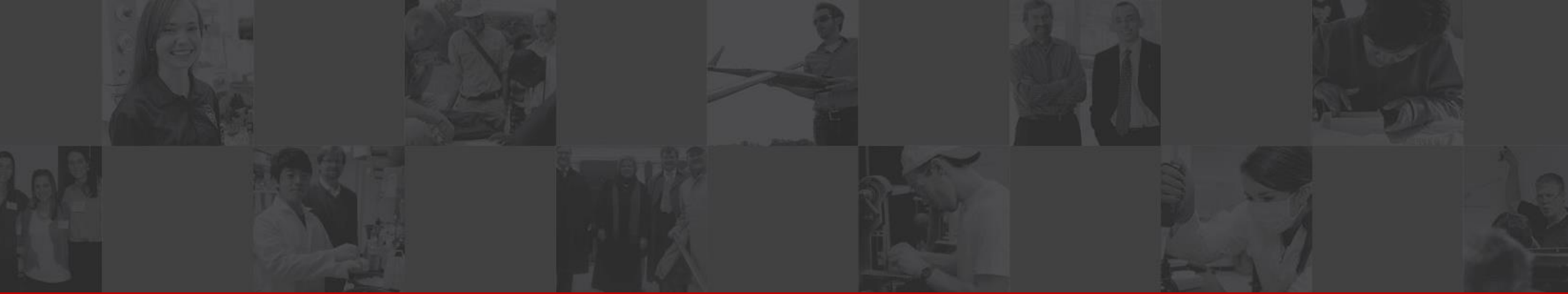

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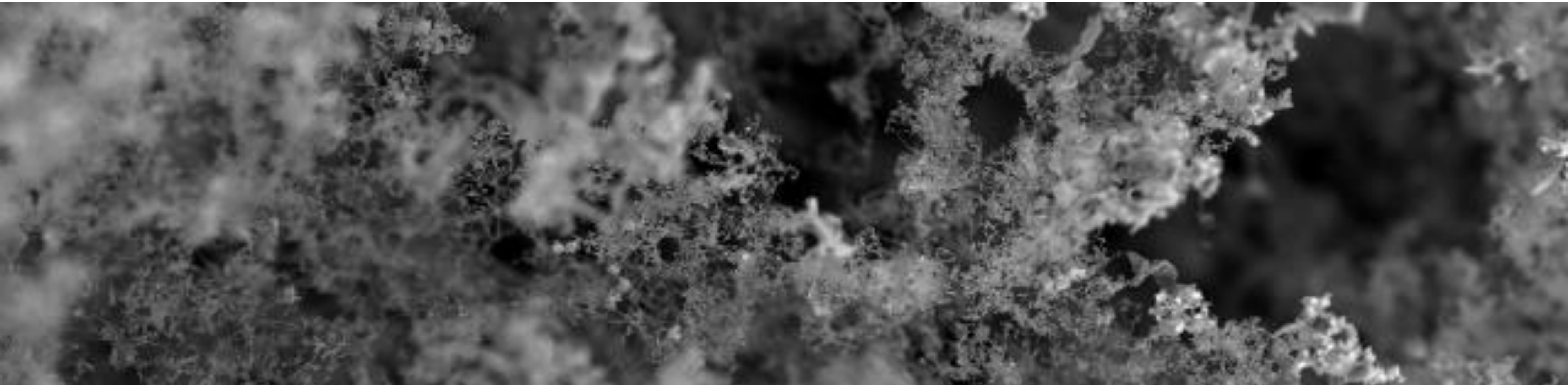
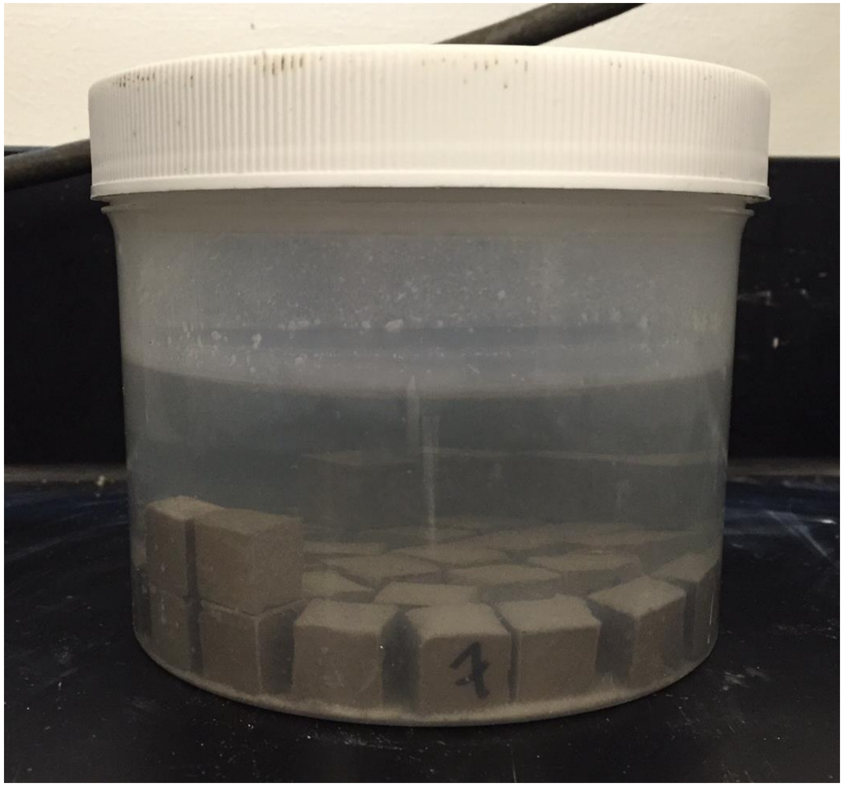
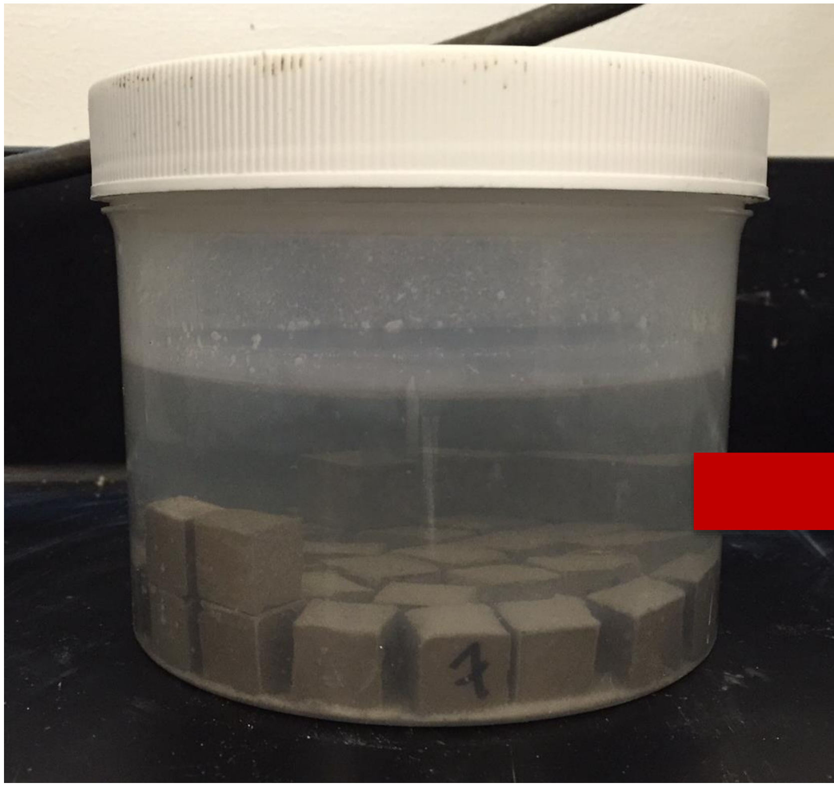
CSA Cement Curing for Optimal Hydration and Property Development

Cansu Acarturk & Lisa Burris
Civil, Environmental, and Geodetic Engineering





2 cm CSA cubes in limewater - Day 1



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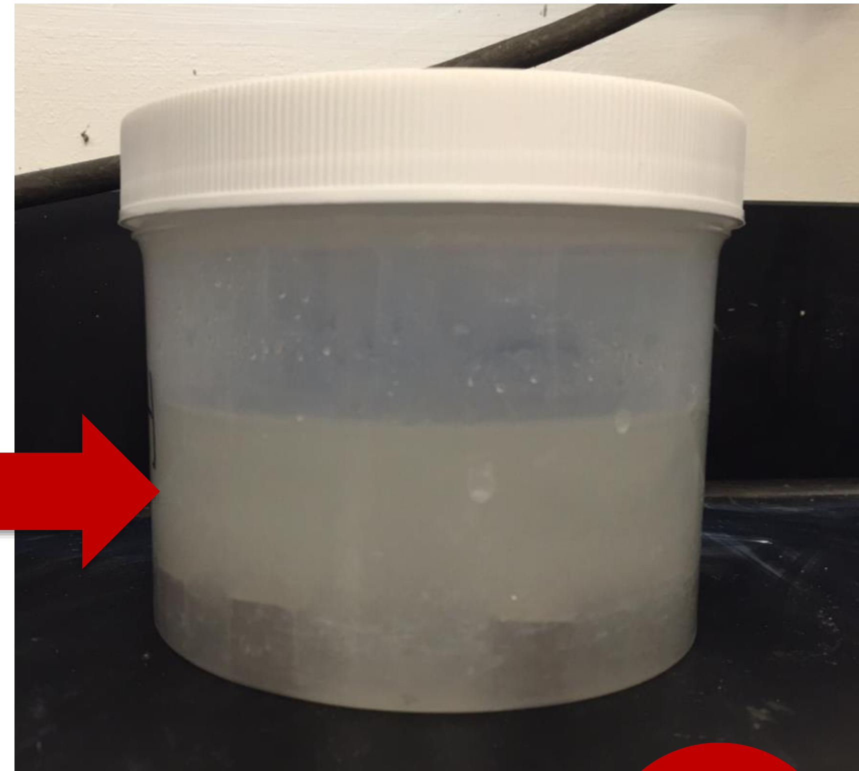
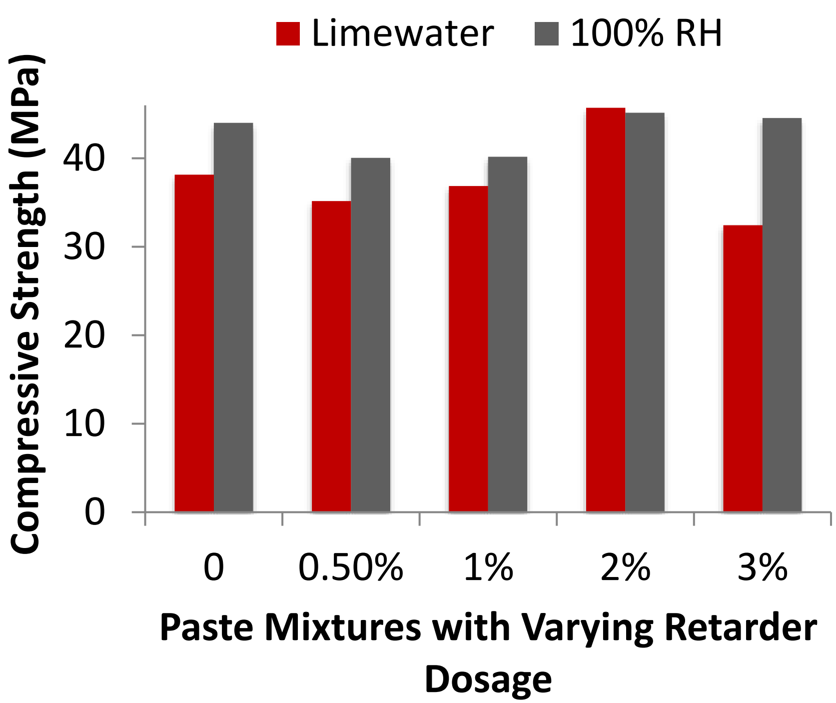
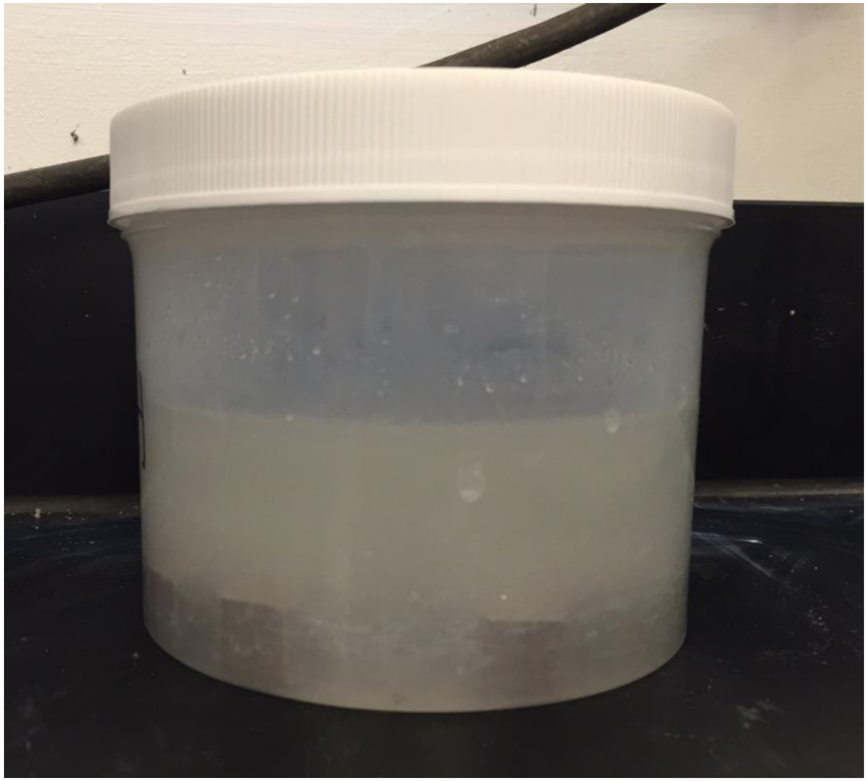
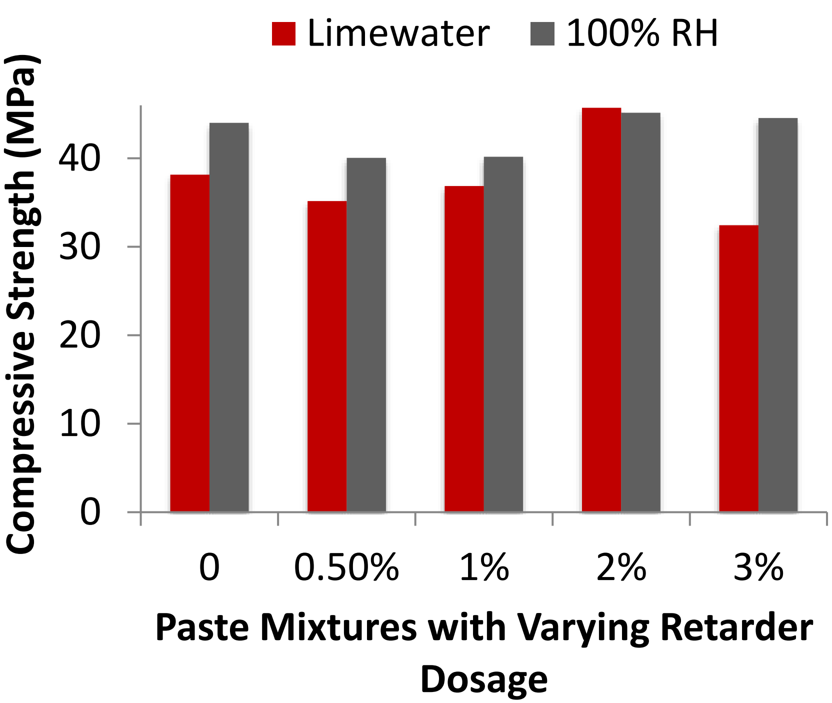


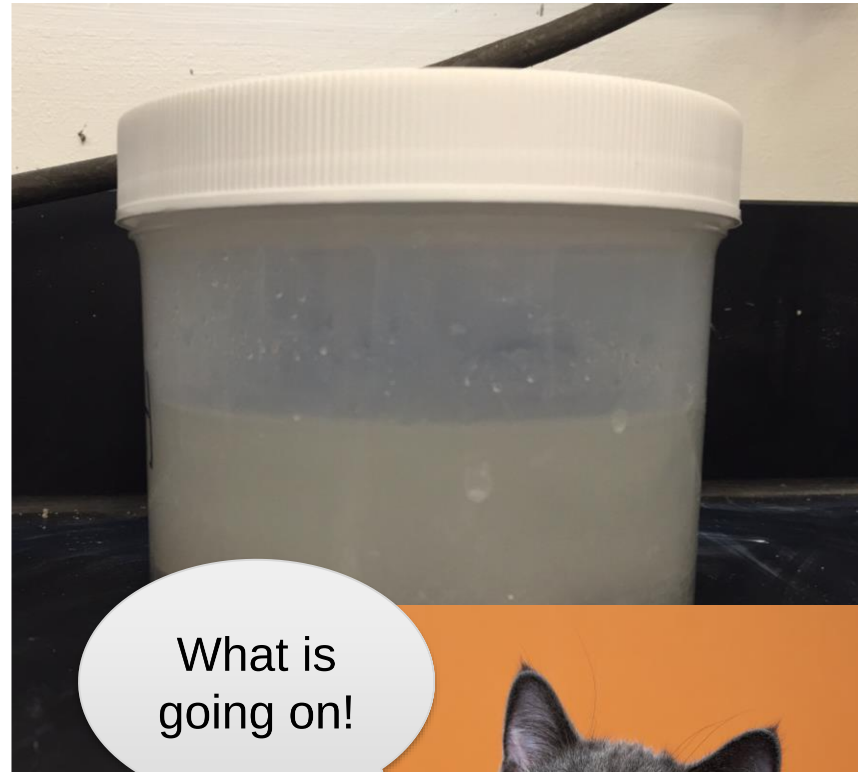
Day 7





'Gelling' accompanied by strength loss





‘Gelling’ accompanied by strength loss

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Phases	**CSA (wt%)**	**OPC (wt%)**
Alite (C_3S)	-	54.61
Belite (C_2S)	21.09	17.35
Brownmillerite (C_4AF)	7.03	12.41
Aluminate (C_3A)	6.69	6.38
Calcite	2.49	-
Anhydrite	14.97	1.54
Hemihydrate	-	4.04
Gypsum	-	0.83
Ye'elimite	45.46	-
Quartz	0.23	-

CSA vs. OPC Hydration Process

OPC

$$2C_3S + 6H \rightarrow C-S-H + 3CH$$

alite + water → calcium silicate hydrate + calcium hydroxide

CSA

$$C_4A_3\overline{S} + 2C\overline{S} + 38H \rightarrow C_6A\overline{S_3}H_{32} + 2AH_3$$

ye'elimite + anhydrite + water → ettringite + aluminum hydroxide

$$2C_2S + 4H \rightarrow C-S-H + CH$$

belite + water → calcium silicate hydrate + calcium hydroxide

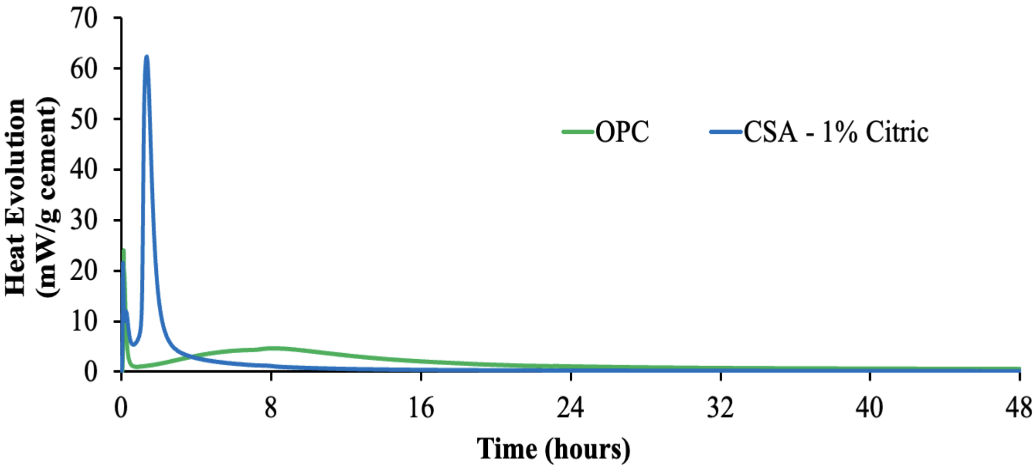
OPC & CSA Hydration Process Comparison

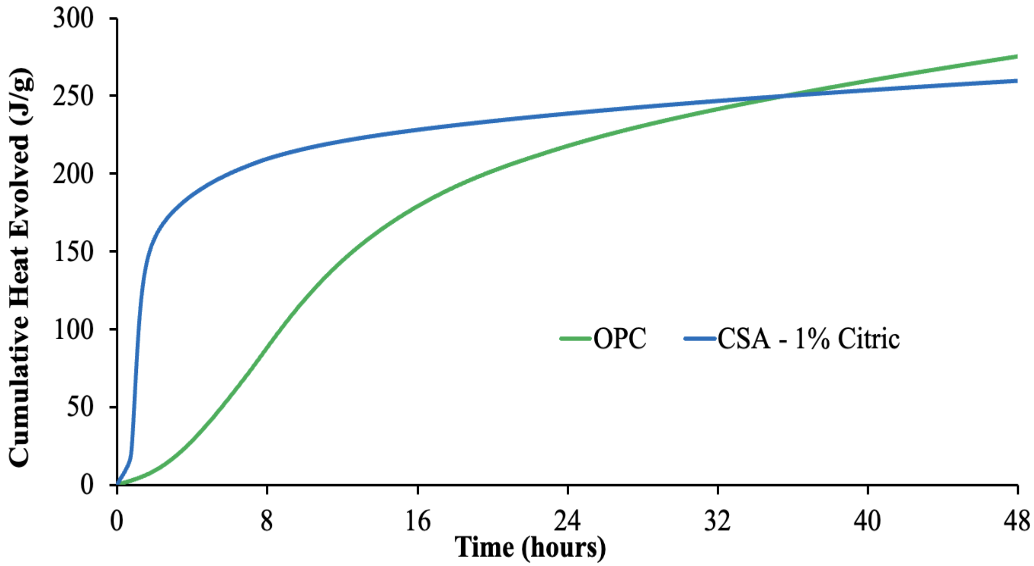
Further…

CSA hydrates MUCH faster

Do we really need 7 days for CSA curing?

Specification	Minimum required days for curing
ACI 308	7 days
Ohio DOT	7 days
Florida DOT	3 days
Texas DOT	4 days
Illinois DOT	3 or 7 days (application dependent)
Virginia DOT	7 days
New York DOT	7 days
Louisiana DOT	7 days
California DOT	7 days





Hypotheses:

1. CSA will require reduced curing periods compared to OPC.

2. CSA does not benefit from curing in limewater or DI water.

3. CSA properties can be improved using solutions containing CSA hydration product components.

Experimental Approach:

Testing:
Changes in hydration: phase development
Changes in Performance: Compressive strength & drying shrinkage

Samples:
2” mortar cubes and 3x4x16” beams
w/c = 0.485, 0.5% citric acid retarder

Curing:

Curing duration evaluation

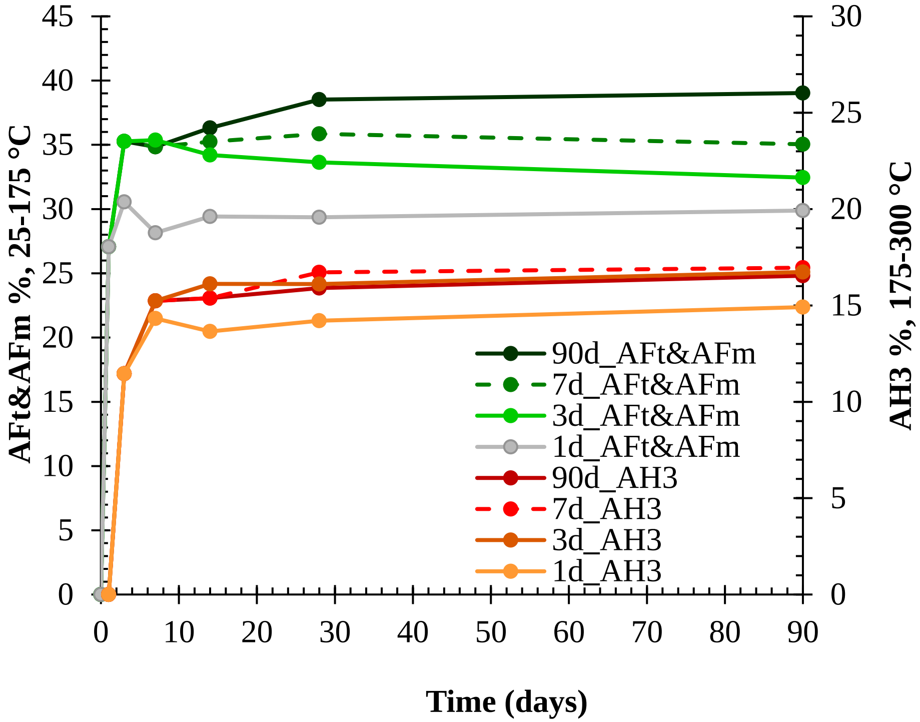
DAYS	1	2	3	7	28	90
OPC_7d	100% RH				50% RH	
CSA_1d	100% RH	50% RH				
CSA_2d	100% RH		50% RH			
CSA_3d	100% RH			50% RH		
CSA_7d	100% RH				50% RH	
CSA_90d	100% RH					
CSA_105 °C	100% RH	105 °C		50% RH		

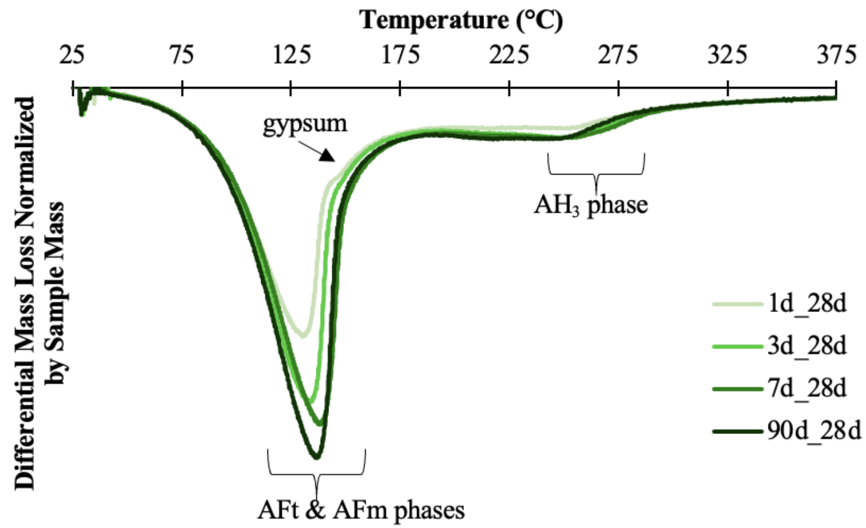
Curing solution evaluation

DAYS	1	2	3	7	28	90
DI	100% RH	Deionized water				
CH	100% RH	Calcium hydroxide solution				
CS	100% RH	Calcium sulfate solution				
AS	100% RH	Aluminum sulfate solution				
AN	100% RH	Aluminum nitrate solution				

Curing Duration Results

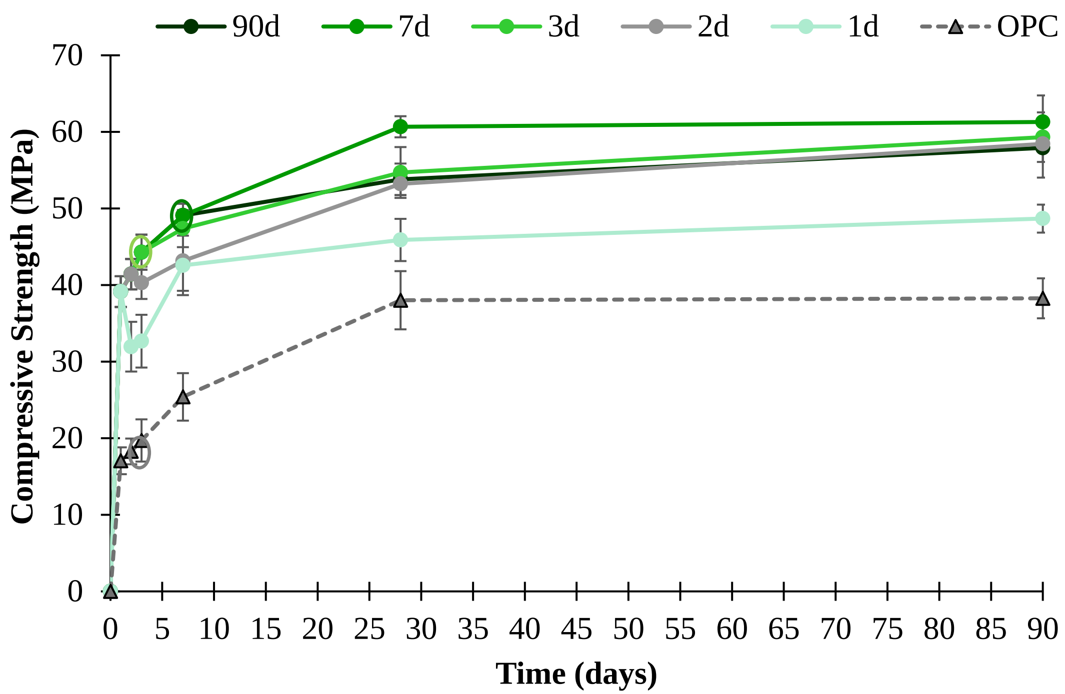
Hydrated Phase Development with Curing Length:





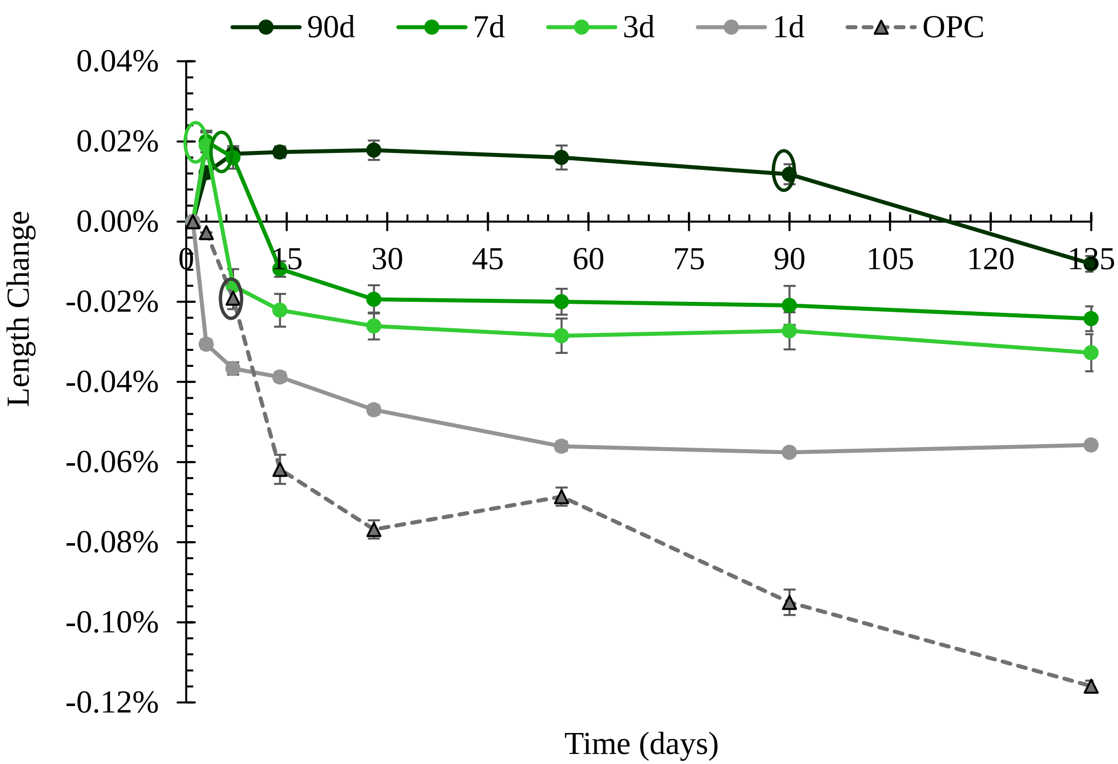
- Direct correlation between ettringite and monosulfoaluminate quantities and curing time
- 1 day curing resulted in reductions in both alumino silicates and aluminum hydroxide

Compressive Strength Development with Curing Length



- Curing for <2 days reduced long term (90d) strength gain
- Insignificant differences between 2 – 90 day curing lengths

Drying Shrinkage with Curing Length



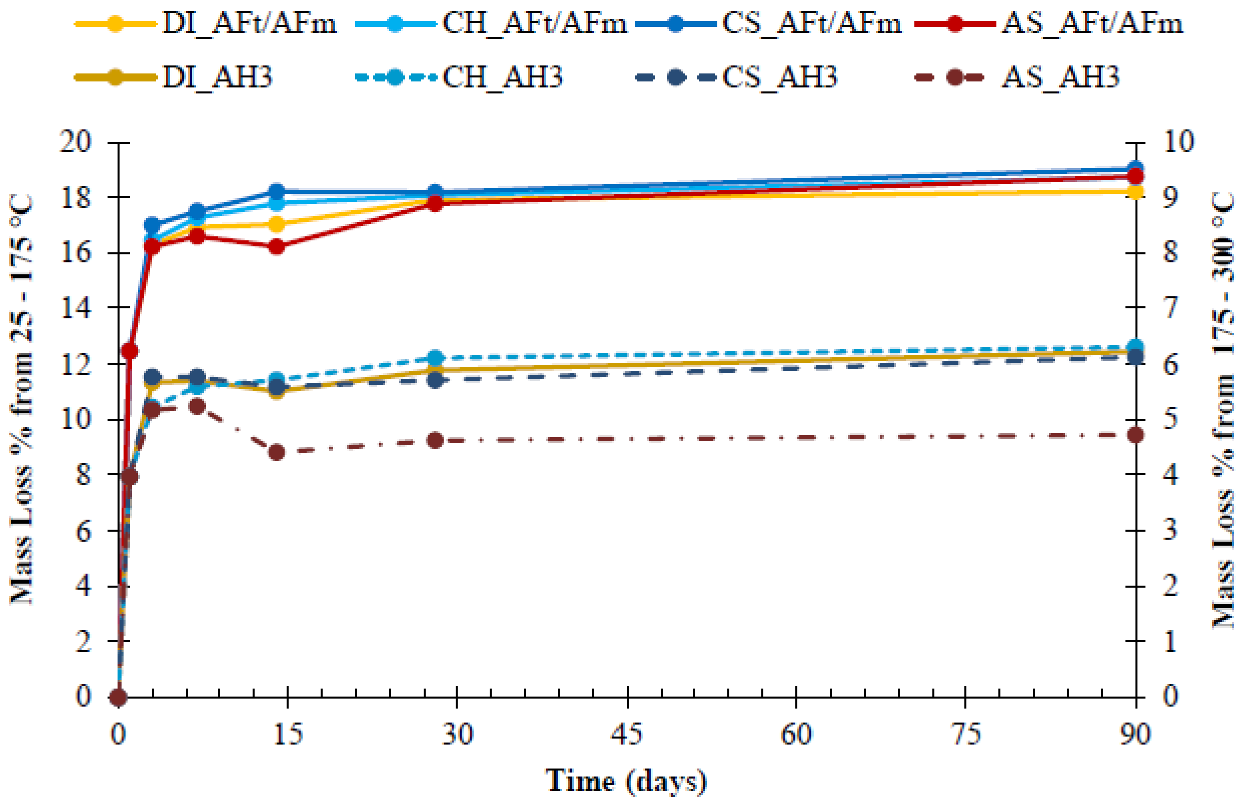
- All CSA samples showed expansive behavior when in 100% RH until removal
- Total drying shrinkage correlated inversely with curing time (more curing = less shrinkage)
- Even minimal curing with CSA samples reduced overall shrinkage extent relative to OPC

Alternative Curing Solution Results

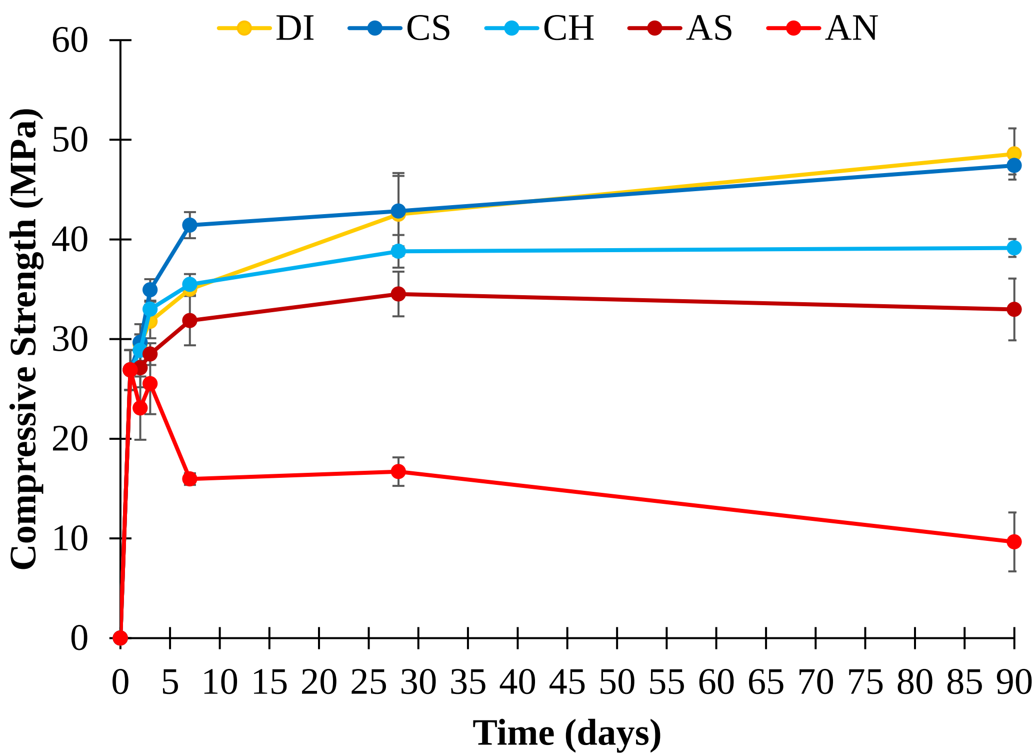
DI water – Limewater – Calcium sulfate

Aluminum sulfate – Aluminum nitrate

Hydration in Alternative Curing Solutions



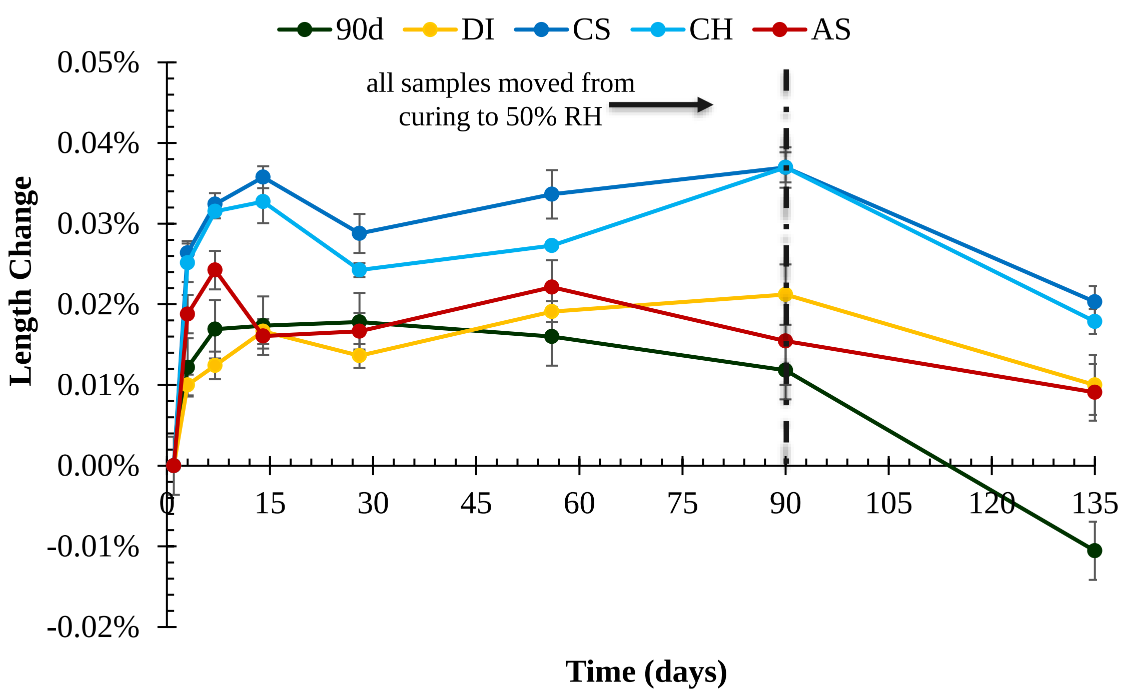
Strength and Shrinkage in Alternative Curing Solutions



- Curing in aluminum solutions resulted in significant reductions in strength
- Curing in DI water or calcium sulfate solution resulted in greater strength than in limewater

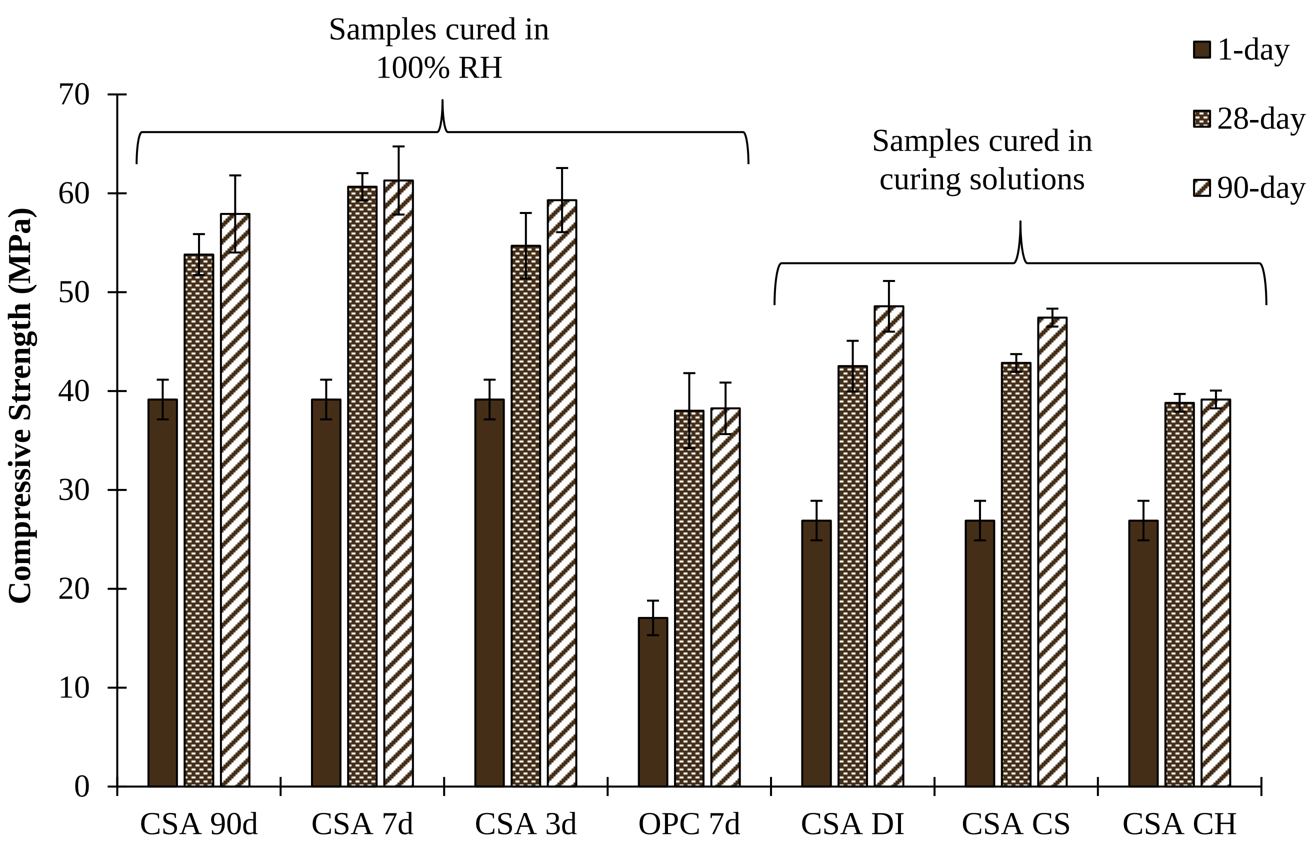
DI water 90d strength:

Strength and Shrinkage in Alternative Curing Solutions



- All samples expanded in all curing solutions through 90 days.
- All samples decreased in length when moved to 50% RH after 90 days of curing.
- Curing resulted in at least short-term reductions in drying shrinkage compared to 100% RH curing
- Calcium solutions reduced shrinkage most significantly

Strength Development Curing Method Comparison



Relative to moist curing (100% RH):

DI water & calcium sulfate solution lowered 90d strength by as much as 18%.

36% strength loss when curing in limewater!

Conclusions

Hypothesis 1: CSA will require reduced curing periods compared to OPC.

- Extended curing in 100% RH is not required for CSA cement mixes beyond 3 days.
  - Samples cured for 2- 3 days reached similar compressive strengths, slightly lower amount of hydration products and slight increases in drying shrinkage.

Hypothesis 2: CSA does not benefit from ponded curing in limewater or DI water.

Hypothesis 3: CSA properties can be improved using solutions with CSA hydration product components.

- Curing samples by ponding in any solution resulted in strength reductions
  - Strength loss was minimized using DI water or calcium sulfate solution
  - Strength loss in limewater was considerable and use of limewater should be avoided for curing CSA
  - Aluminum solutions were very harmful to hydration and strength development

- Curing samples by ponding in any non-acidic solution resulted in shrinkage reductions
  - Shrinkage was minimized in calcium-containing solutions, but use of DI water resulted in only 0.01% more shrinkage
  - All samples cured for >1d resulted in less shrinkage than in the OPC system

- Use of solutions containing hydration process products did not increase overall hydration.

Curing Recommendations

- Curing specifications should require maximum 48 hours of wet curing for CSA concretes
- Use of curing tanks should not be permitted for CSA samples.