30MPa

10Ksi ≈ 70 MPa

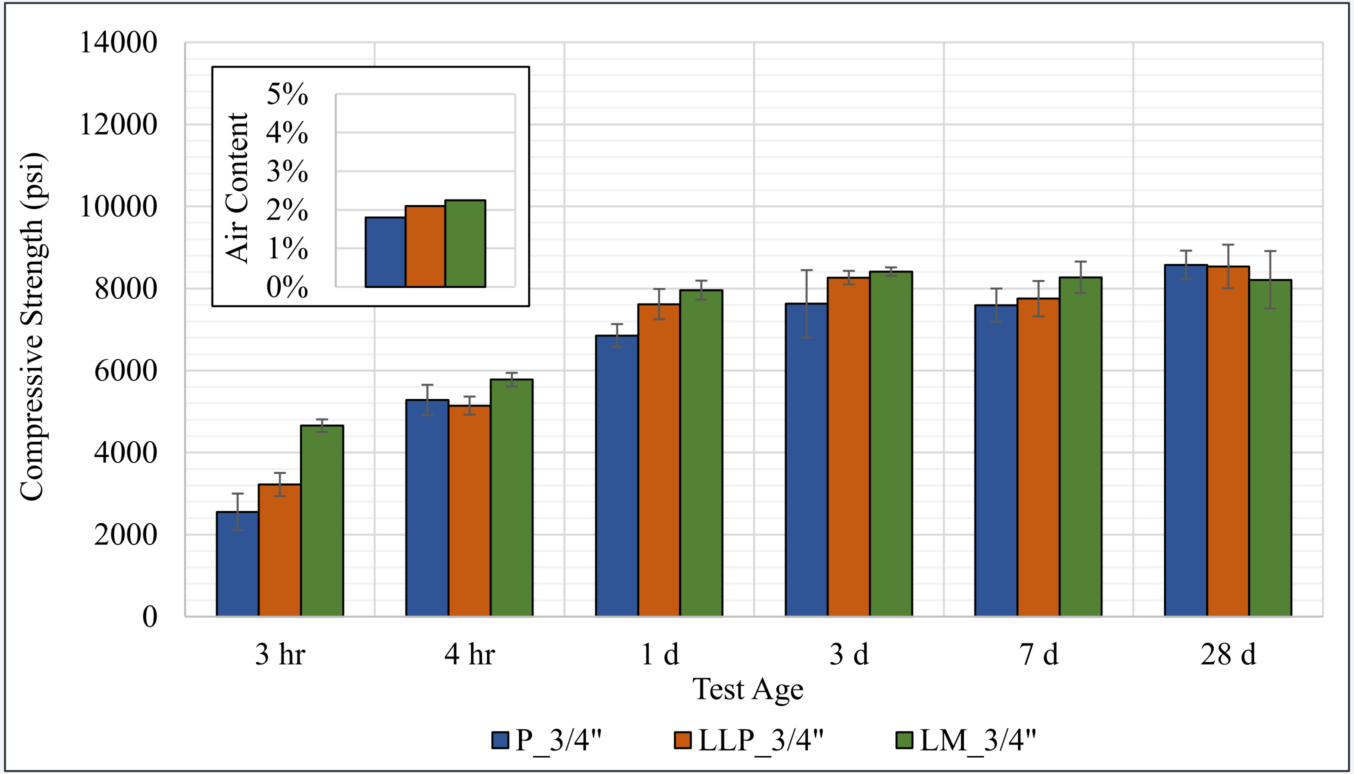
Phase I: LLP CA/FA Blends



Phase I: LM CA/FA Blends

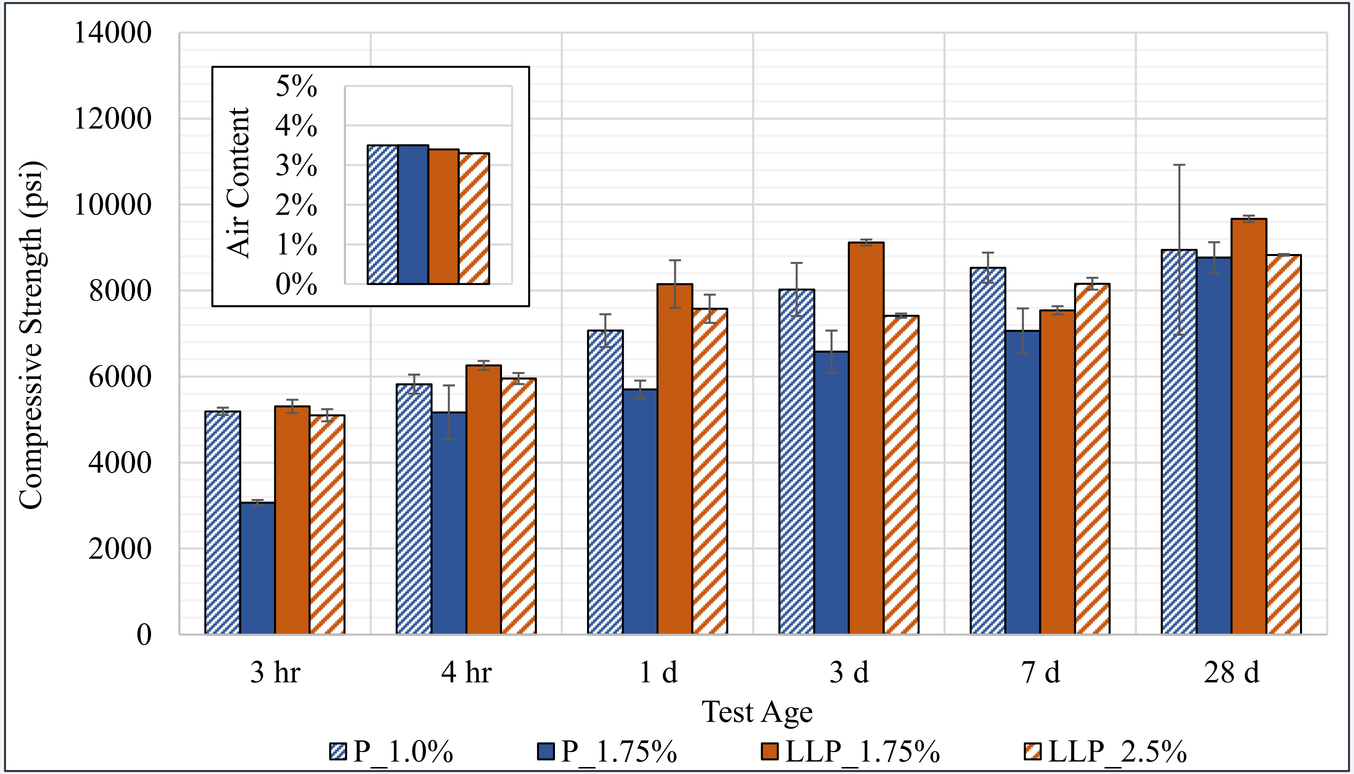


Phase I: NMSA

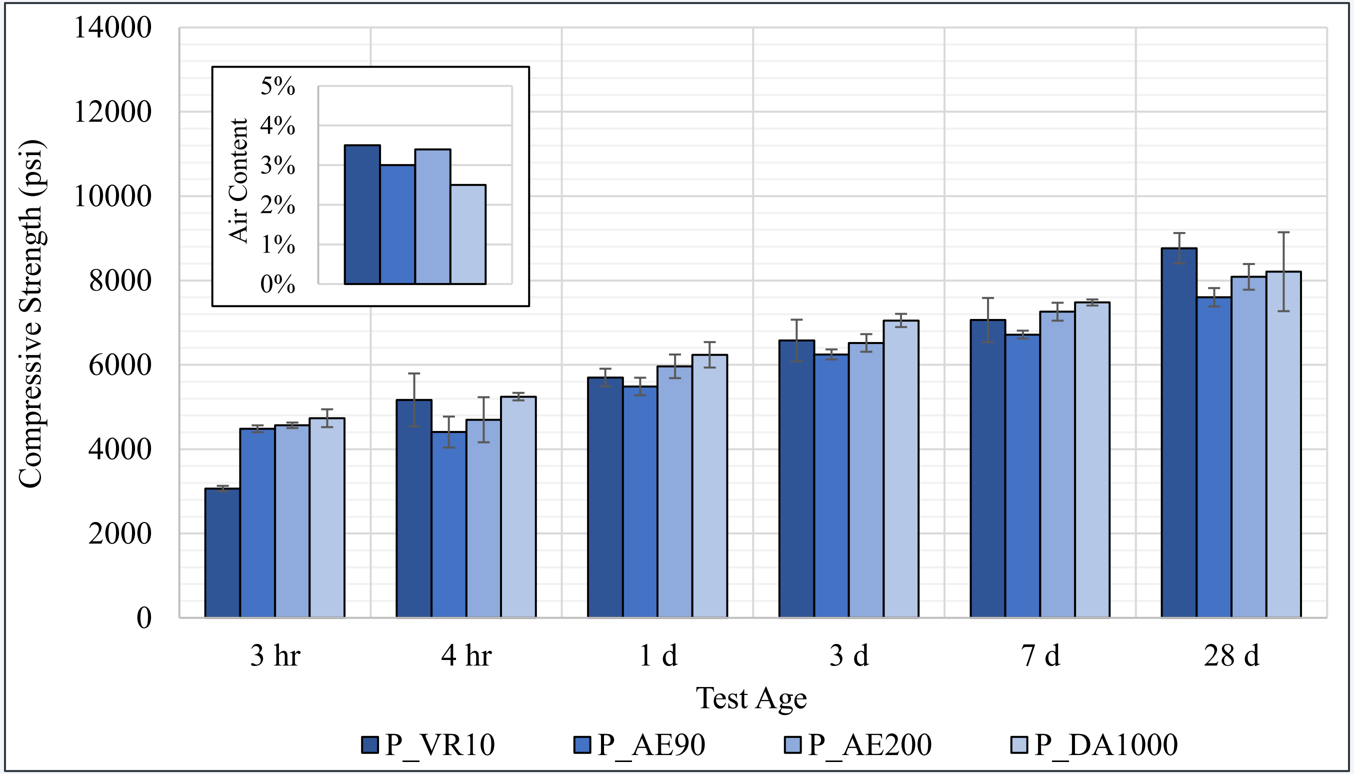


Compressive Strength (psi)
14000
12000
10000
8000
6000
4000
2000
0
Air Content
5%
4%
3%
2%
1%
0%
3 hr
4 hr
1 d
3 d
7 d
28 d
Test Age
P_3/4"
LLP_3/4"
LM_3/4"

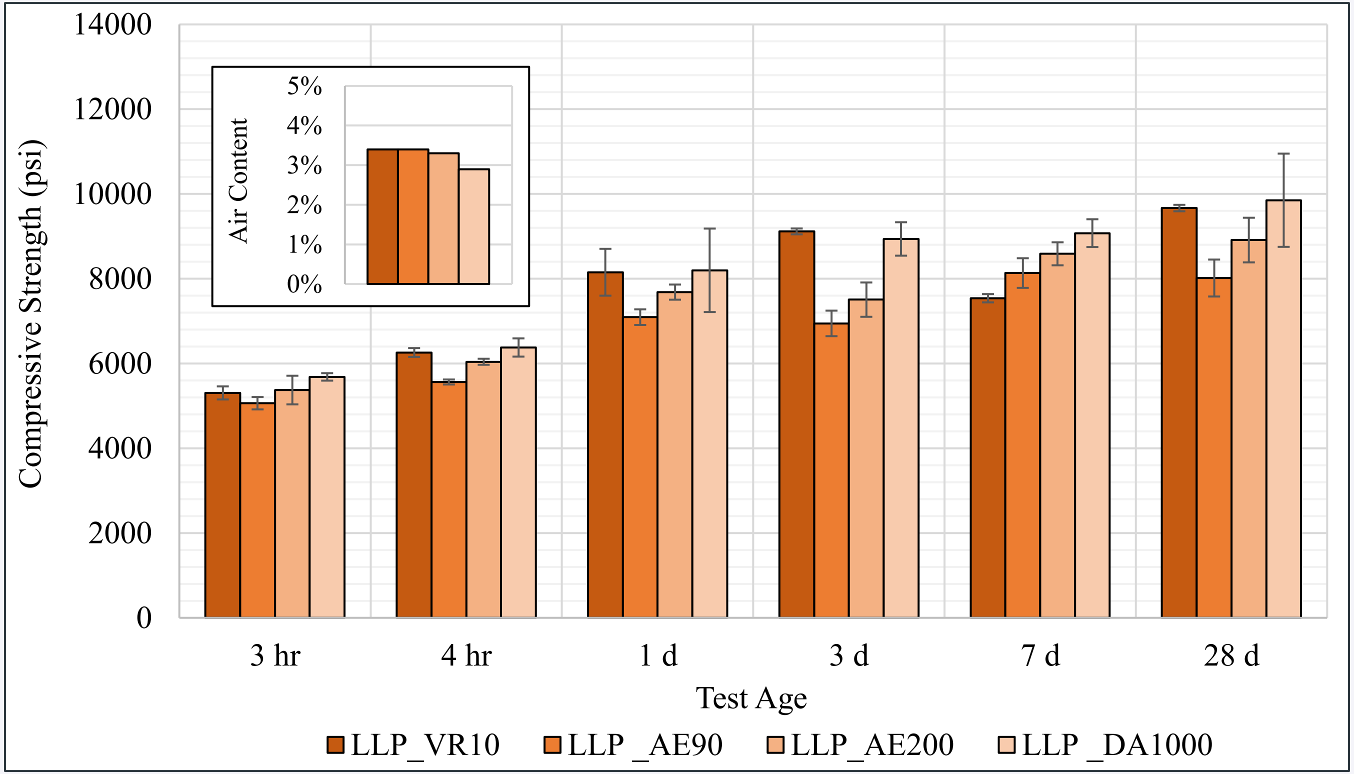
Phase II: AEA Dosage



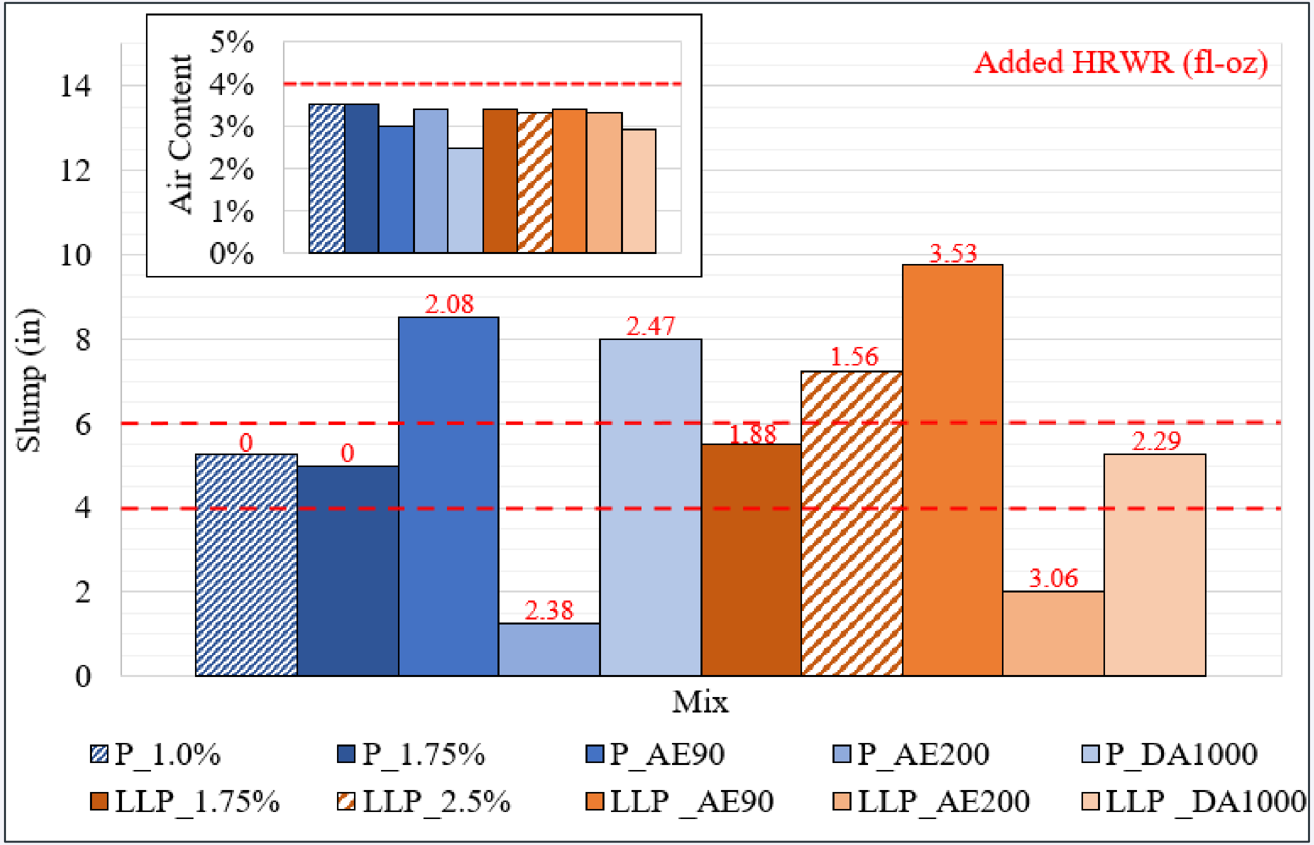
Phase III: CSAP AEA Type



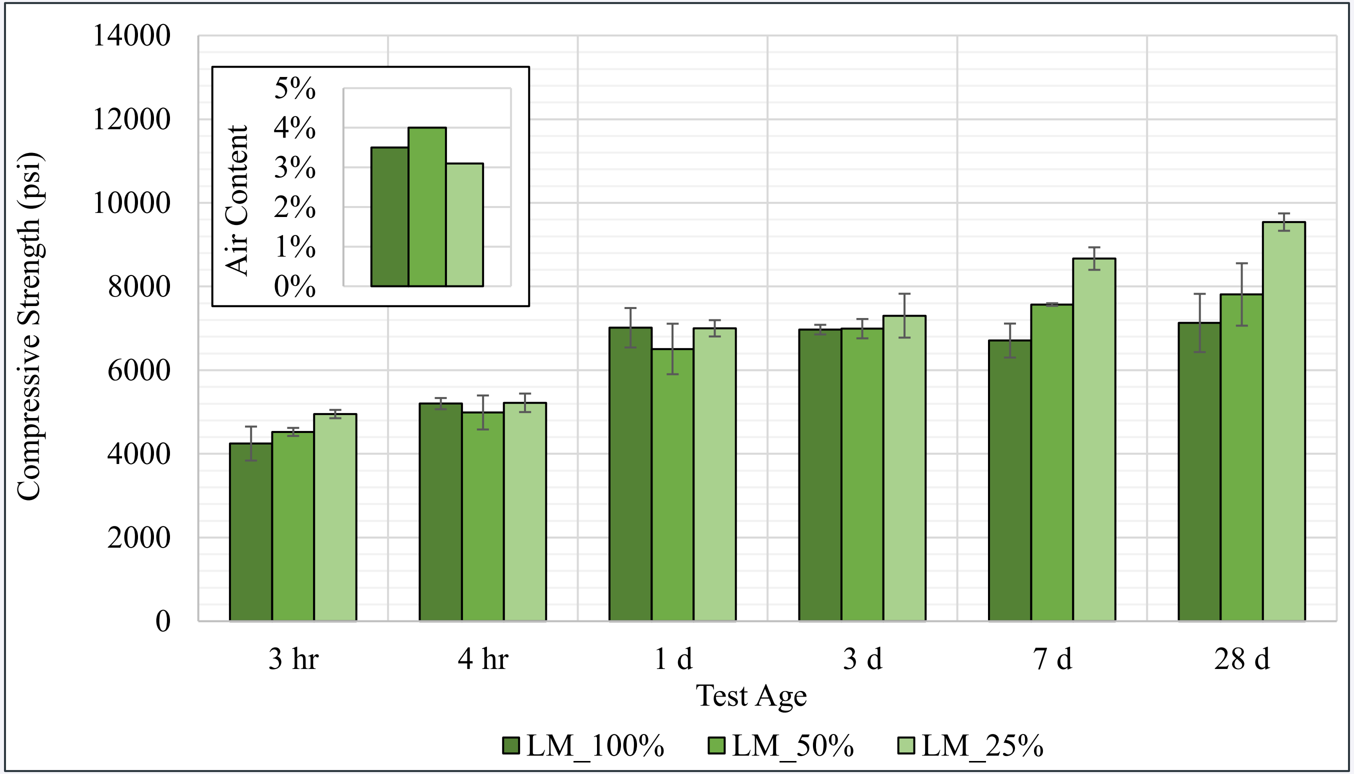
Phase III: LLP AEA Type



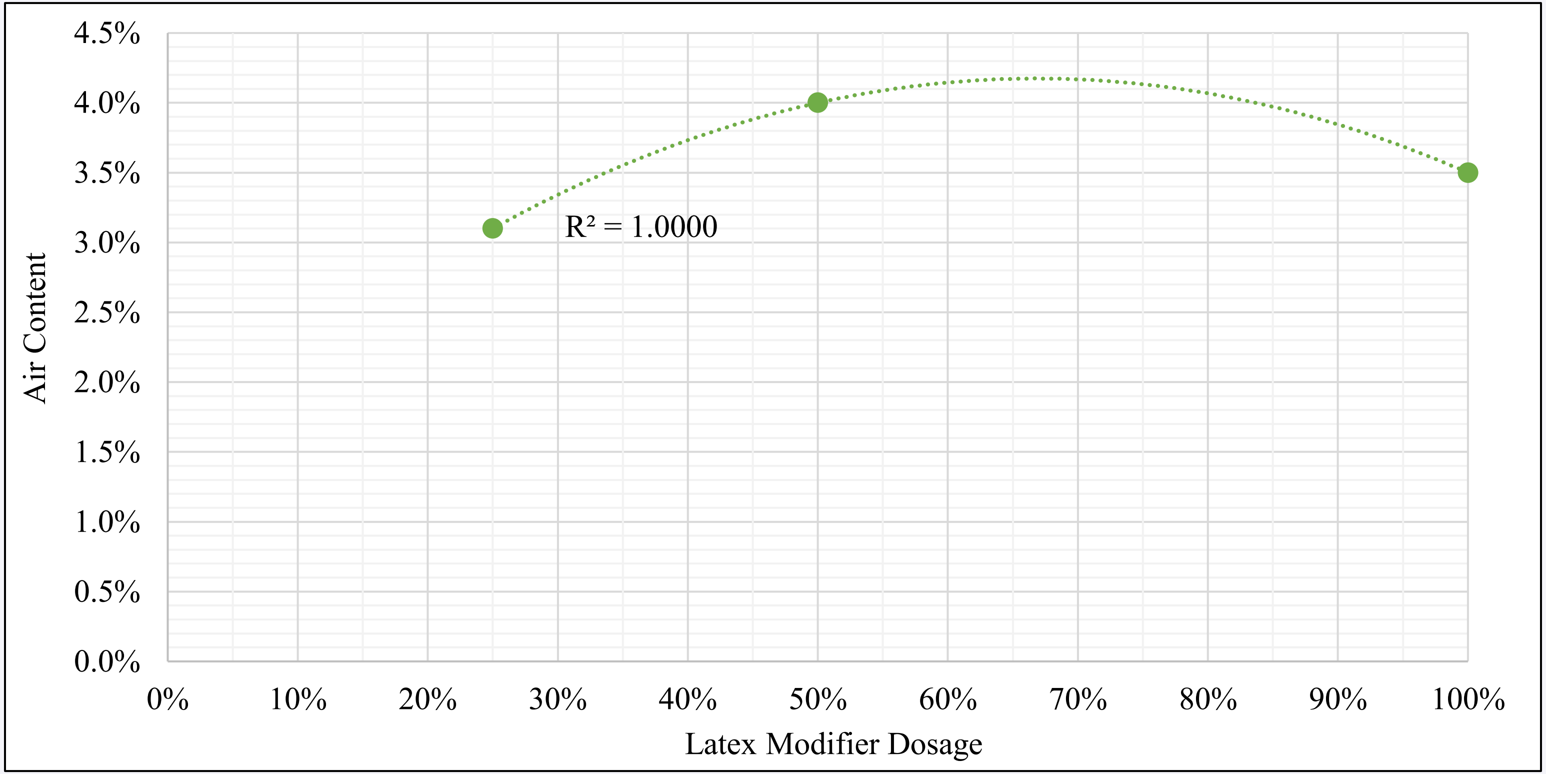
Phase II/III: Workability & Air



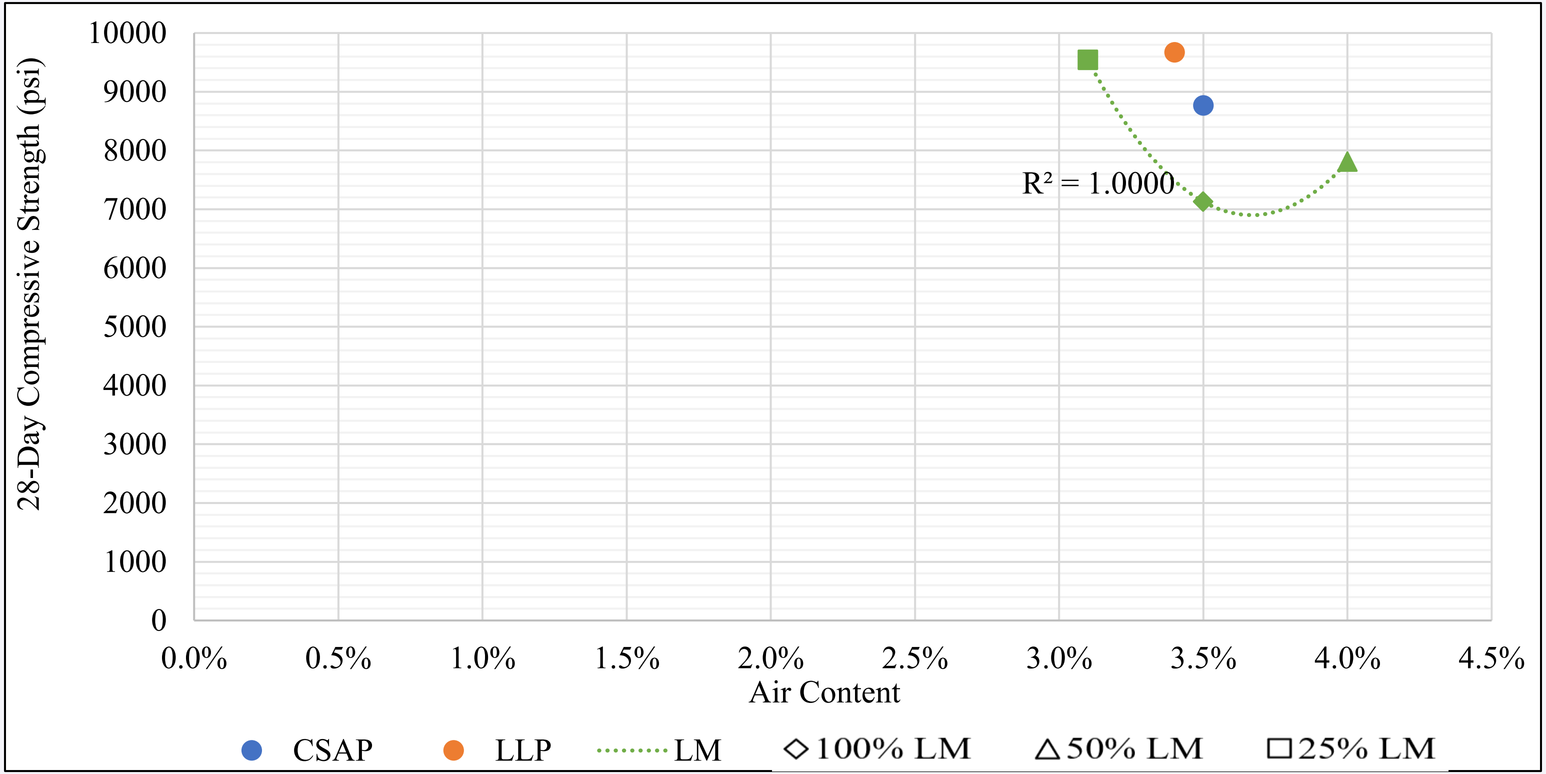
Phase IV: Latex Modifier Dosage



Phase IV: Latex Dosage vs. Air Content



Phase IV: Latex Air Content vs. 28d Strength



Characterization: Summary

Phase I: Aggregates

- Higher FA blends (35/65) ↑ air content, ↓ strength
- Larger NMSA (3/4") ↓ air content but also ↓ strength
- Slightly coarser blends (45/55 vs. 48.9/51.1) improved long-term strength

3/8" NMSA
CA/FA = 48.9/51.1

Phase II & III: AEA Dosage and Type

- Parabolic trend: initial ↑ in air with dosage, then plateau/decline
- Performance varied by formulation, despite similar base
- None of the mixes achieved min. 4% air content target

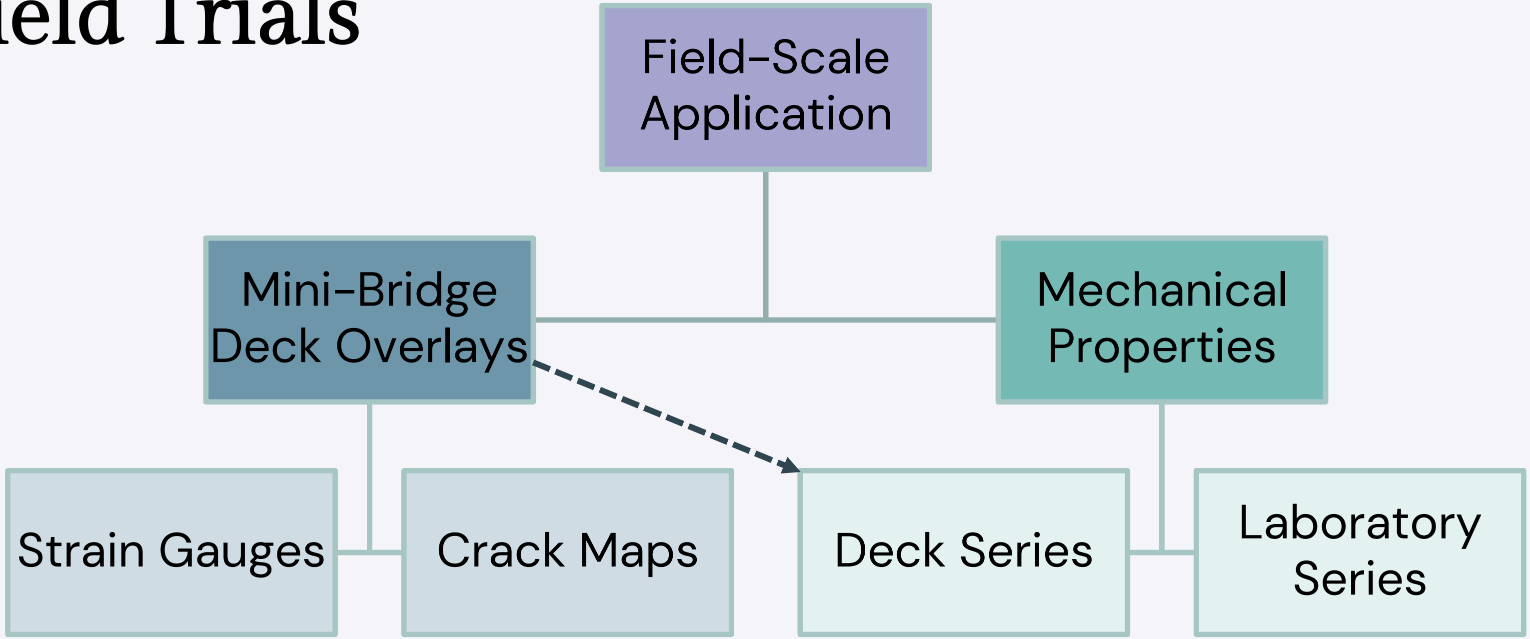
VR10 @ 1.75%

Phase IV: Latex Quantity

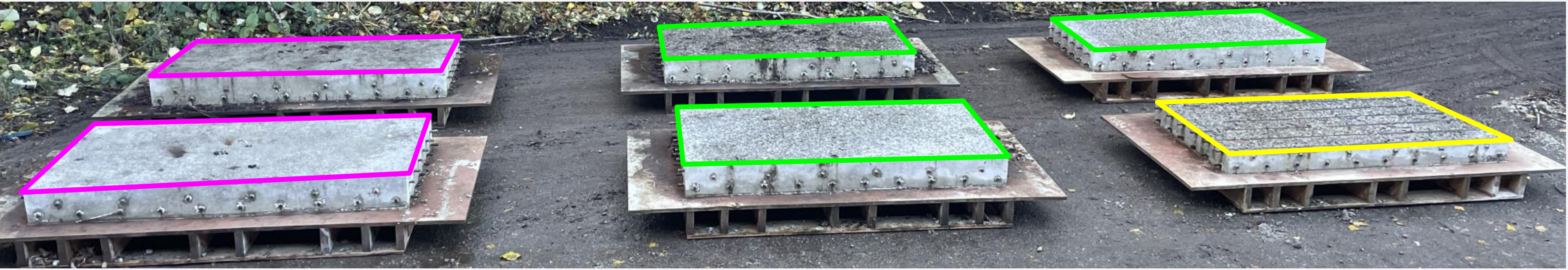
- Strong parabolic relationship with air content and strength
- Air peaked at 50% latex, then declined at 100%
- 25% dosage gave best strength

25% & 100%
Standard

Field Trials



Field Trials: Substrates

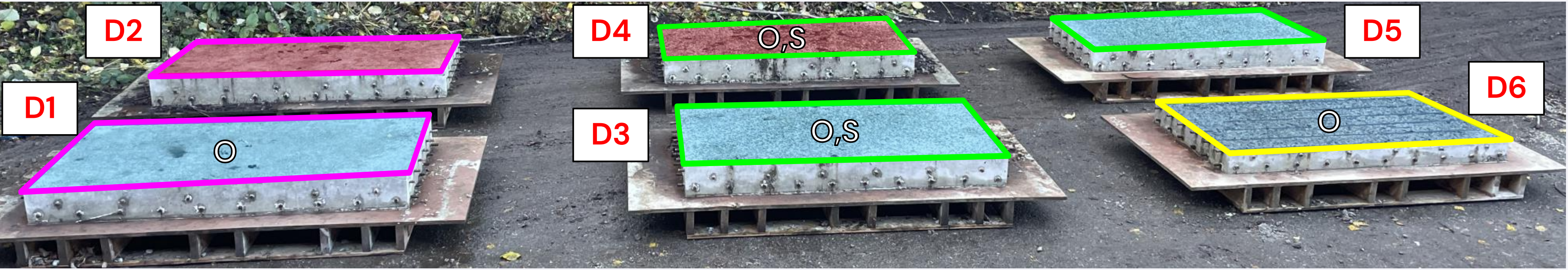


Sandblasted (SB)

Exposed Aggregate (EA)

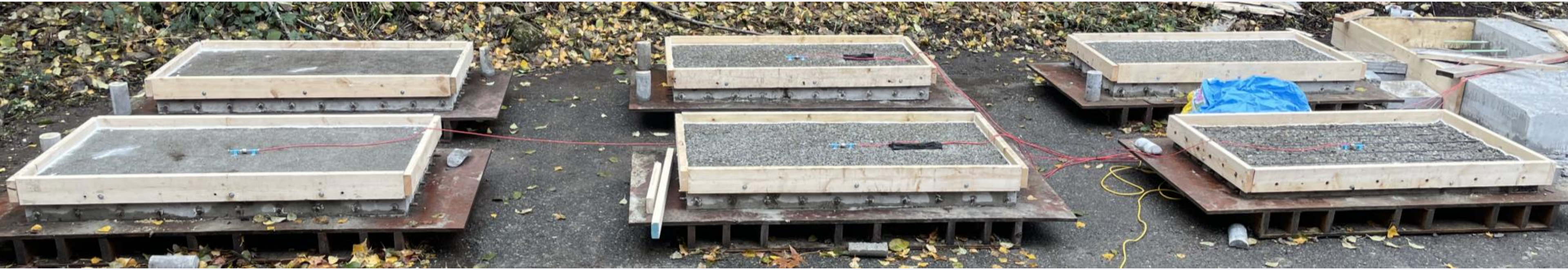
Exposed Aggregate & Rebar (ER)

Field Trials: Overlay Plan

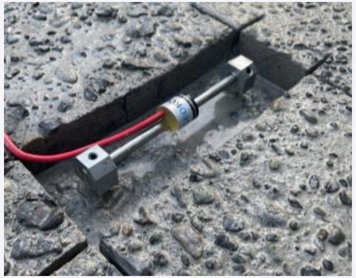


D2_LLP_SB (none)	D4_LLP_EA (Overlay, Substrate)	D6_CSAP_EA (none)
D1_CSAP_SB (Overlay)	D3 _CSAP_EA (Overlay, Substrate)	D5_CSAP_ER (Overlay)

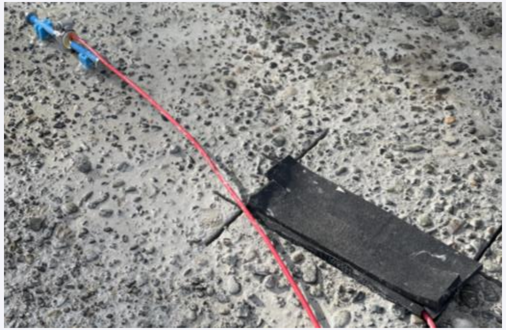
Field Trials: Forms & Strain Gauges



Overlay
Strain Gauge



Substrate
Strain Gauge



Field Trials: Casting

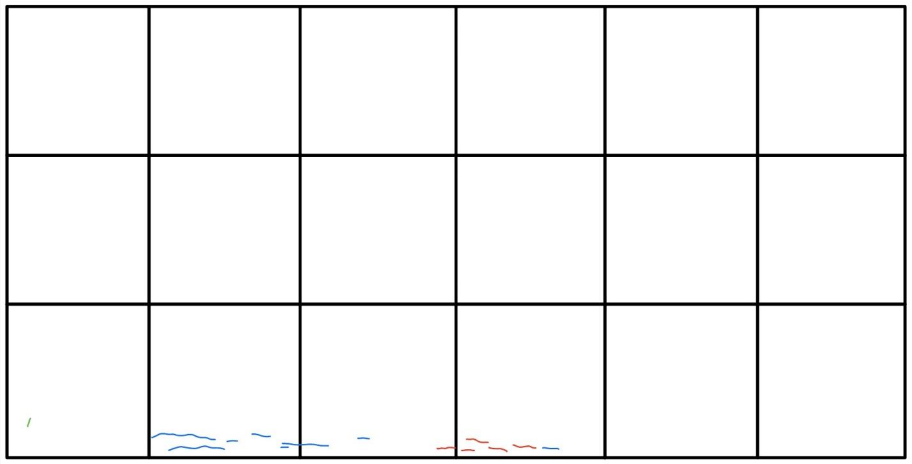
Field Trials: Curing

Field Trials: Mixture IDs for Field/Lab

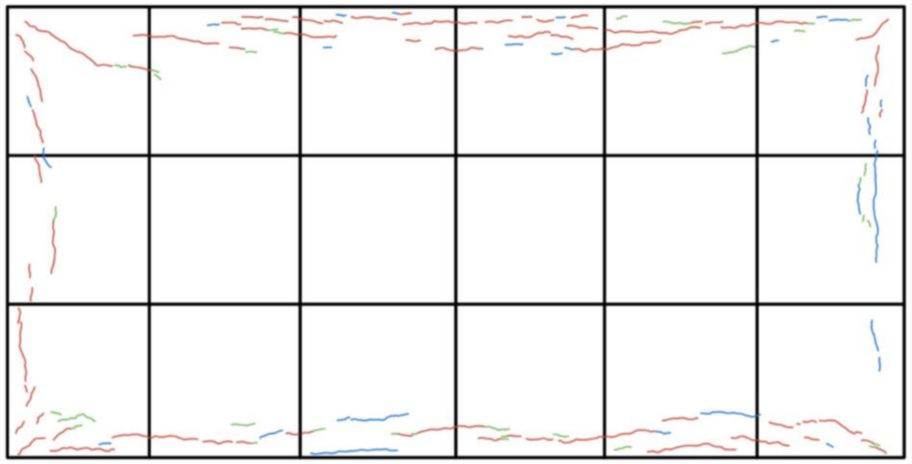
Deck Series	Lab Series
• CSAP_deck • LLP_deck	• CSAP • LLP • LM100 • LM25

Results: Field Trials

Crack Maps



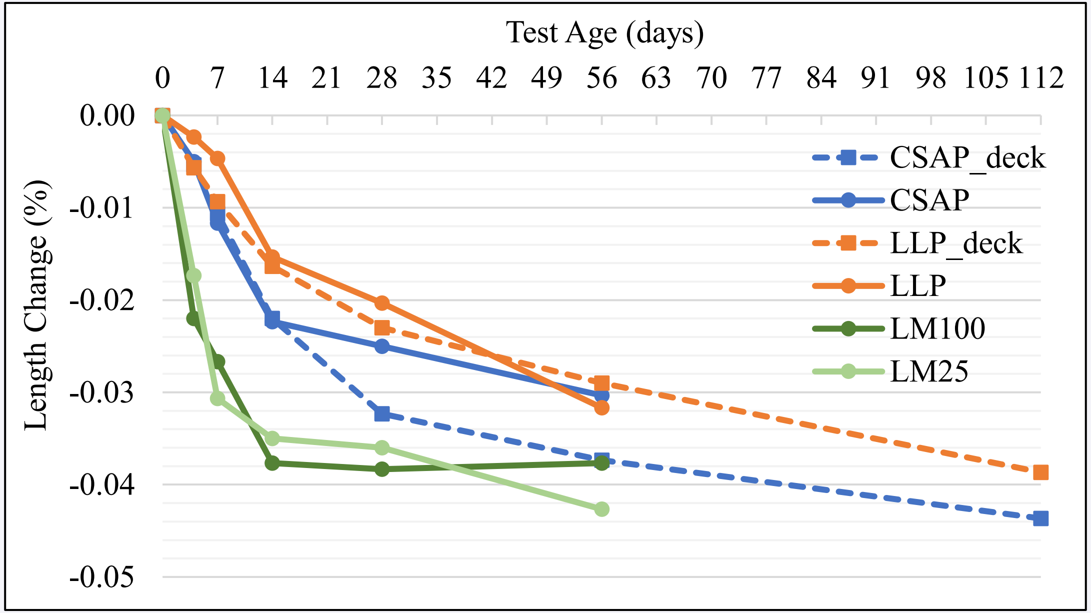
D3_CSAP_EA



D4_LLP_EA

- LLP decks showed more transverse/vertical cracking than CSAP
- CSAP had lower shrinkage and better strain control

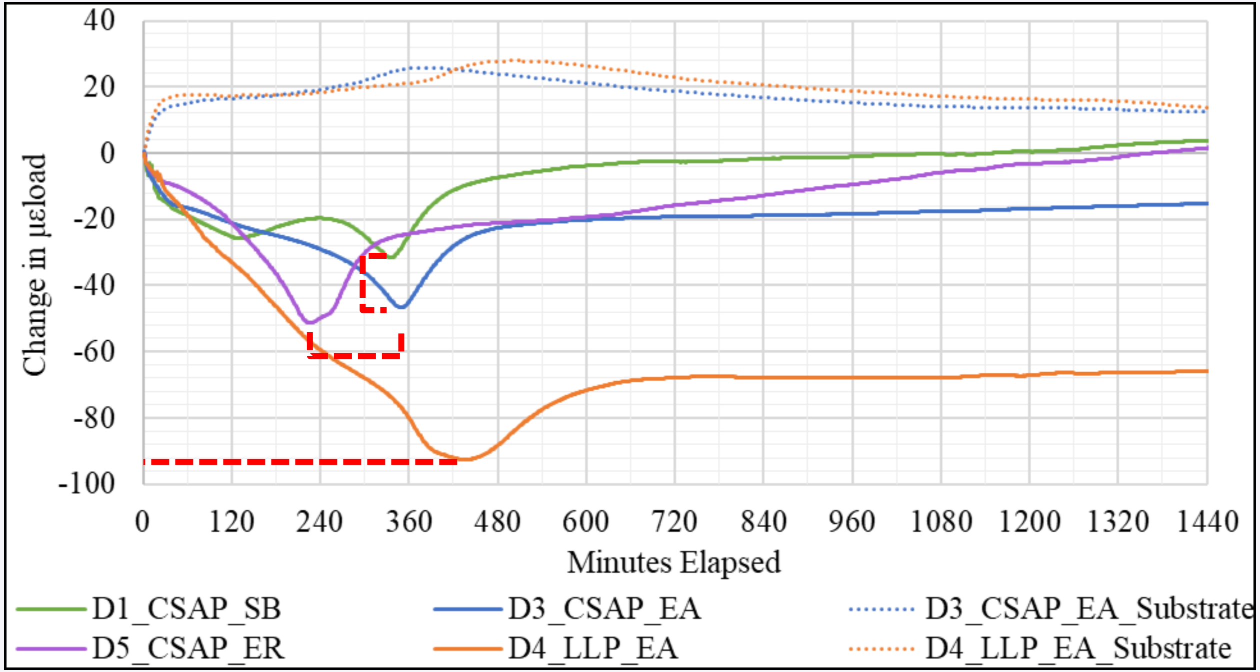
Mech. Properties: Drying Shrinkage



Most DOT specs recommends ≤ 0.06% at 56 days.

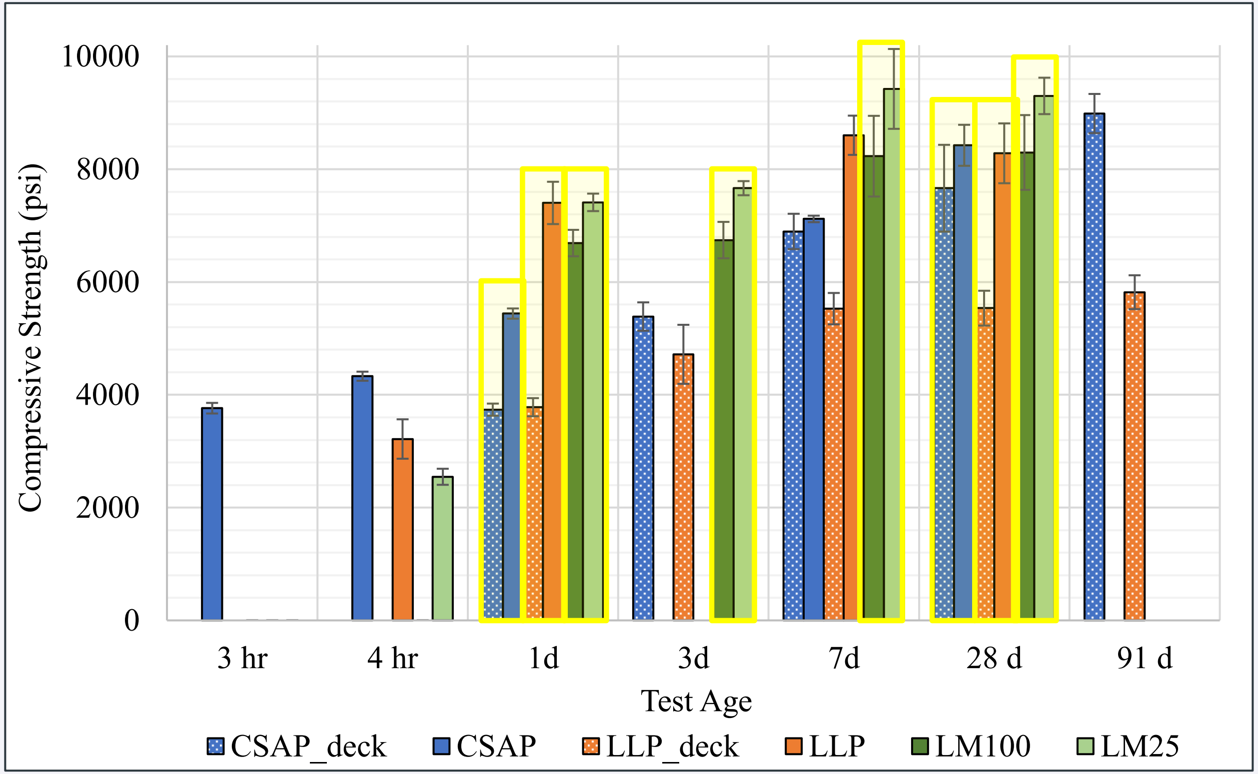
- LM mixes shrank faster at early ages
- Similar shrinkage between deck and lab series up to 2 weeks

Strain Gauges: Early-Age Volume Change



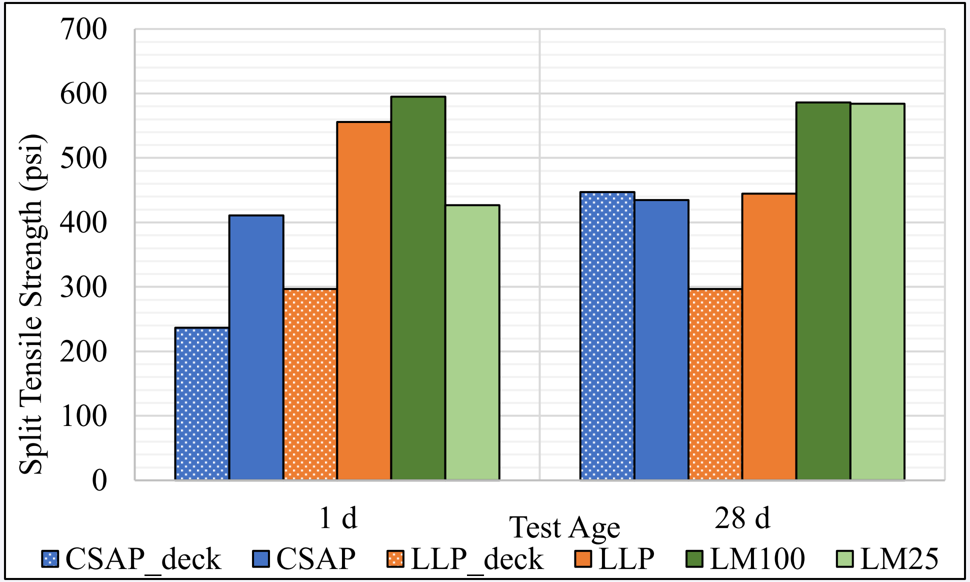
- Significant shrinkage in LLP overlay
- Less shrinkage with SB finish
- Shrinkage rate increased with ER

Mech. Properties: Compressive Strength



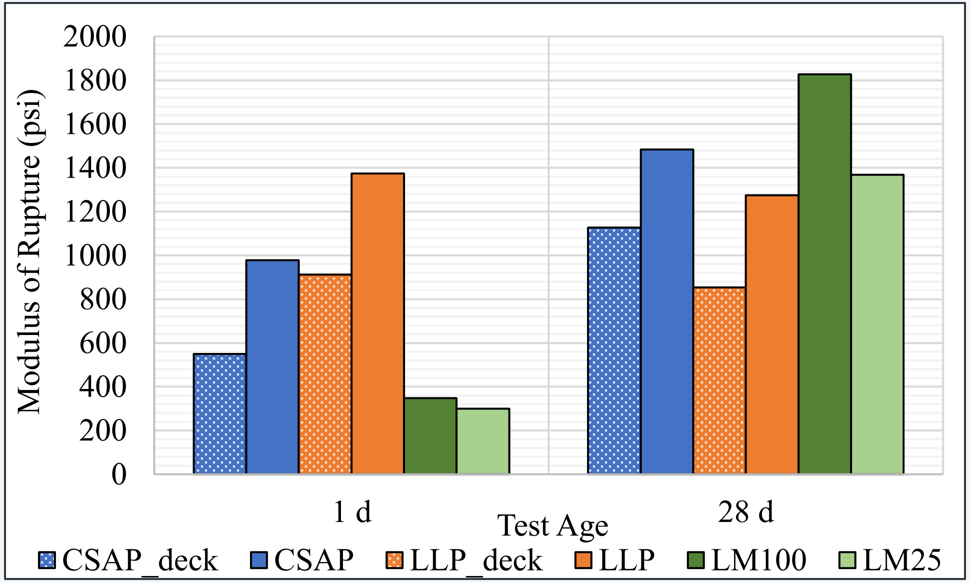
- CSAP_deck delayed strength gain
- LLP_deck strength not recovered
- LM25 consistently stronger than LM100

Mech. Properties: Tensile Strength



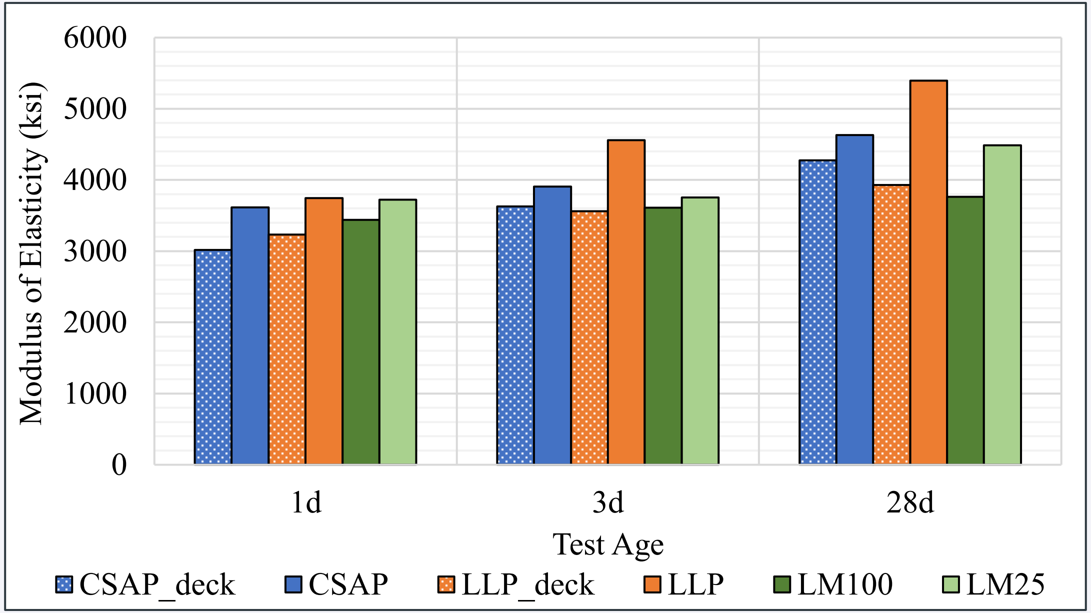
- Similar strength trends for deck series
- LM25 matched LM100 by 28 days

Mech. Properties: Flexural Strength



- Similar strength trends for deck series
- LM100 outperforms LM25

Mech. Properties: Modulus of Elasticity



- All mixes showed increase stiffness
- LM25 showed greater stiffness than LM100

Field Trials: Summary

Crack Maps	More edge cracking in LLP overlays
Strain Gauges	Less shrinkage and better strain stabilization in CSAP overlays
Mechanical Properties	Early-age strength differences between CSAP_deck, LLP_deck, and lab mixes
	LLP_deck showed limited long-term strength gain
	LM25 ≥ LM100 in strength and stiffness, with less shrinkage
	LM mixes shrank more at early-age

Durability

Autogenous Deformation

Plastic Shrinkage

Freeze-Thaw Resistance

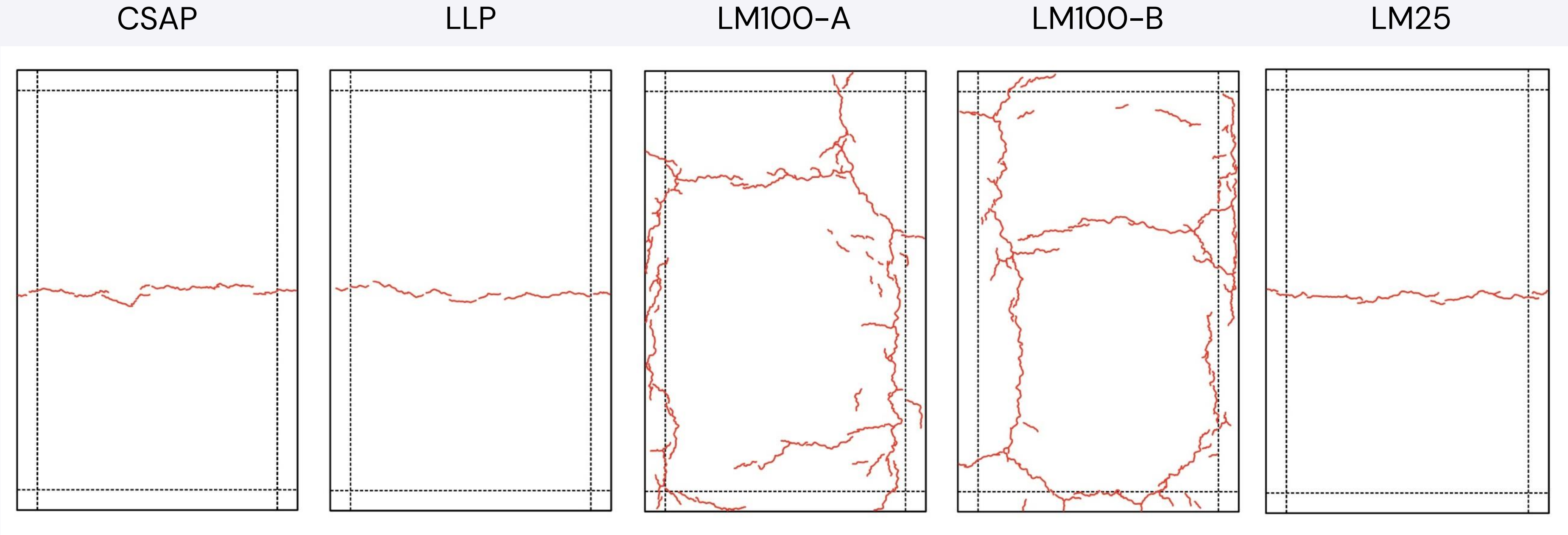
Salt-Scaling Resistance

Slant-Shear Test

Coefficient of Thermal Expansion

Results: Durability

Plastic Shrinkage



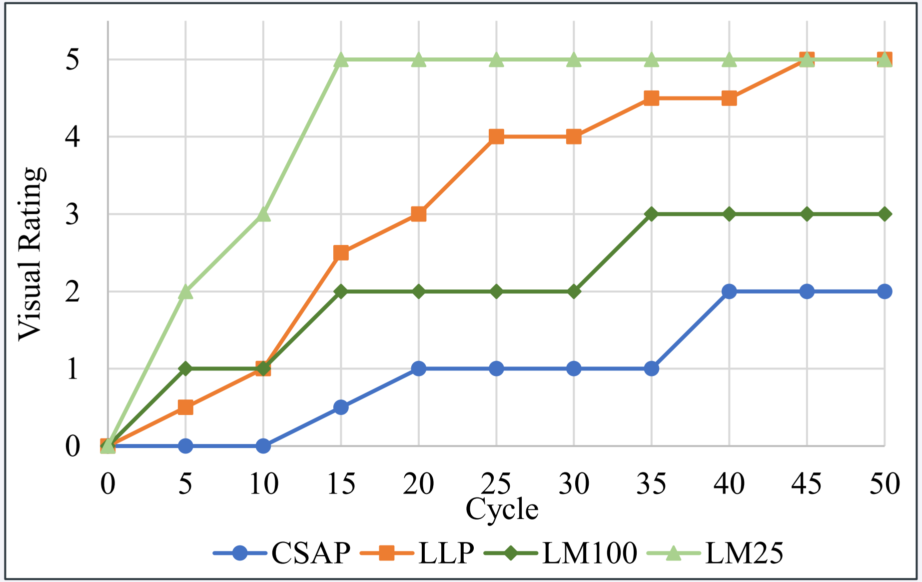
- Significant traverse and vertical cracking in LM100 panels → latex crust
- Crack widths: LM25 > CSAP > LLP
- Agrees with drying shrinkage results

Plastic Shrinkage: Average Crack Width

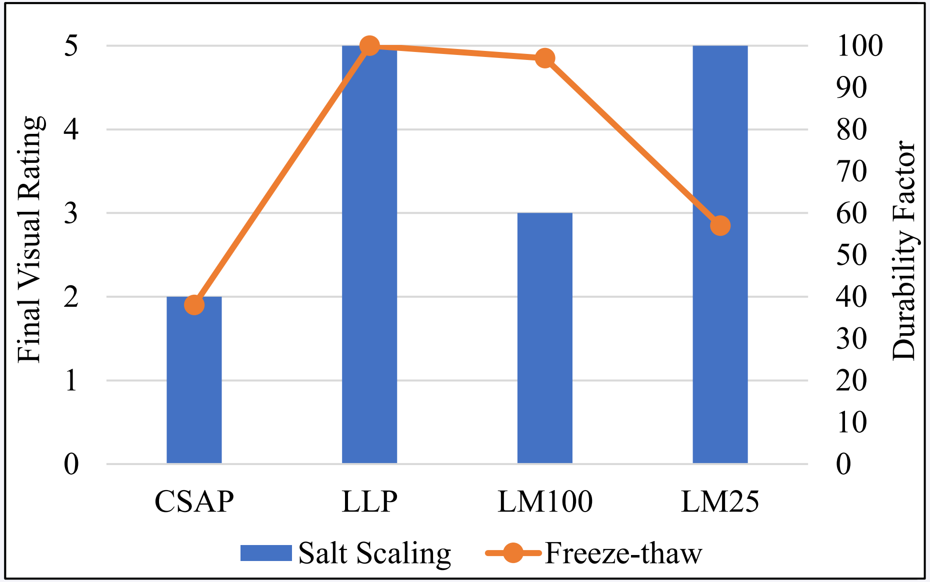
Mixture	Average Crack Width (in)	
	Vertical	Transverse
CSAP	N/A	0.0032
LLP	N/A	0.0025
LM100	0.0427	0.0521
LM25	N/A	0.0078

Freeze-Thaw & Salt-Scaling

Salt-Scaling Visual Ratings



Salt-Scaling vs. Freeze-Thaw Results



- LM mixes followed expected trends
- ↓ in latex, ↓ durability factor, ↓ salt-scaling resistance
- CSAP and LLP showed inverted trends

Durability: Summary

Autogenous Deformation

- Significant variability in CSAP shrinkage
- LLP & LM25 stabilized early

Plastic Shrinkage

- LM100 showed transverse and vertical cracking
- LLP showed smaller crack widths than CSAP

Freeze-Thaw Resistance

- CSAP and LM25 dropped below the 60% RDME threshold = not durable

Salt-Scaling Resistance

- CSAP performed the best
- LM100 outperformed LM25

Slant-Shear Test

- Steeper angles, ↑ bond strength
- LLP showed no bond failures compared to CSAP

- Variability in CSAP performance
- LLP durability results contrasted Field Trial results
- Decrease in Latex resulted in reduced durability

Conclusions

Key Findings

- AEA and latex dosage parabolic trends
    - Mixes did not achieve min. 4% air content target; but close enough
- Potential but contrasting performance of CSAP and LLP
    - CSAP: better volume stability, but variable durability
    - LLP: significant cracking and limited strength, but good durability
- LM25 better or similar mechanical properties
- LM100 greater durability

Significance

- Advanced understanding of polymer-modified BCSA cement
- Identified AEA-polymer interaction dilemma
- Bridged the gap between lab work and field application
- Revealed critical lab-field performance discrepancies
- Enhanced understanding of dimensional stability of CSA systems

Thank You!

Questions?

CENTER FOR EDUCATION AND RESEARCH IN CONSTRUCTION

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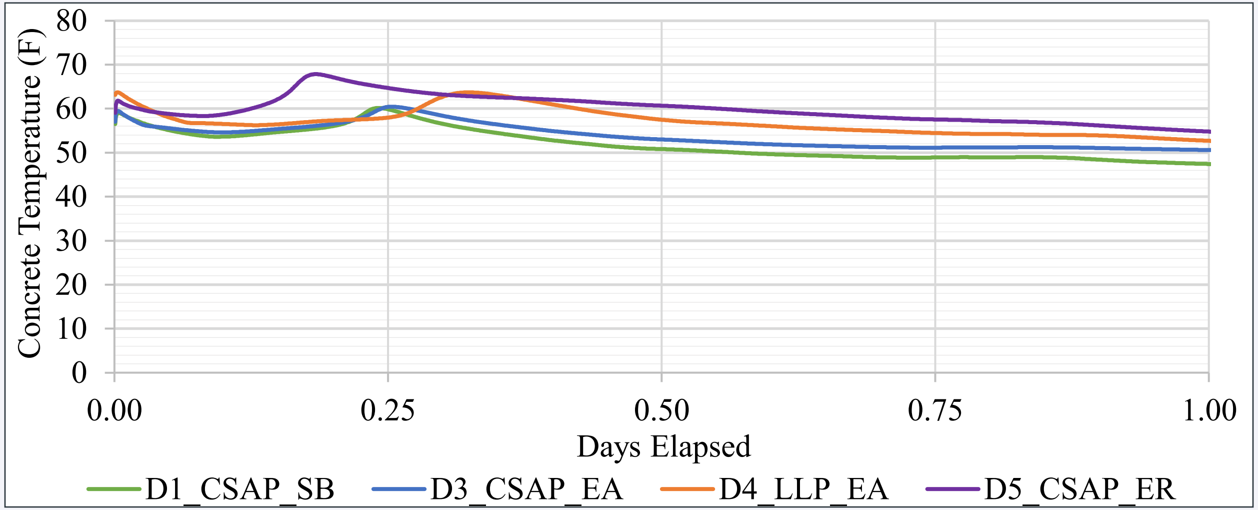
Appendix: Characterization

Appendix: Field Trials

Field-Scale Testing: Fresh Properties

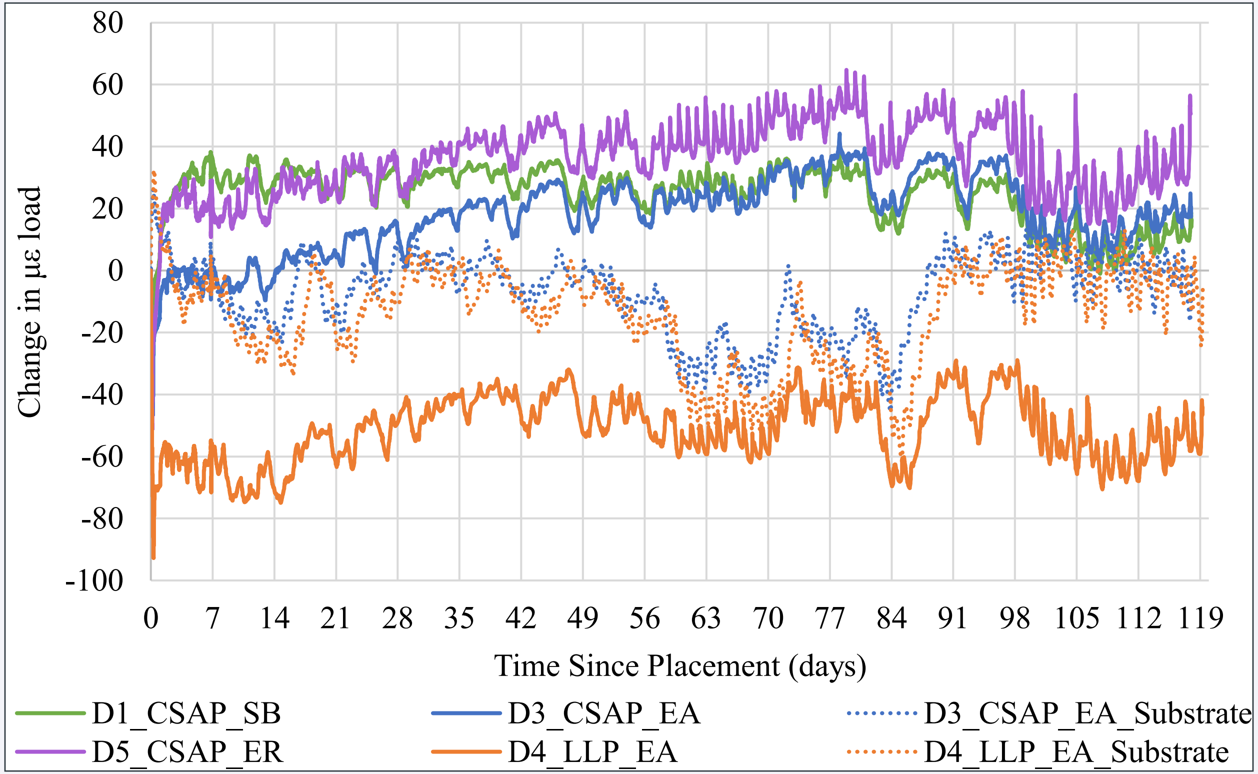
Mixture	Temperature (F)	Air Content (%)	Slump (in)	Unit Weight (pcf)
CSAP_deck	62	4.5	8.50	N/A
LLP_deck	62	4.0	4.75	N/A
CSAP	65	4.0	9.50	149.2
LLP	67	5.7	7.50	147.2
LM100	63	3.1	9.25	148.0
LM25	67	3.1	6.50	146.8

Field-Scale Testing: Fresh Properties



Deck	Max (F)	Min (F)	ΔT (F)	1-Day (F)
D1_CSAP_SB	60.16	53.62	6.54	48.99
D3_CSAP_EA	60.45	54.62	5.83	51.22
D4_LLP_EA	63.72	56.24	7.48	54.05
D5_CSAP_ER	67.84	58.34	9.51	57.05

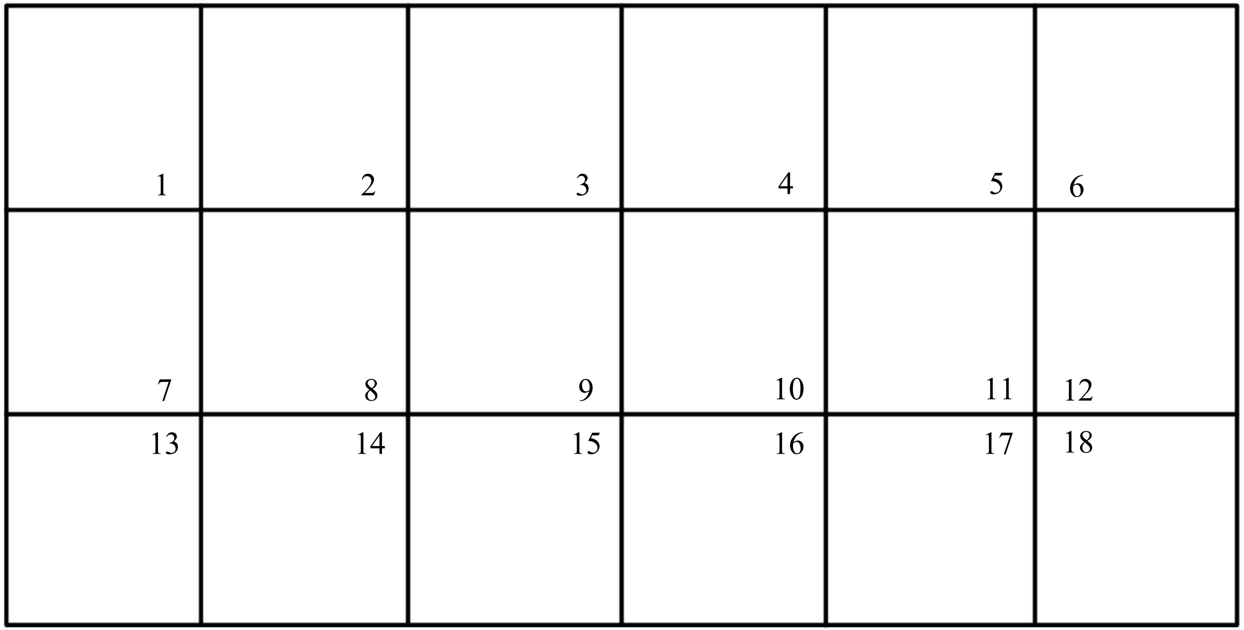
Strain Gauges: Long-Term Volume Change



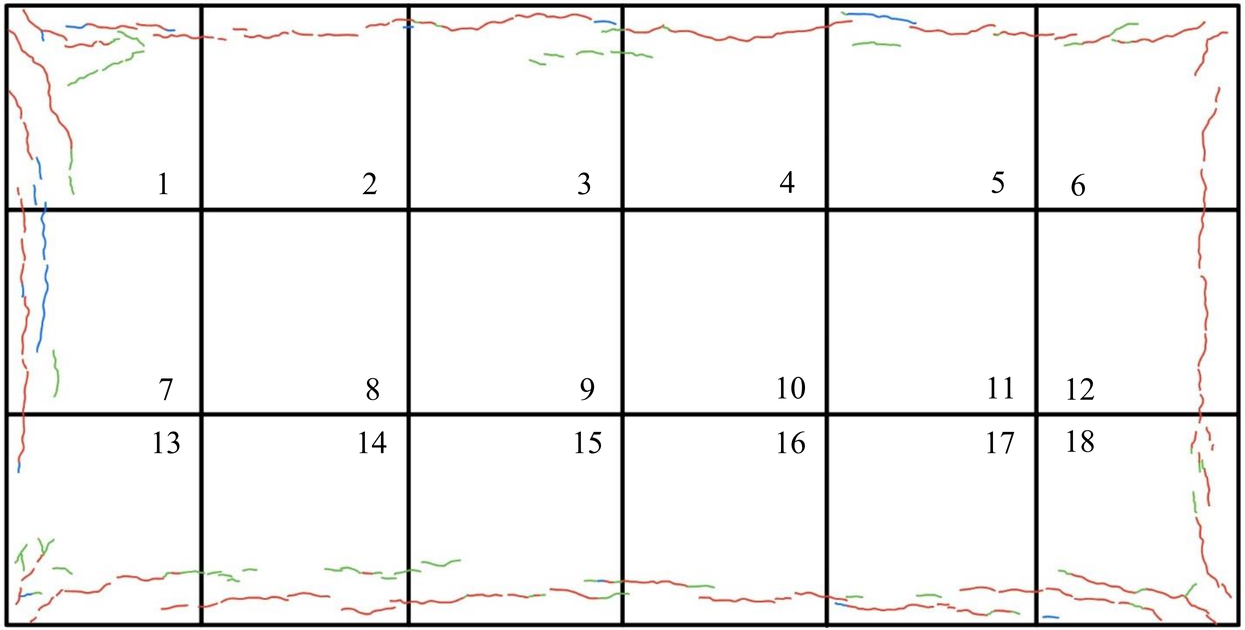
Crack Maps: 1st Assessment Crack Data

Deck ID	Total Crack Count		Average Crack Width (in)	
	Vertical	Transverse	Vertical	Transverse
D1_CSAP_SB	0	0	N/A	N/A
D2_LLP_SB	10	5	0.005	0.004
D3_CSAP_EA	1	0	0.004	N/A
D4_LLP_EA	14	4	0.004	0.005
D5_CSAP_ER	1	0	0.004	N/A
D6_CSAP_EA	0	2	0.004	0.004

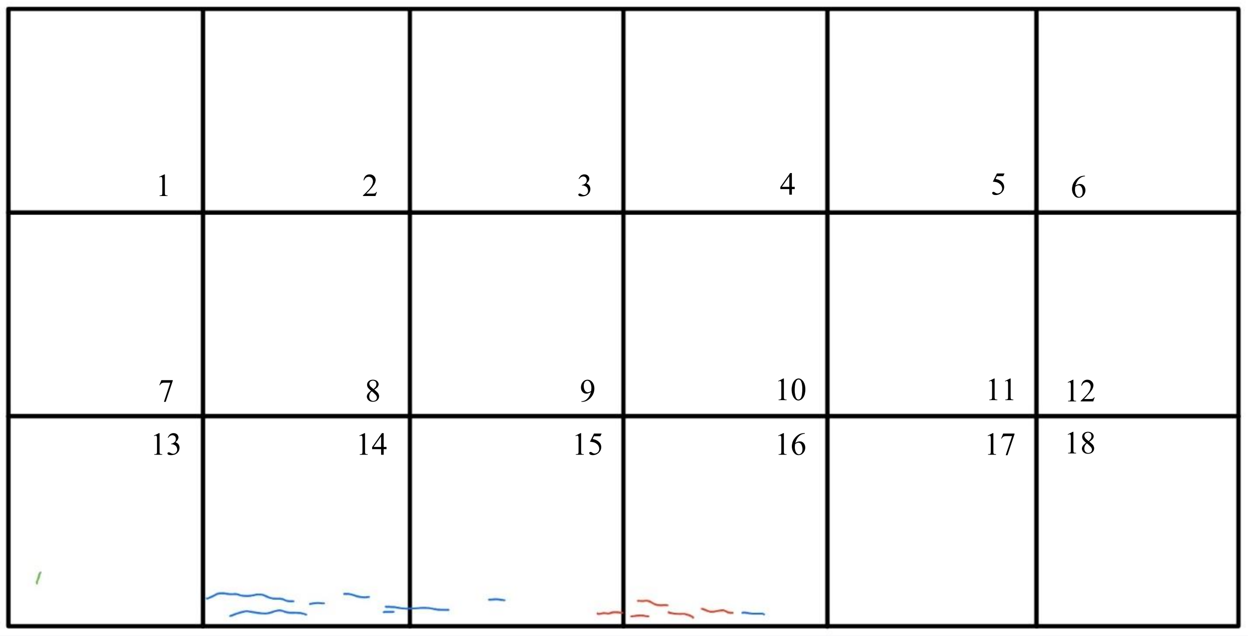
Crack Maps: Deck 1 — Sandblasted, CSAP



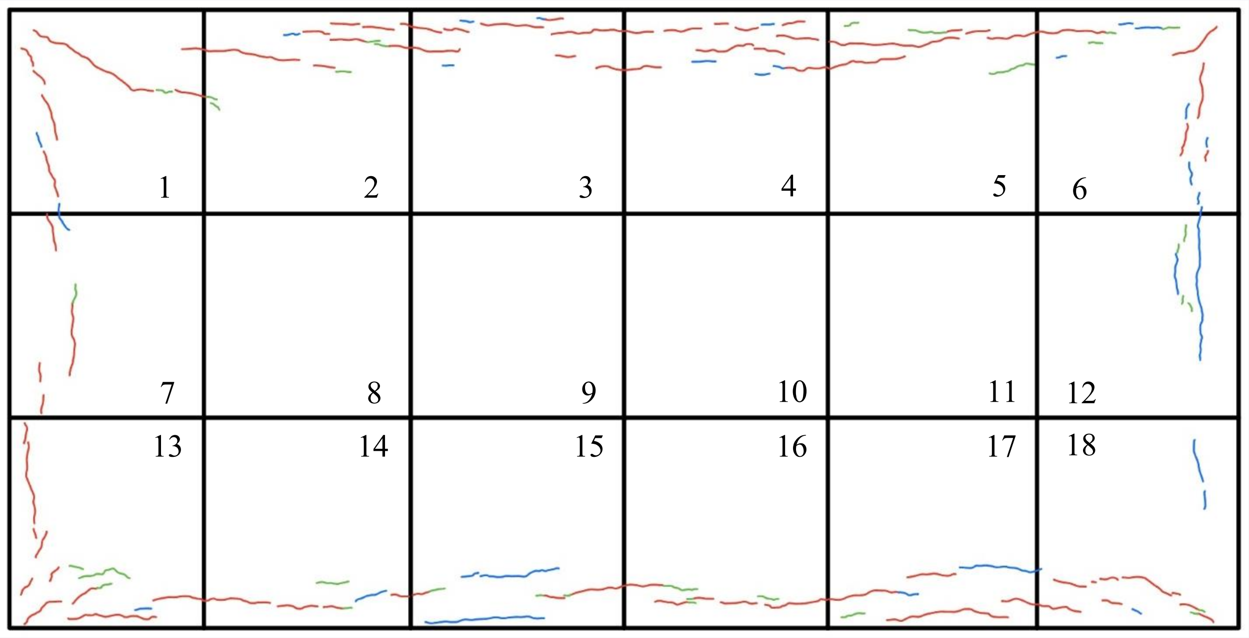
Crack Maps: Deck 2 — Sandblasted, LLP



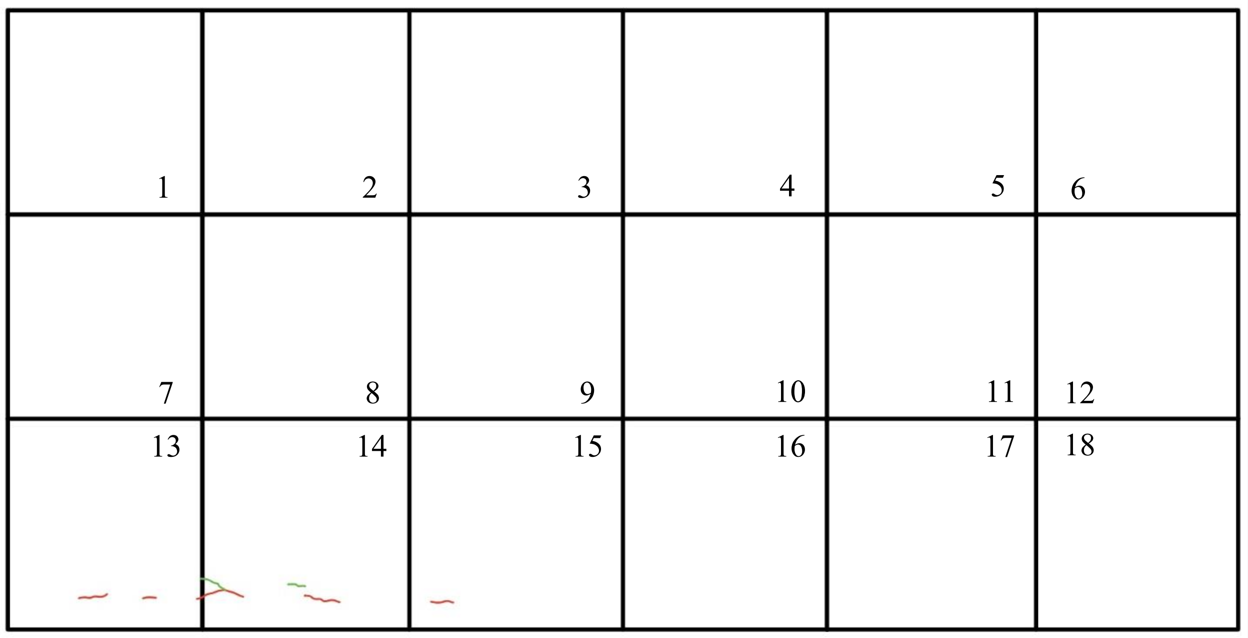
Crack Maps: Deck 3 — Exposed Aggregate, CSAP



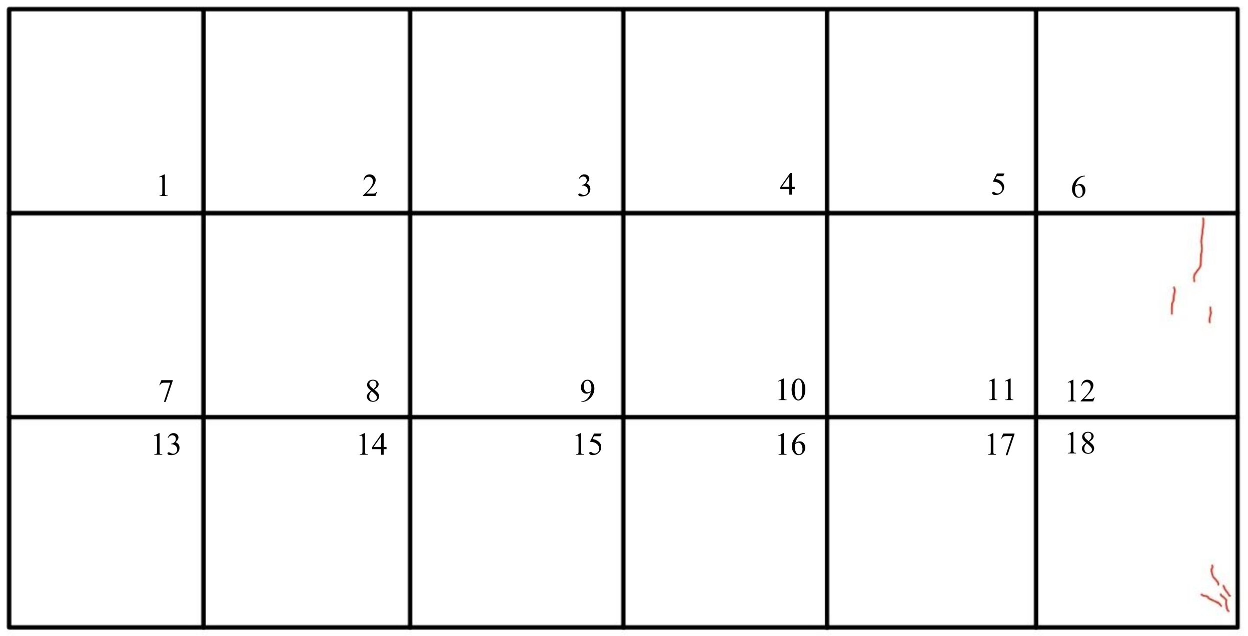
Crack Maps: Deck 1 — Exposed Aggregate, LLP



Crack Maps: Deck 1 — Exposed Rebar, CSAP

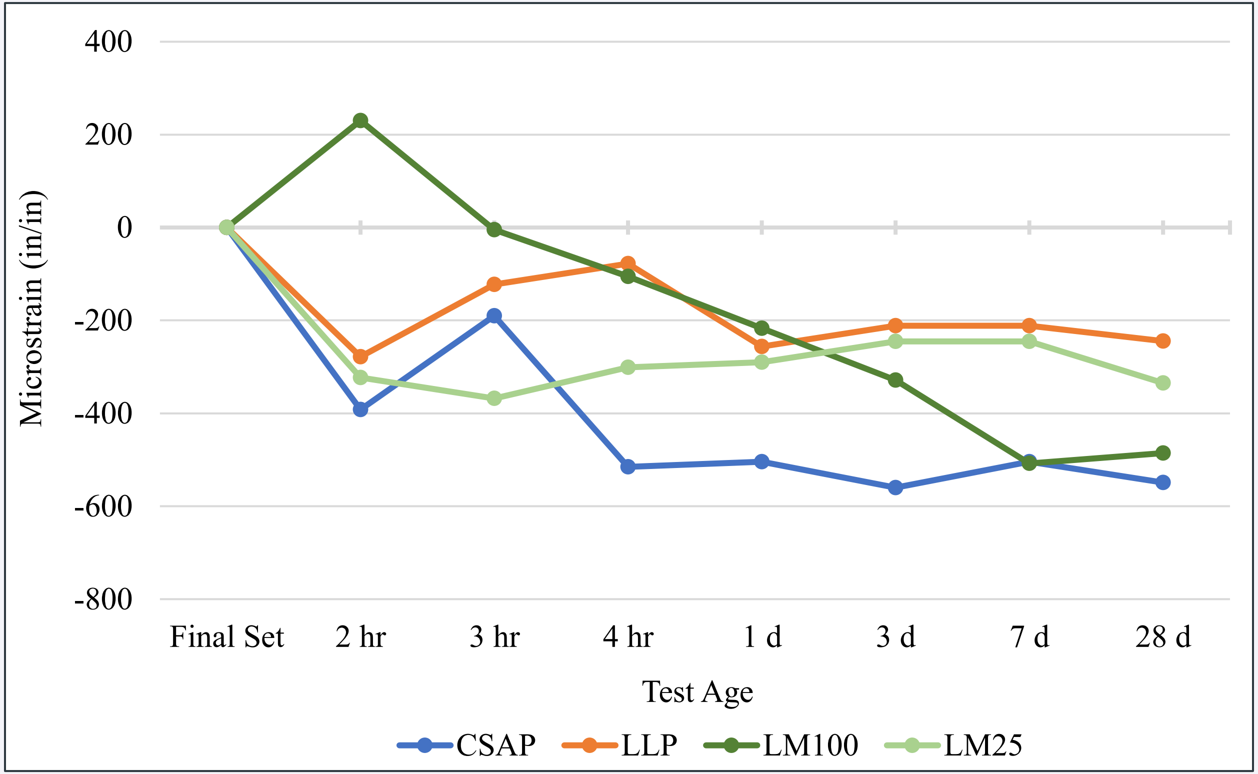


Crack Maps: Deck 1 — Exposed Aggregate, CSAP

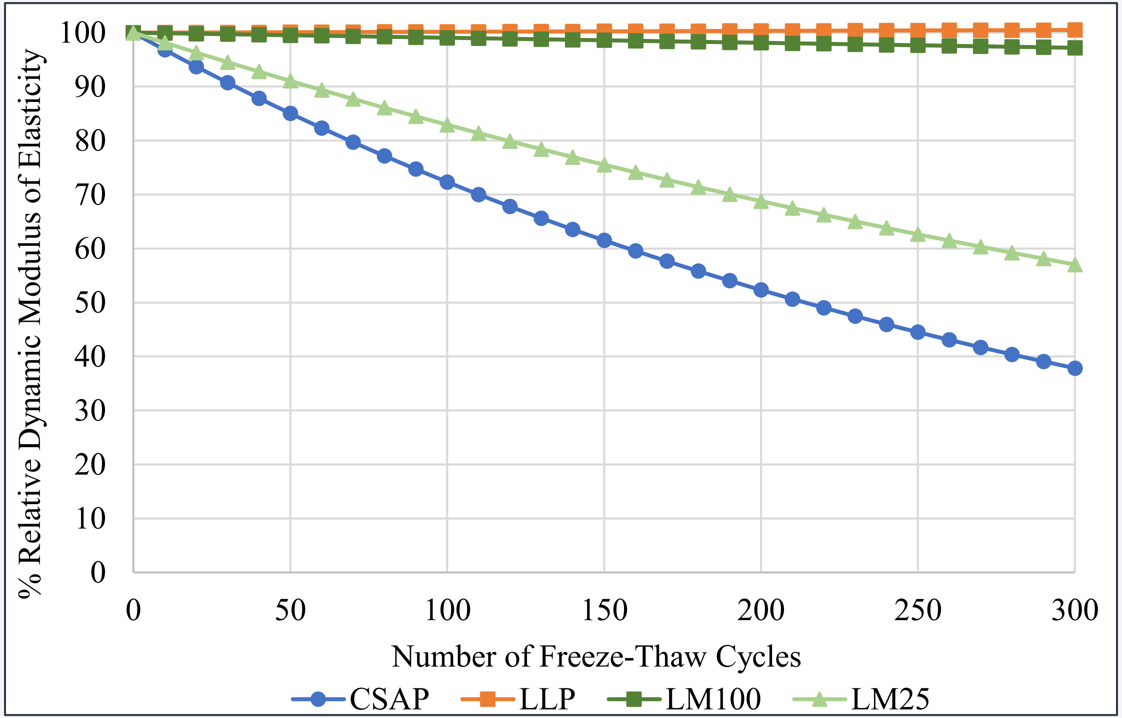


Appendix: Durability

Autogenous Deformation: 23C Mortar



Freeze-Thaw: %RDME and DF

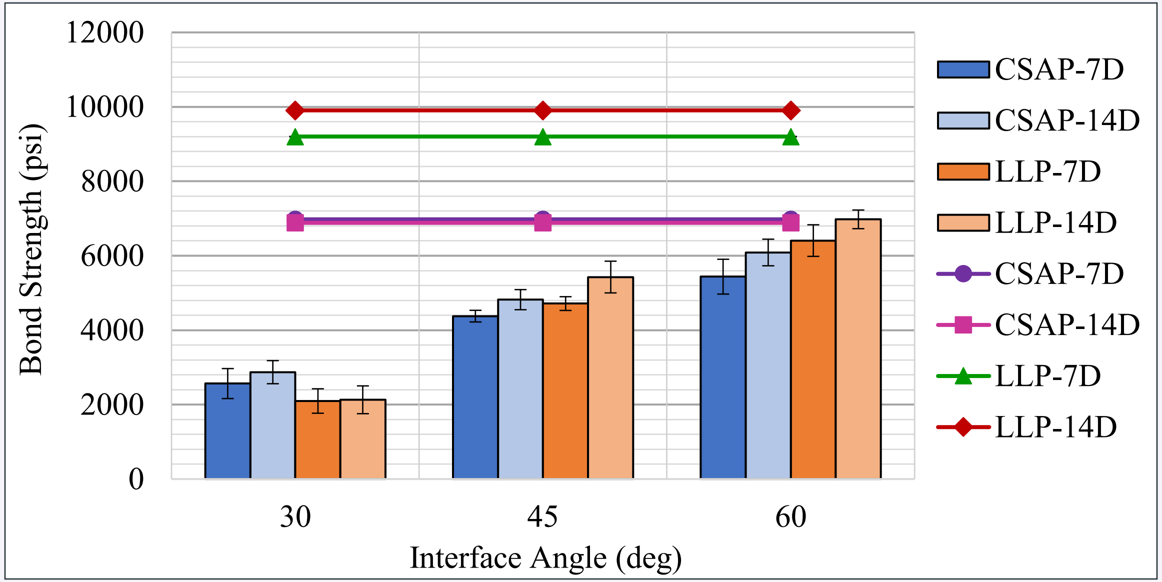


Mixture	% RDME	Durability Factor
CSAP	37.9	38
LLP	100.5	100
LM100	97.2	97
LM25	57.1	57

Durability: Slant-Shear Test

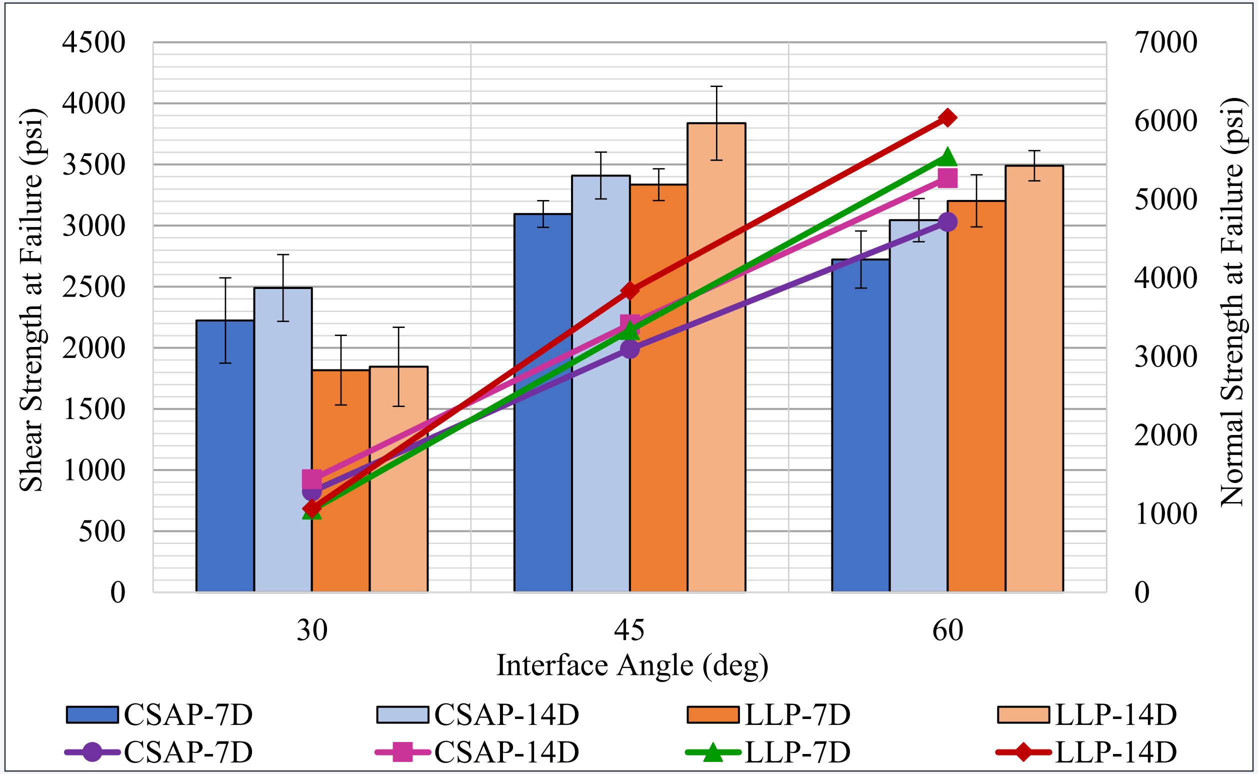
- Bond strength of overlay and substrate
- Includes shear and compressive stress
- 30°, 45°, and 60° interfaces
- Only CSAP and LLP tested

Slant-Shear Test

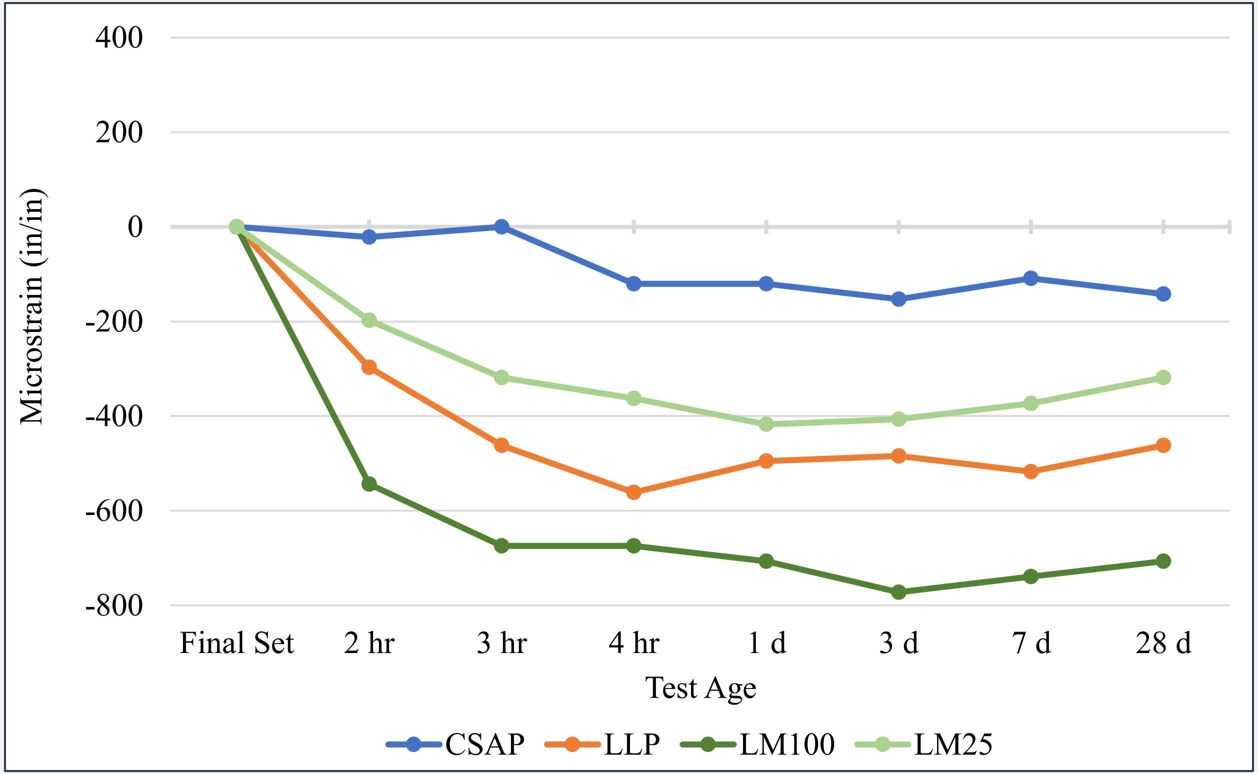


- ↑ angle = ↑ bond strength
- 28% of CSAP overlays failed
- No LLP overlay failures

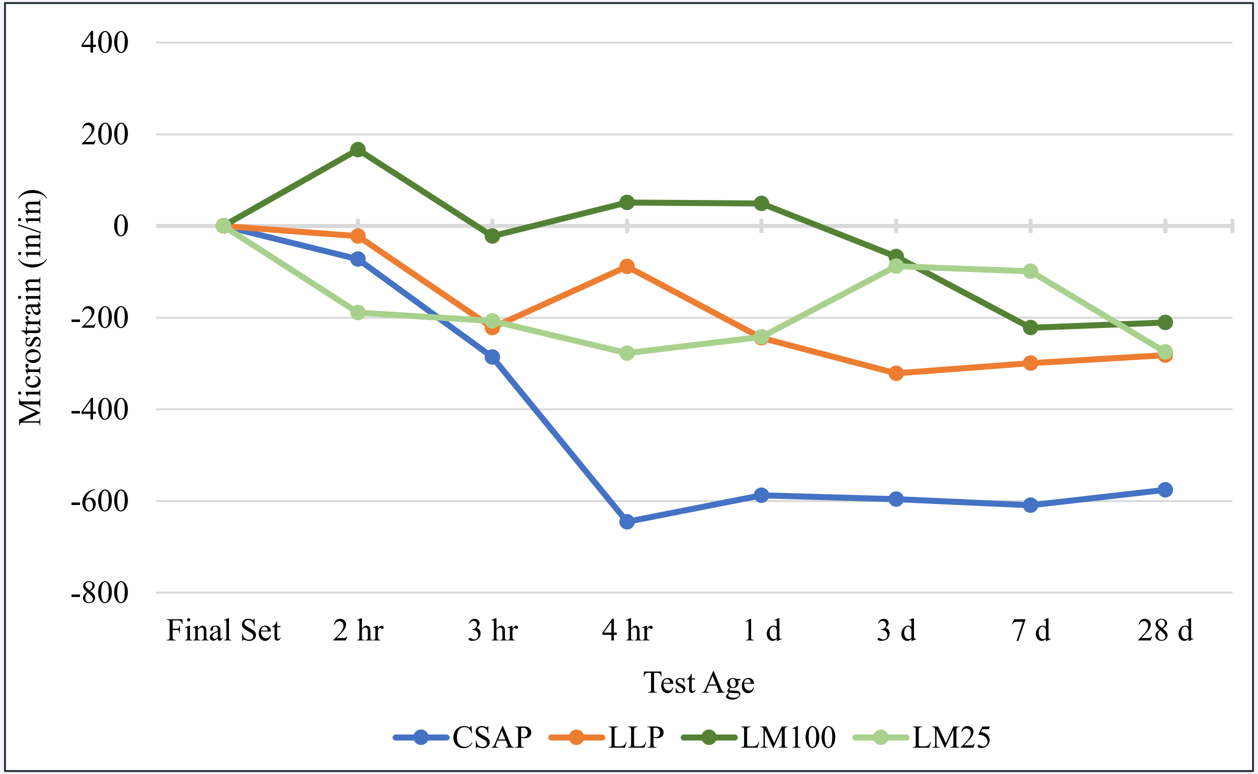
Slant-Shear Test: Shear and Normal Strengths



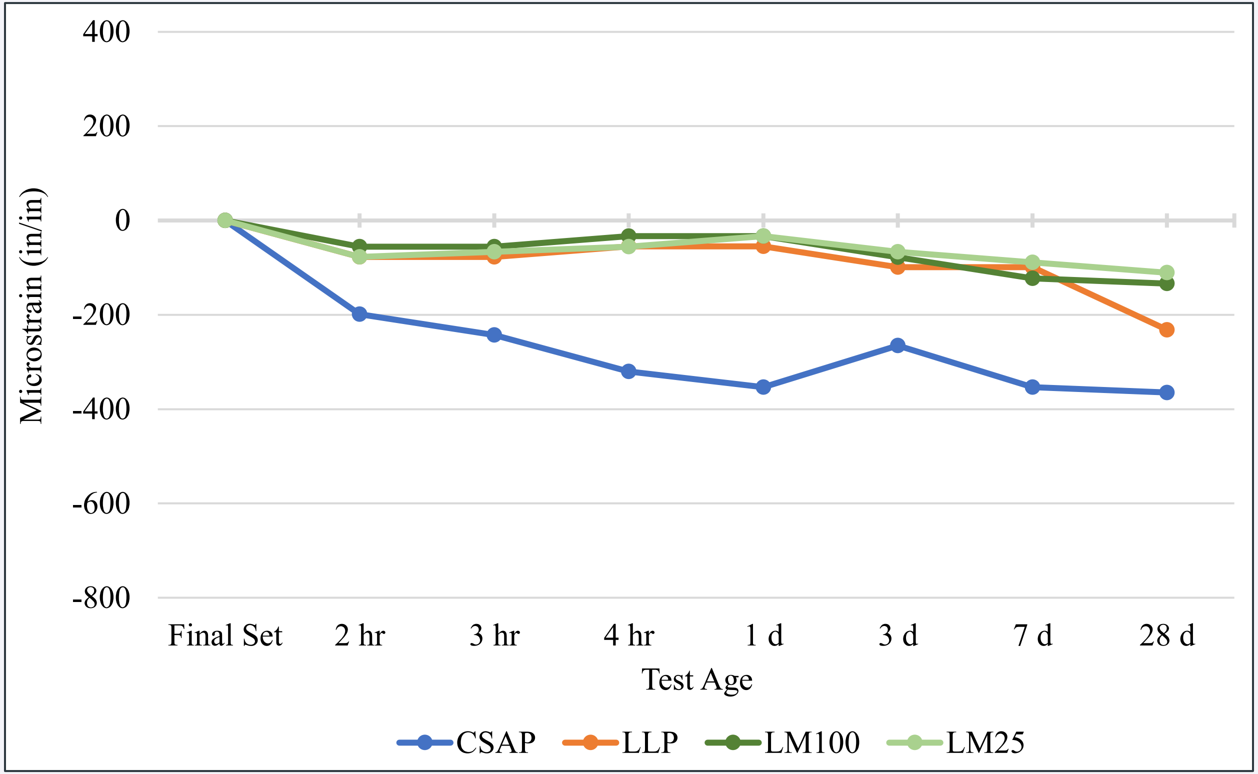
Autogenous Deformation: 23C Paste



Autogenous Deformation: 10C Paste



Autogenous Deformation: 35C Paste



Future Work

AEA-Polymer Interaction Mechanism	Powdered vs. liquid form
CSAP Variability	Causes & mitigation strategies
LLP Lab vs. Field Performance	Assess sensitivity to real-world conditions & mitigation strategies
Optimize Latex Dosage	Balance strength, shrinkage, and durability
Curing Sensitivity	Optimal curing temperature & techniques

Field-Scale Testing: COTE

CSA Mixture	CoTE (in/in/°F)
CSAP_deck	5.63×10^{-6}
LLP_deck	5.96×10^{-6}
CSAP	5.75×10^{-6}
LLP	5.63×10^{-6}
LM100	7.14×10^{-6}
LM25	5.76×10^{-6}

Typical range: 4.5-6.7 (in/in/°F)

Source: Kohler et al. (2007), TRB Annual Meeting