Settlement of Fresh Concrete: Using Neutron Radiography to Quantify the Influence of Mixture Proportions

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Presentation Outline

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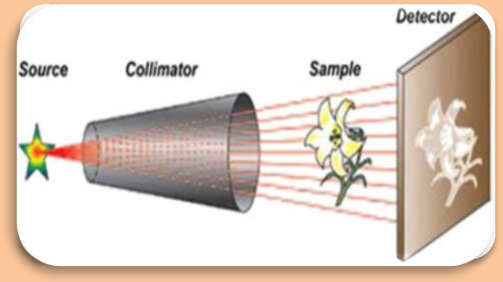

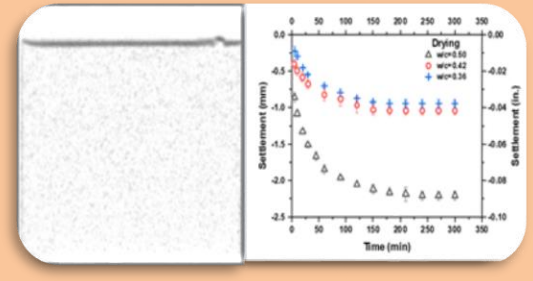

Background

Methodology

Results & Discussion

Conclusion

Causes of Cracking in Fresh Concrete

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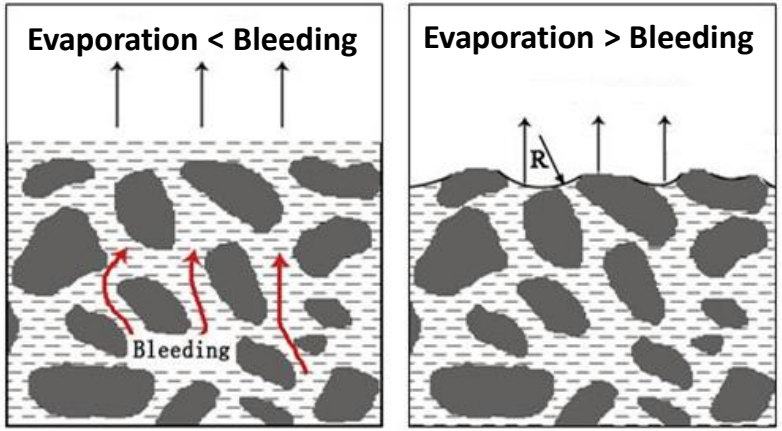
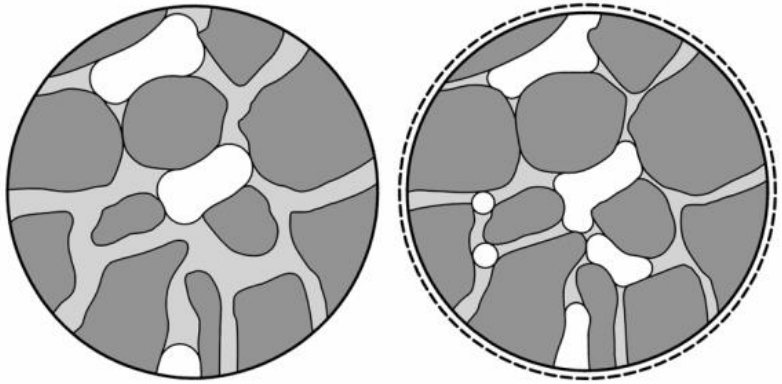
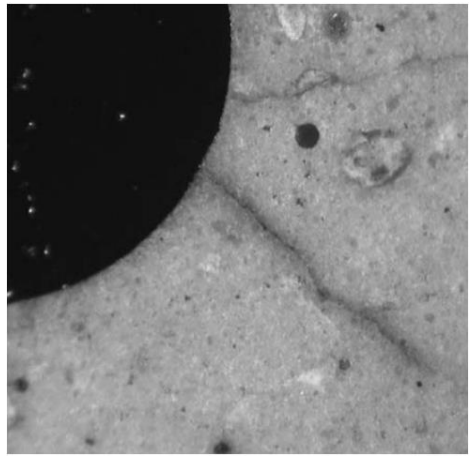
Rapid Evaporation



$$P_{cap} = -\frac{2\gamma cos\theta}{R}$$

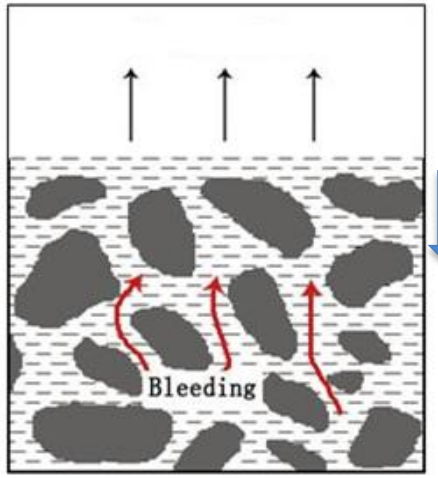
Autogenous Shrinkage



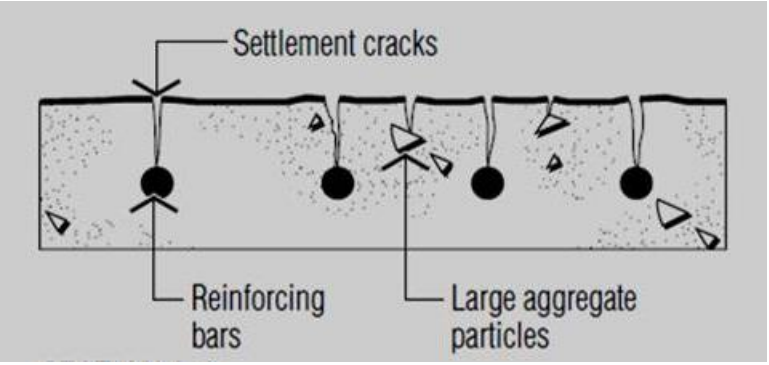


Low w/c !!!

Settlement



Aggregate and cement settlement



Methods to Study Settlement

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Single Point Measurements

- Displacement of steel pin resting on concrete surface
- Movement of a nylon ball at surface
- Dial gages

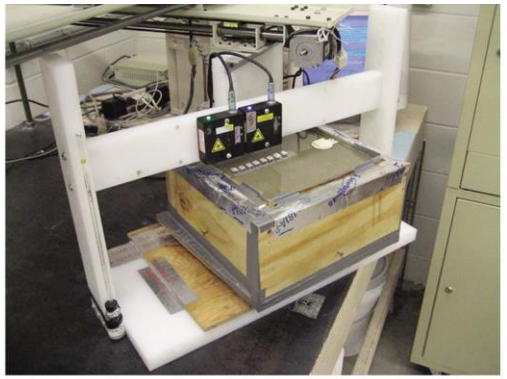
Powers, 1968

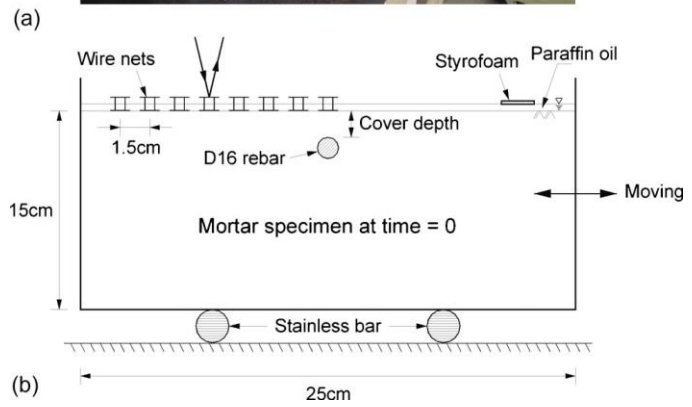
Magnat and Azari, 1990

Sanjuan and Moragues, 1997

Multiple Points Measurement

Noncontact Laser Measurement





Kayir and Weiss, 2002 and Kwak et al., 2010

Neutron Radiography

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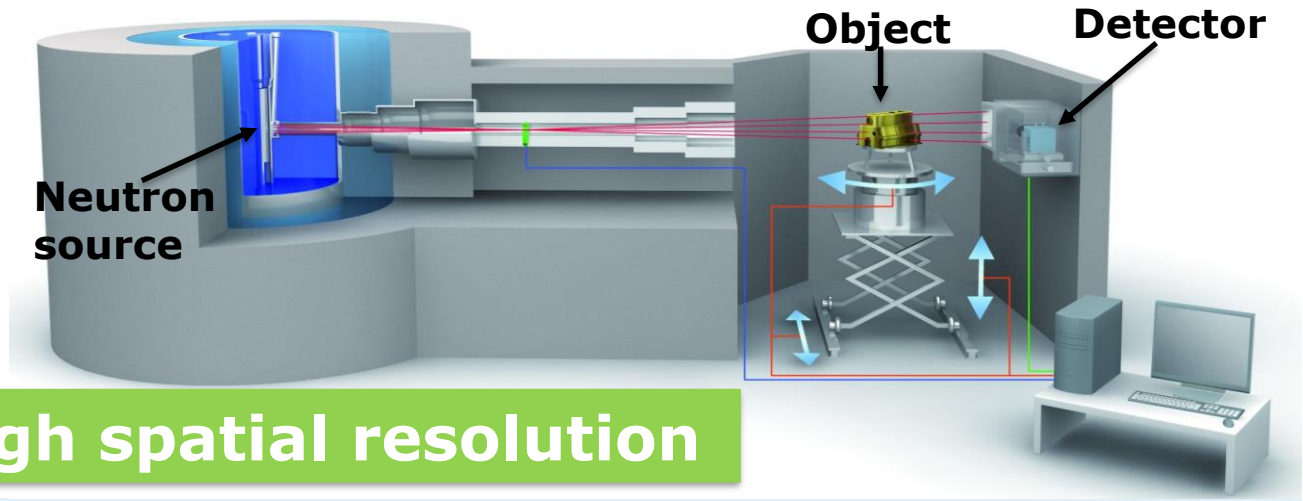
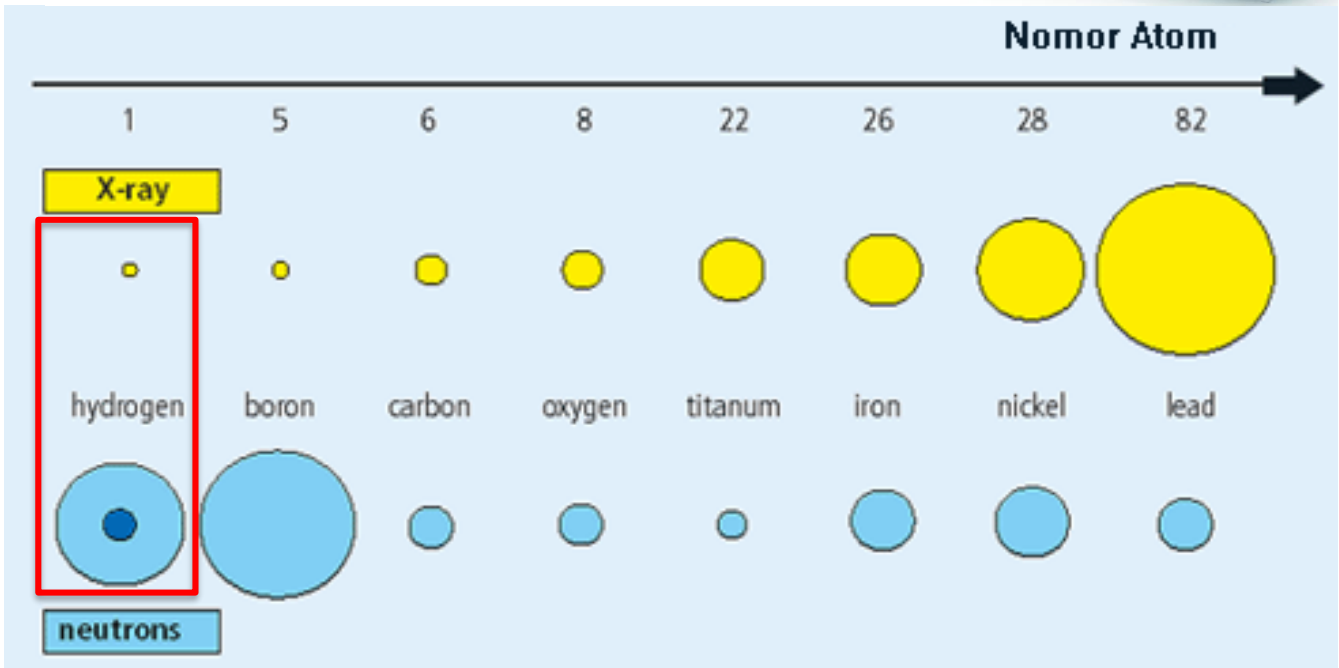
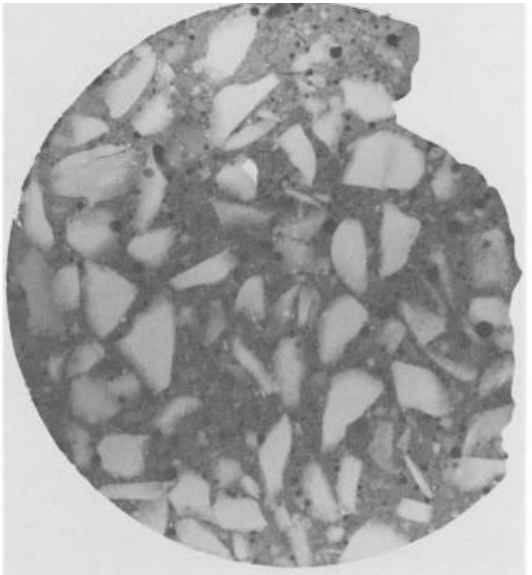


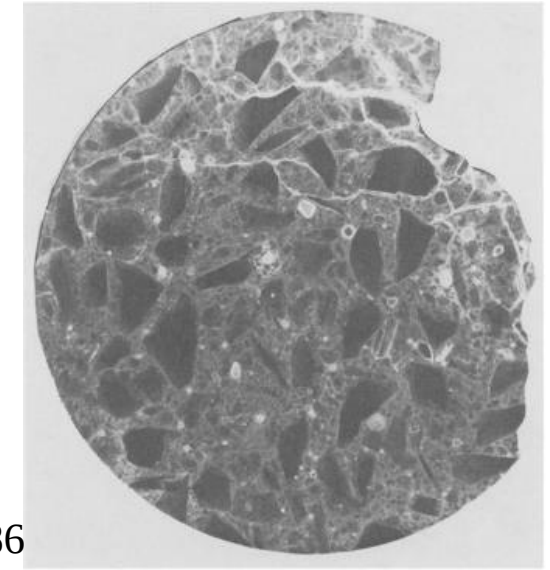
High spatial resolution



X-ray



Neutron



Najjar et al., 1986

Objectives of Study

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(1) Application of Neutron Imaging to study fresh mortar settlement

(2) Influence of w/c on fresh mortar settlement

(3) Impact of water-reducer admixture on settlement (Slump)

(4) Impact of conditioning on settlement (drying vs. sealed)

(5) Influence from rebar on settlement

Neutron Radiography Facility at OSU

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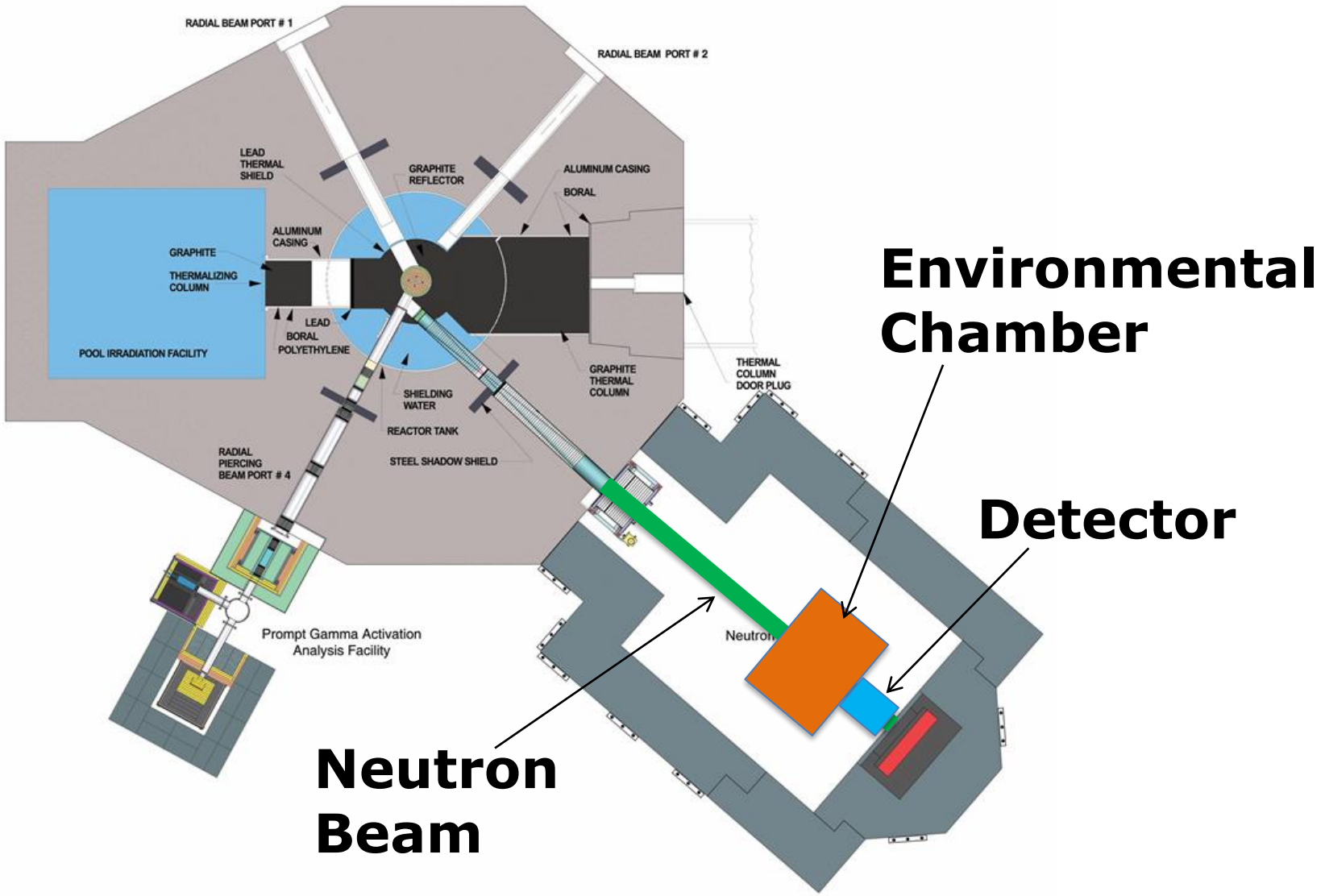

1.1 MW water-cooled research reactor.

The beam within the NRF has a collimation ratio (L/D) of 115 and a thermal neutron flux of 9.4×10^5 cm^{-2} s^{-1}

Imaging Setup

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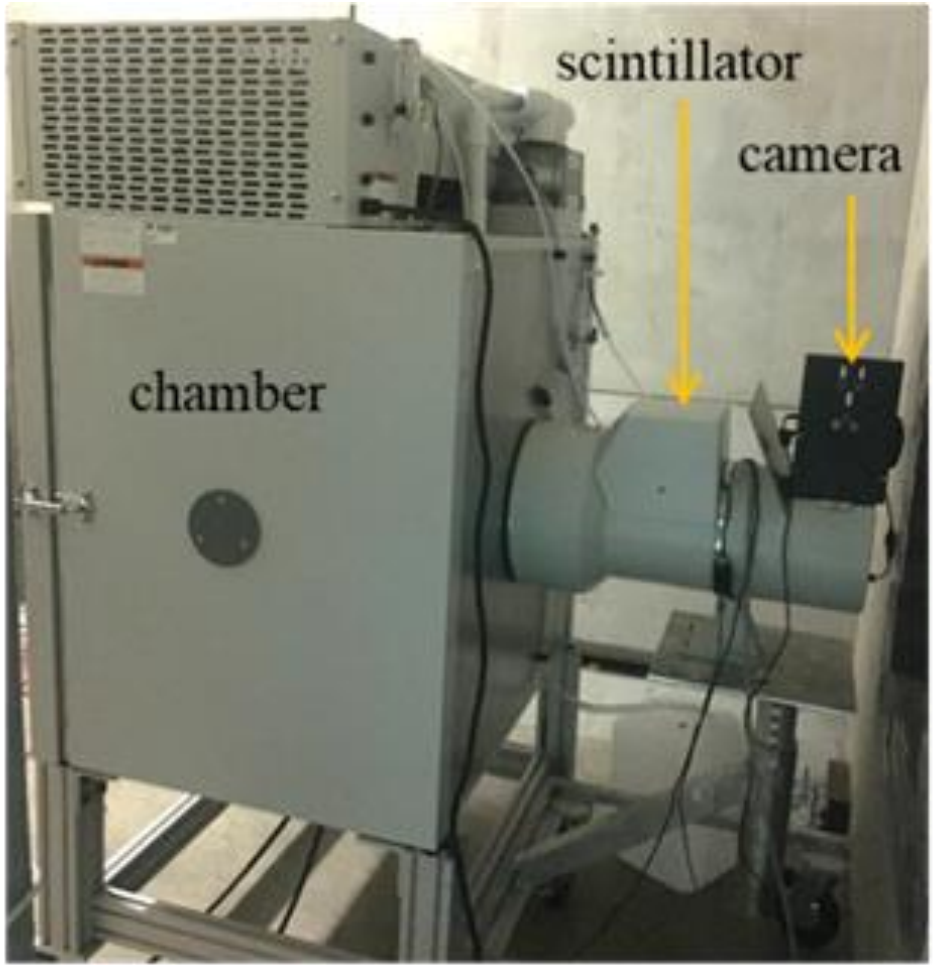
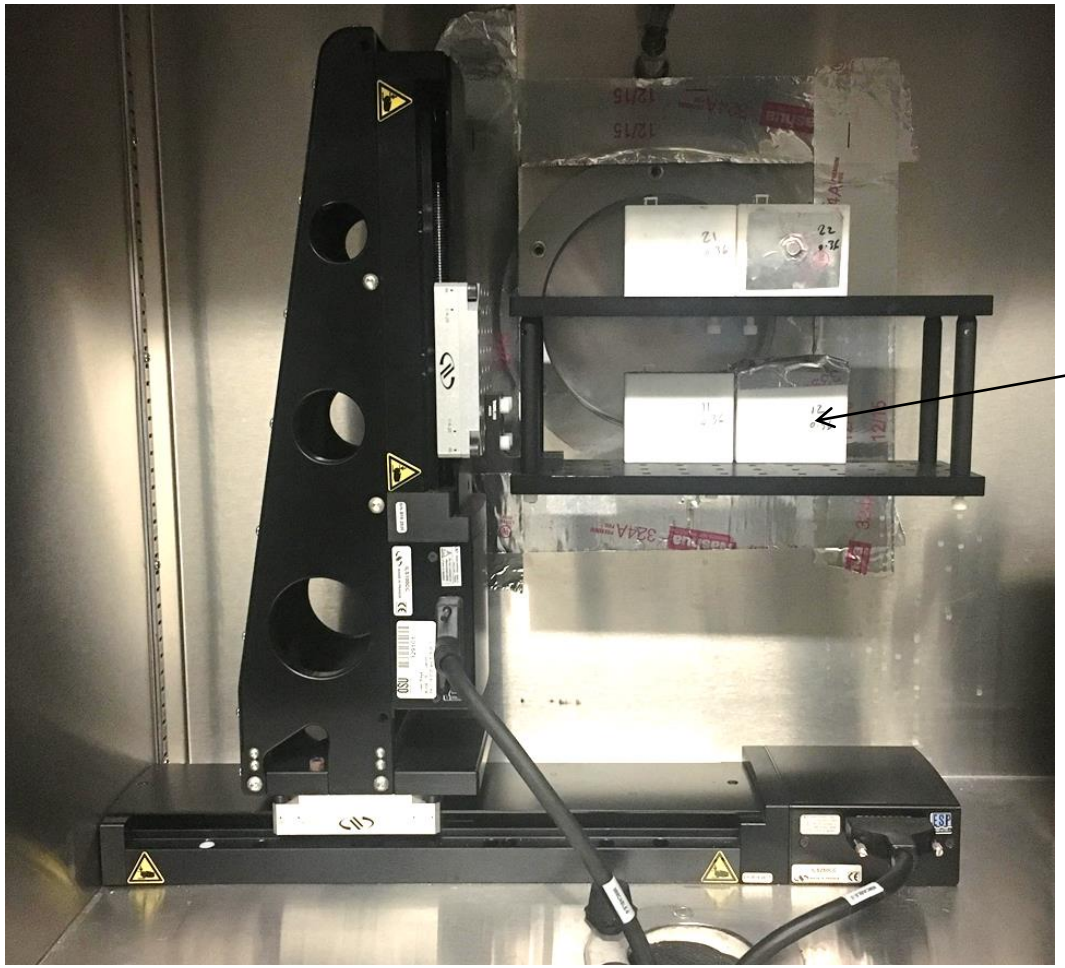


Chamber & Detector



Teflon molds to cast the samples

Sample size: 60×50×20 mm

Moving Table inside the chamber

Water Attenuation Coefficient

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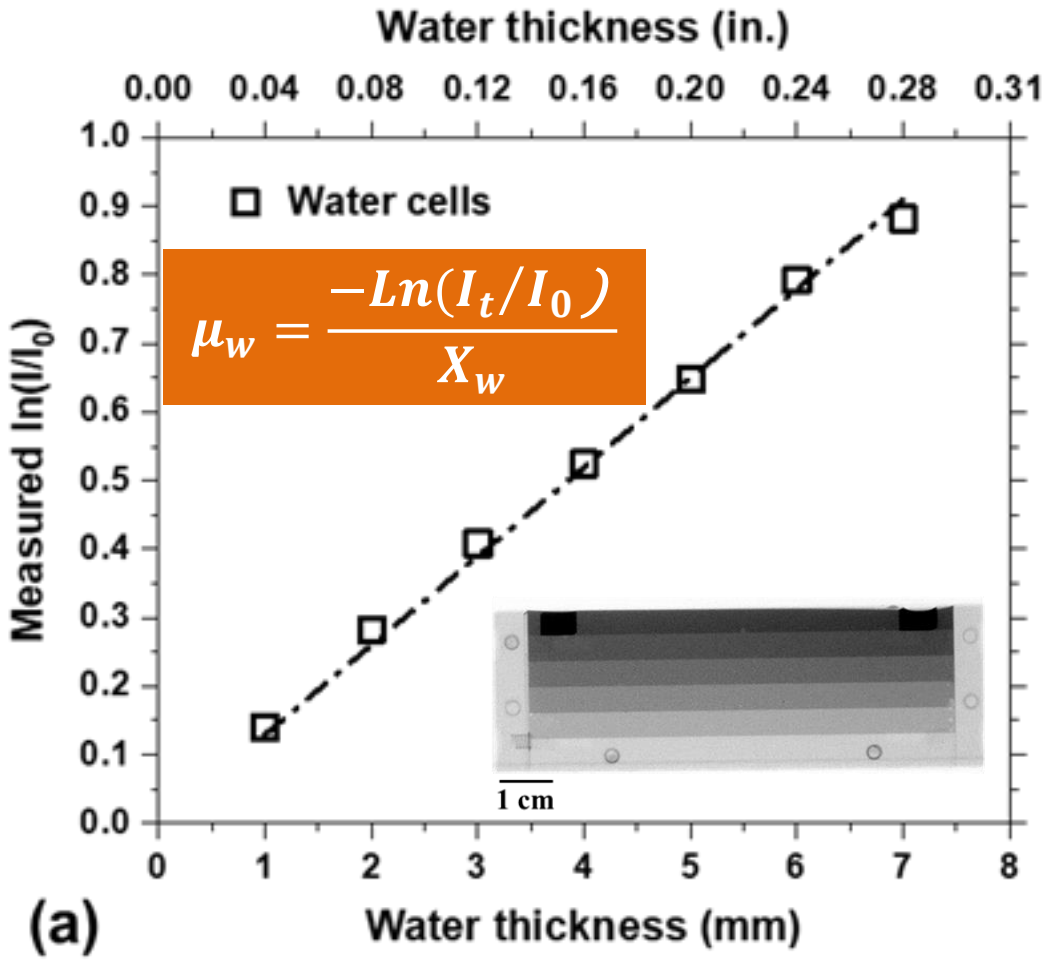

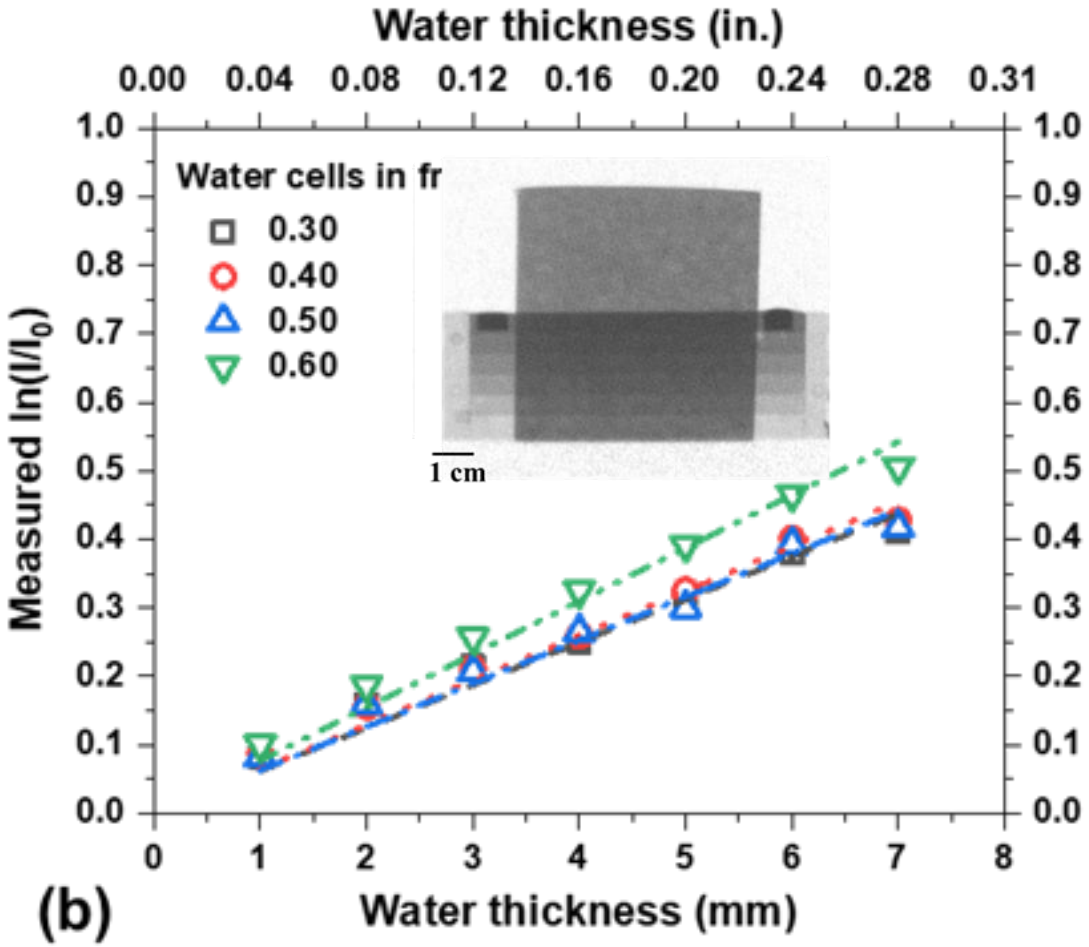

Experimental Program

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Mixture	Cement/Water/Sand	Water Reducer (% mass of cement)	Slump (mm)	Initial/final set time (h)
0.50	1:0.50:2	-	31	4.1/5.7
0.42	1:0.42:2	-	15	2.9/4.3
0.42-WR1	1:0.42:2	0.50	27	
0.42-WR2	1:0.42:2	0.70	41	
0.36	1:0.36:2	-	0	1.8/3
0.36_WR1	1:0.36:2	0.60	19	

Mini Slump Test

A vacuum mixer was used to prepare the mixtures.
A Teflon mold with dimensions of 60×50×20 mm was used to cast the samples.

Conditioning

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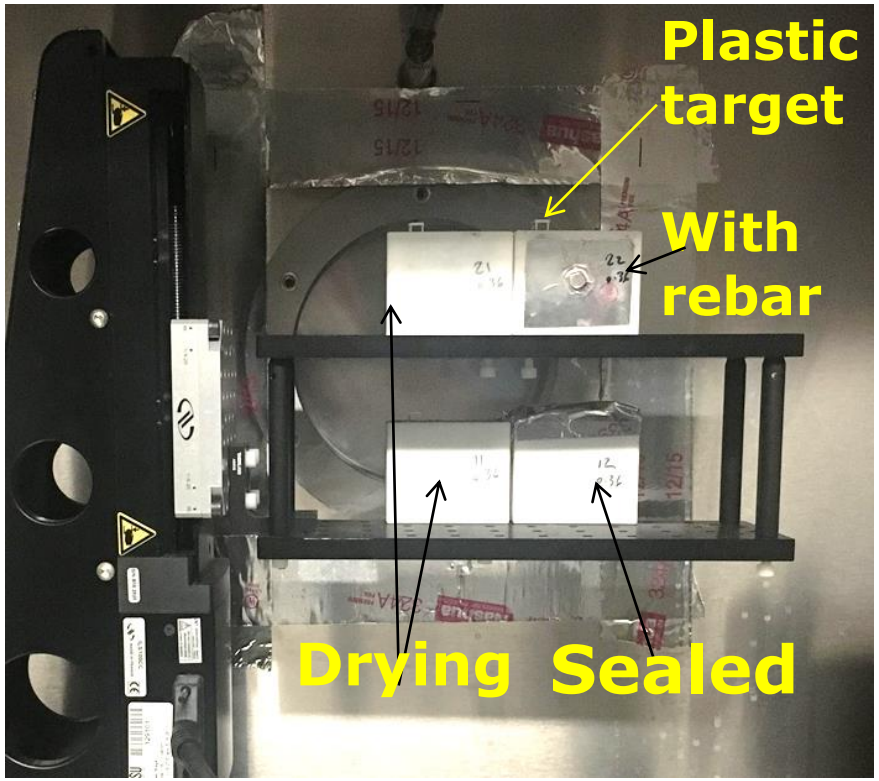
- Samples were tested inside the environmental chamber at 50% RH, 25 ^{0}C. Evaporation rate of 0.92 kg/m^2/h
- 2 replicates in a drying condition
- 1 sample in a sealed condition
- 1 sample with rebar embedded in mortar
- Al tape was used to seal the surface of the sealed samples.
- Imaging was started 5 min after the casting samples



Detail of Embedded Rebar

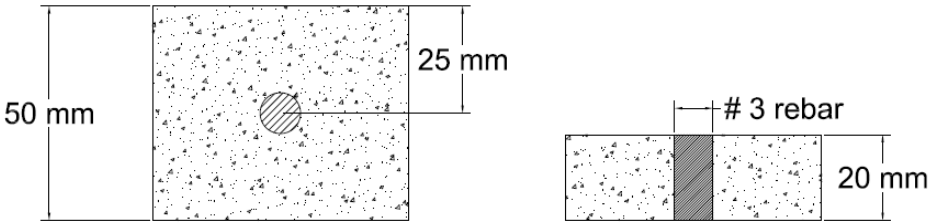


Image Processing

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(1) Background Correction

$$I_{corrected} = \frac{I_{raw\ image} - I_{dark\ field}}{I_{flat\ field} - I_{dark\ field}}$$

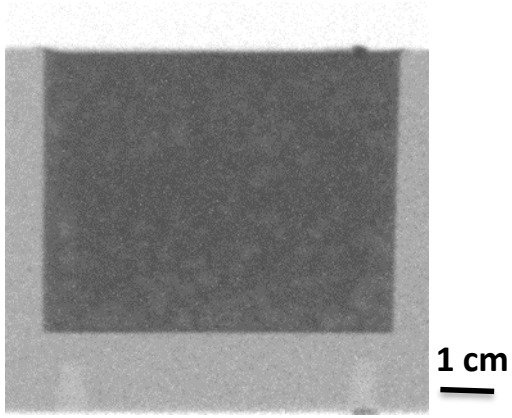

Image Processing

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College of Engineering

(1) Background Correction

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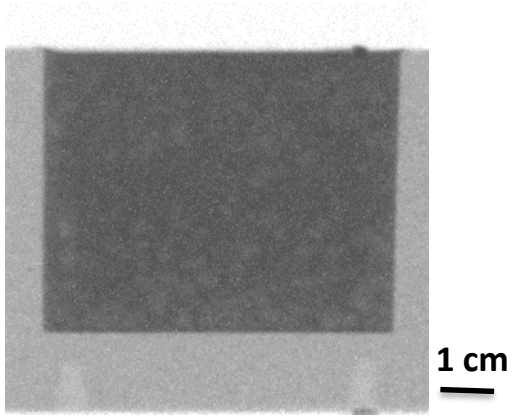
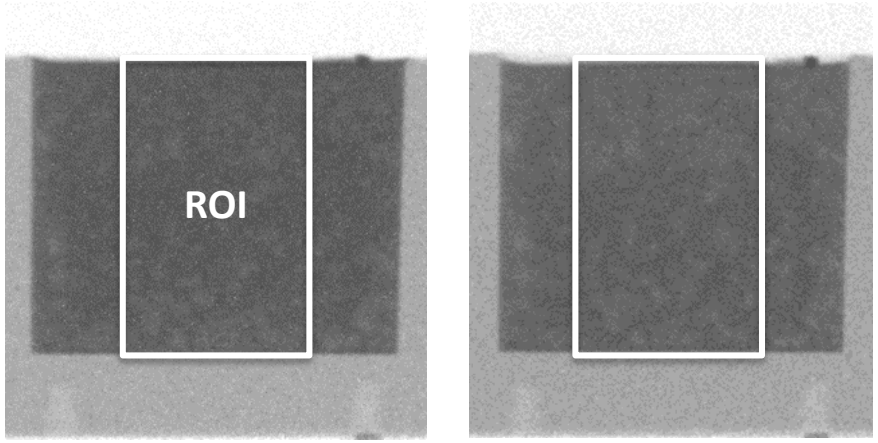


(2) Mass change profiles

$$X_w = \frac{-Ln(I_t/I_0)}{\mu_w}, \qquad \theta = \frac{X_w}{X_s}$$

$$m\,(g) = \theta\left(A_{pixel}X_S\right)\rho_w \quad \text{Mass Loss}$$



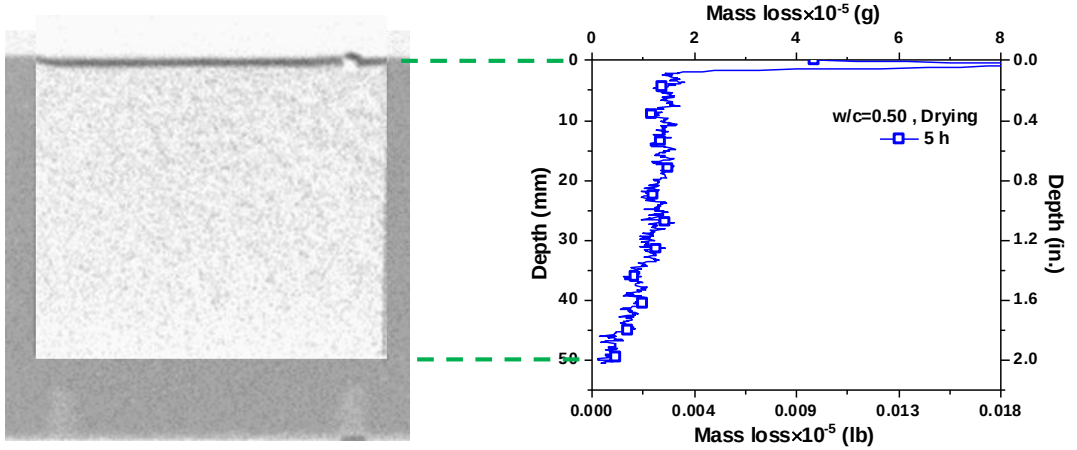


Image Processing

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(3) Cumulative mass change

$$\Delta m\,(g) = \sum m\ .n$$

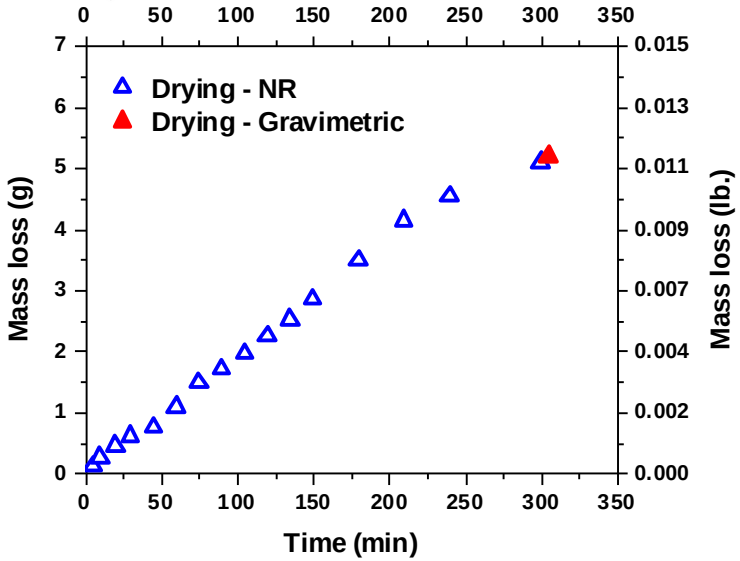

Image Processing

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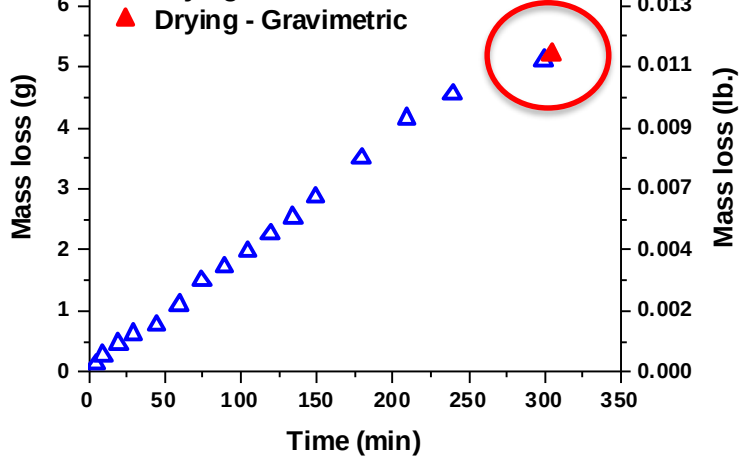
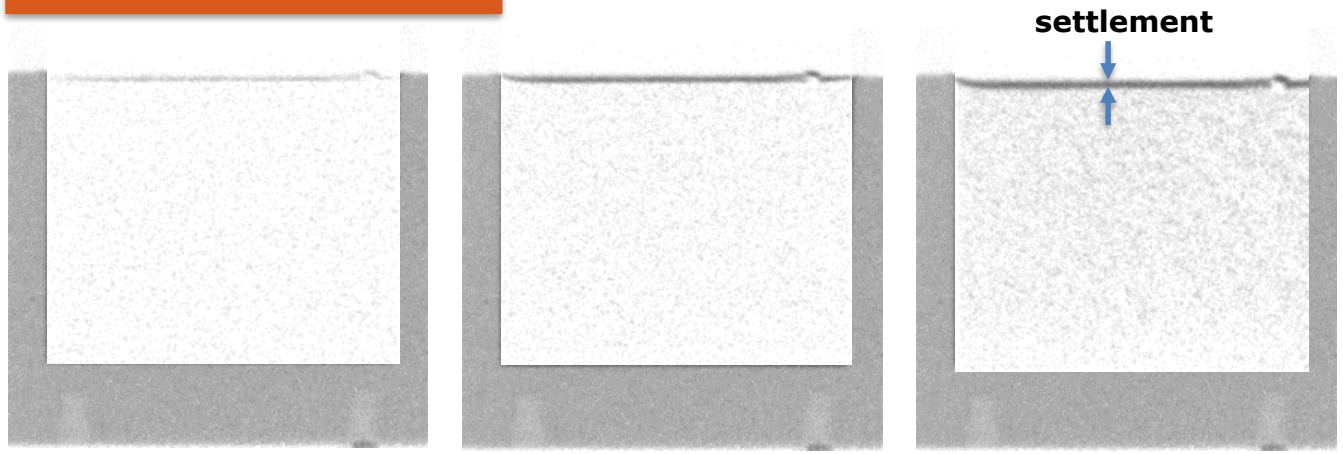
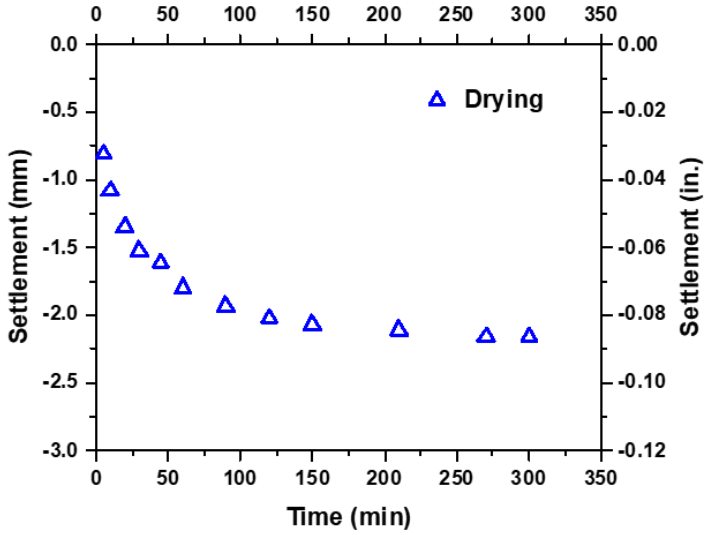


(4) Settlement





Results – Mass loss profiles (varying w/c)

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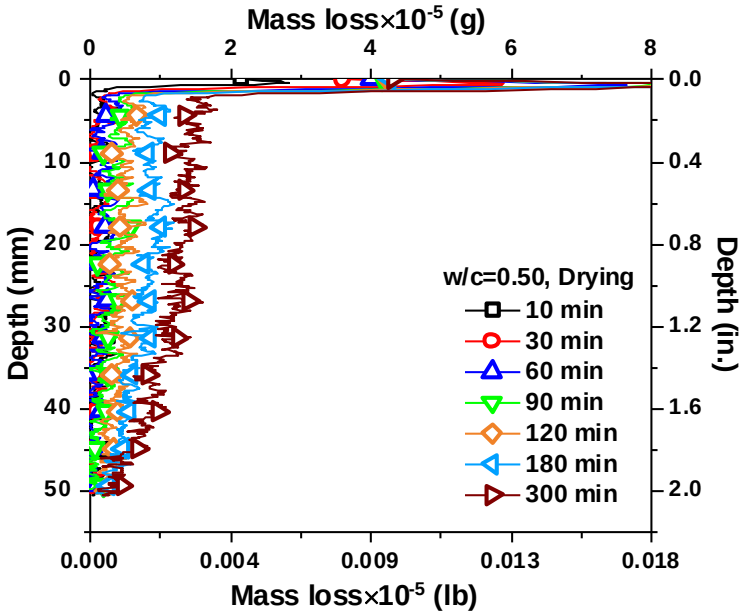
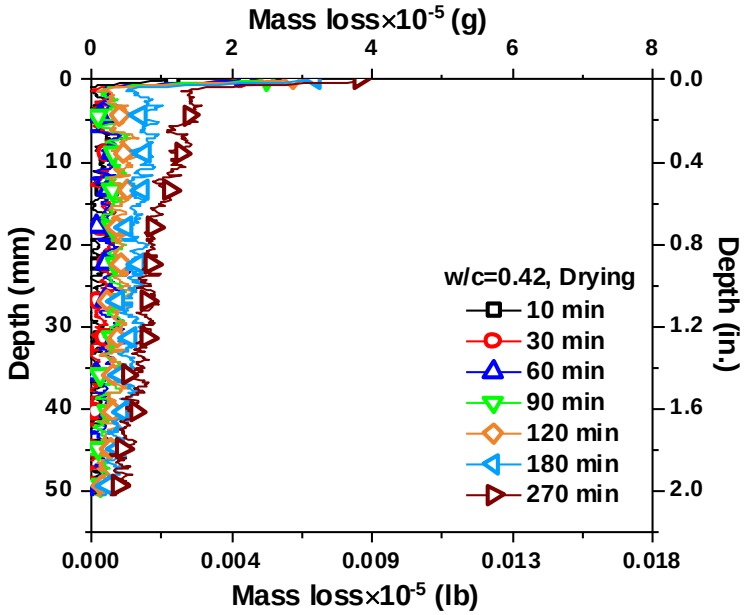
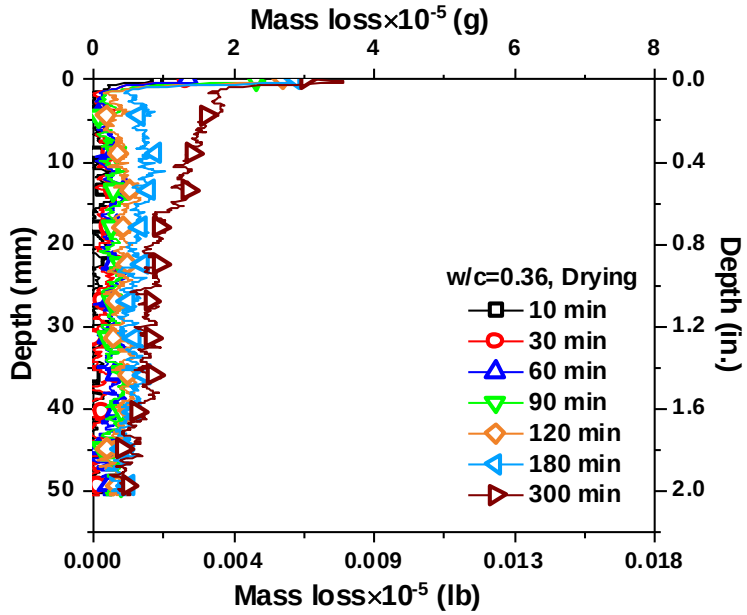
Drying







w/c=0.50 | **w/c=0.42** | **w/c=0.36**

Results – Mass loss profiles (varying w/c)

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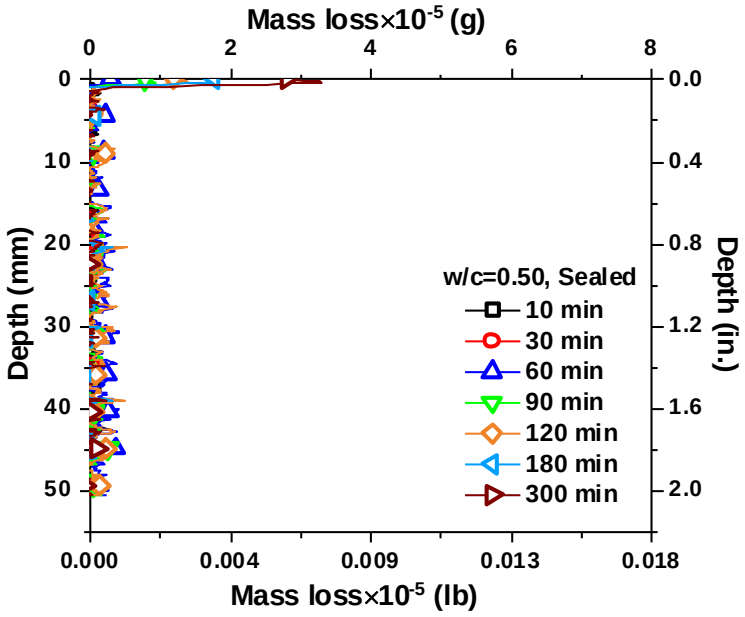
Sealed



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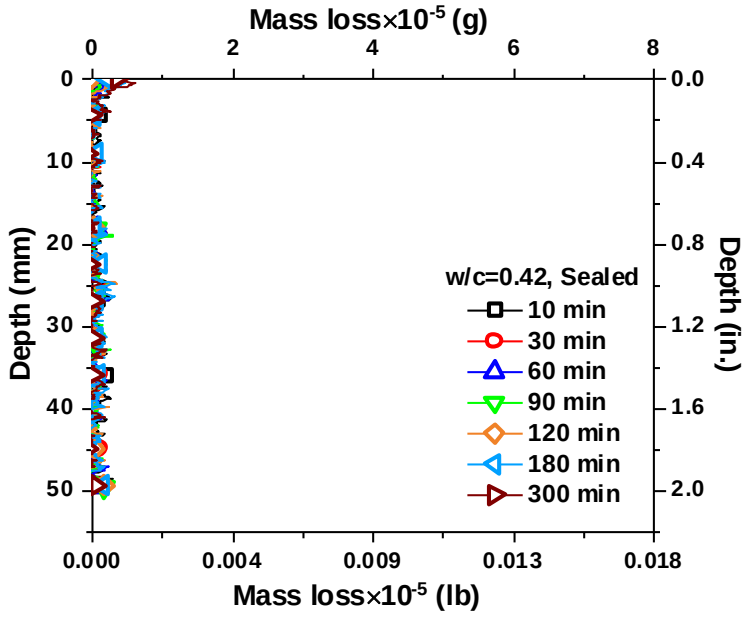

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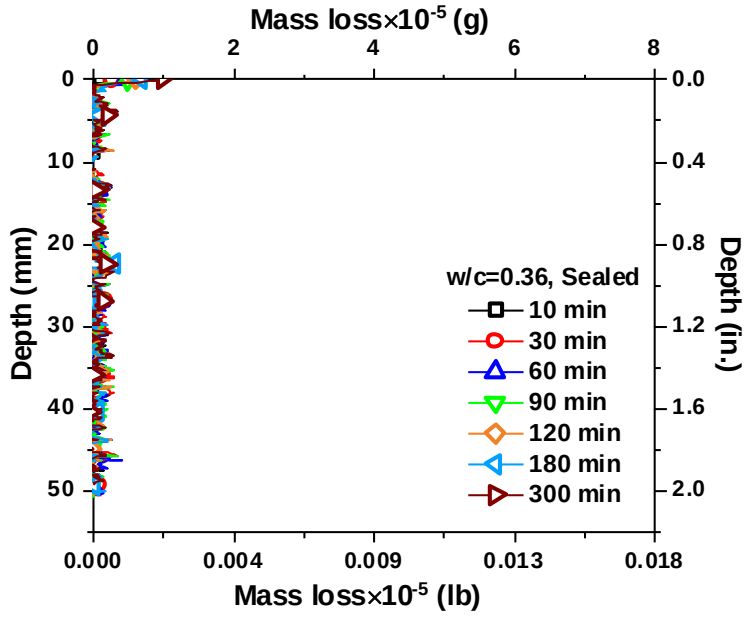

w/c=0.36

Results – Cumulative Mass loss

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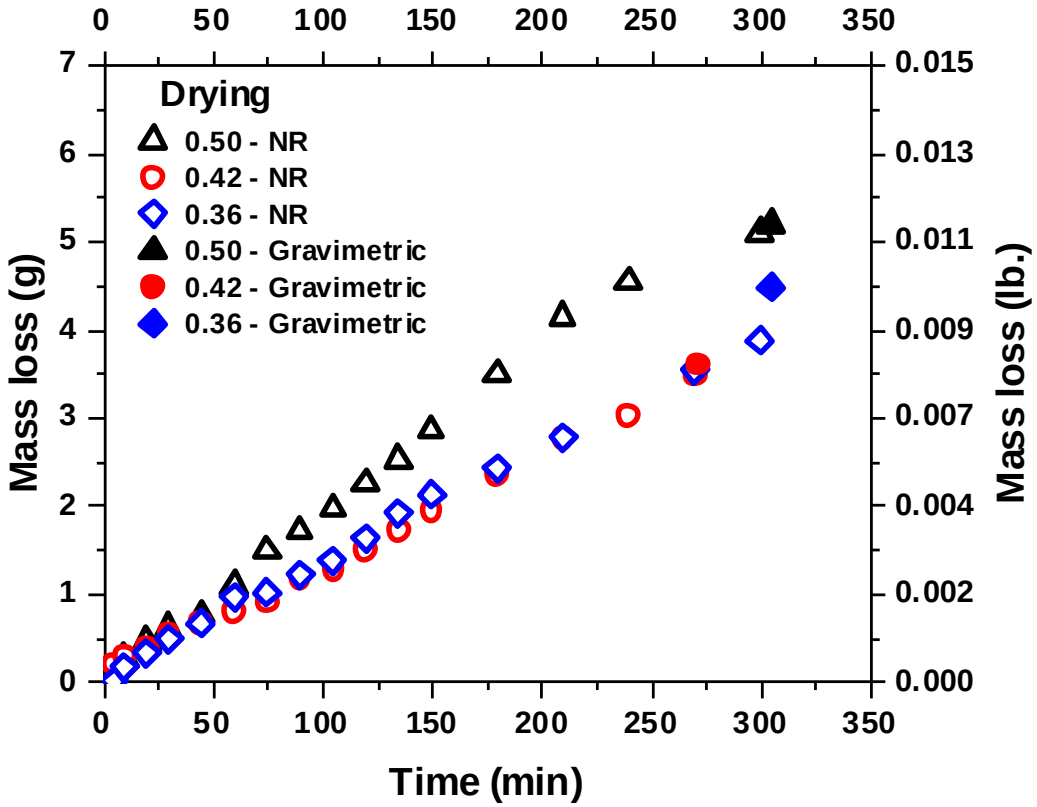
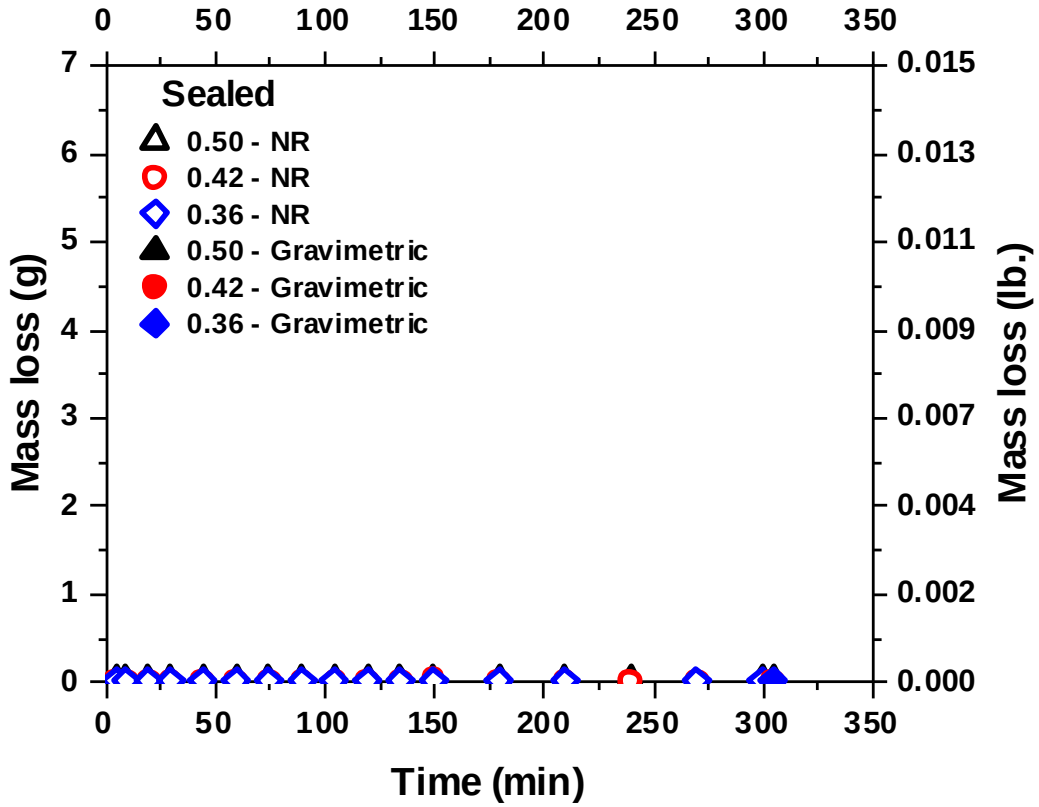


Drying



Sealed

Results – Settlement

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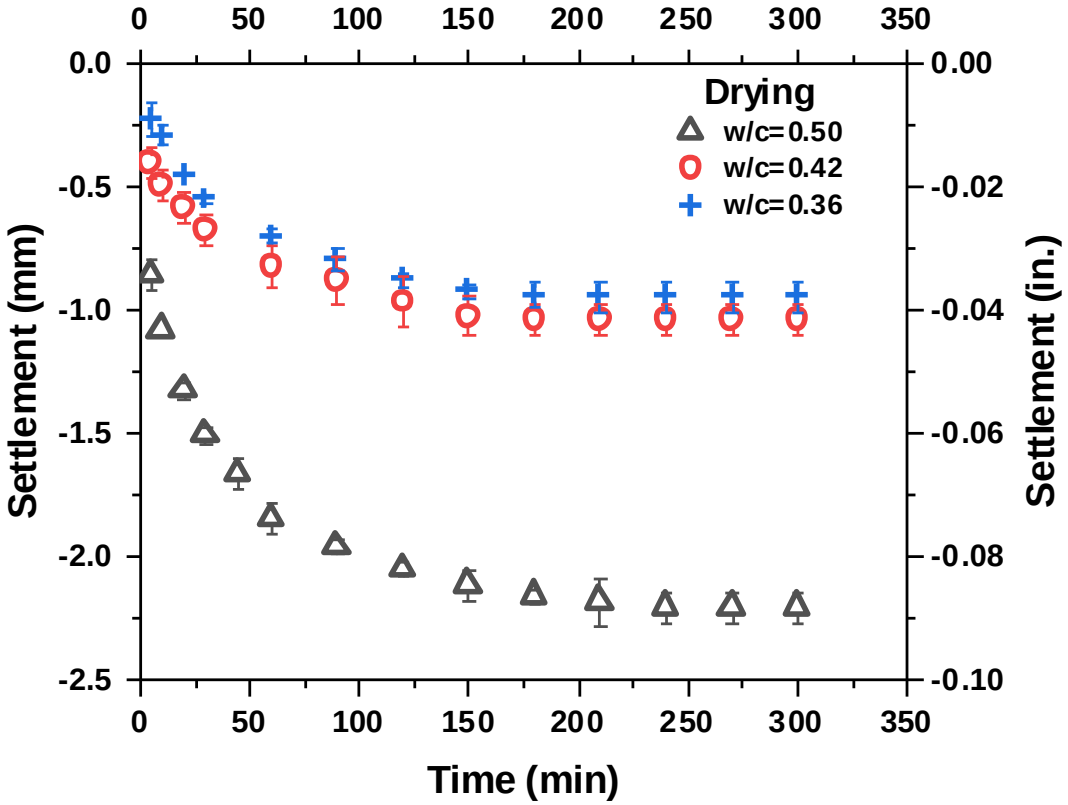
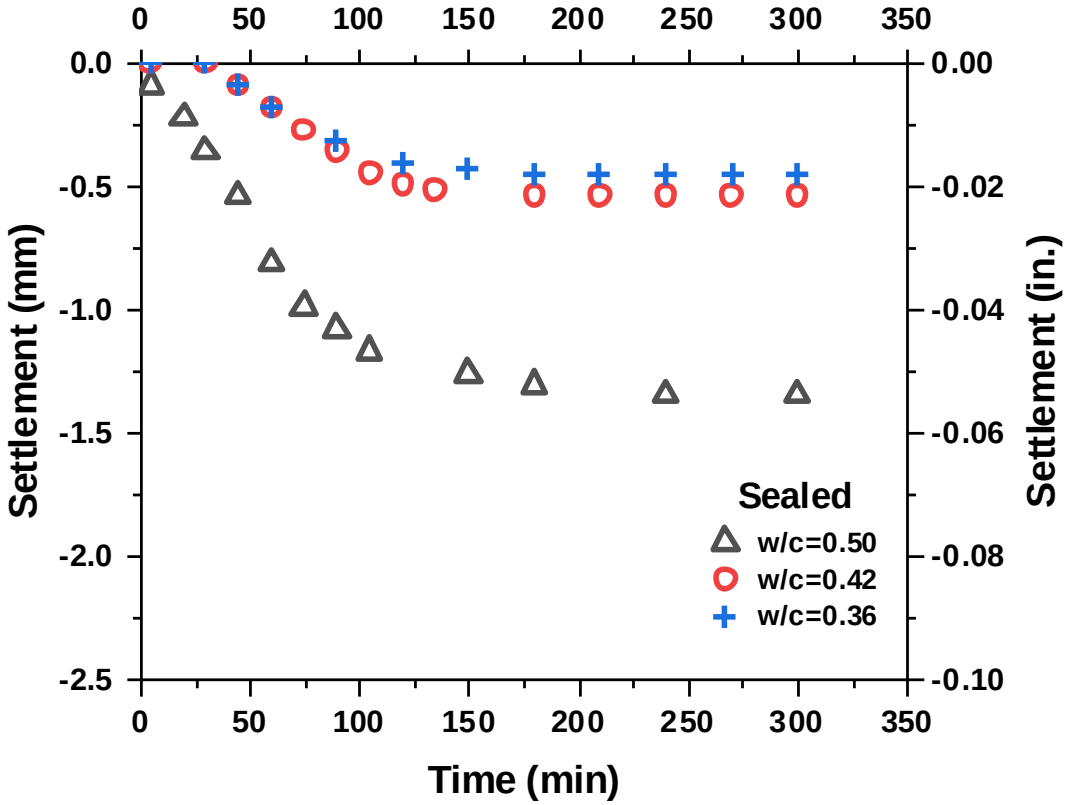


Drying



Sealed

Results – Settlement

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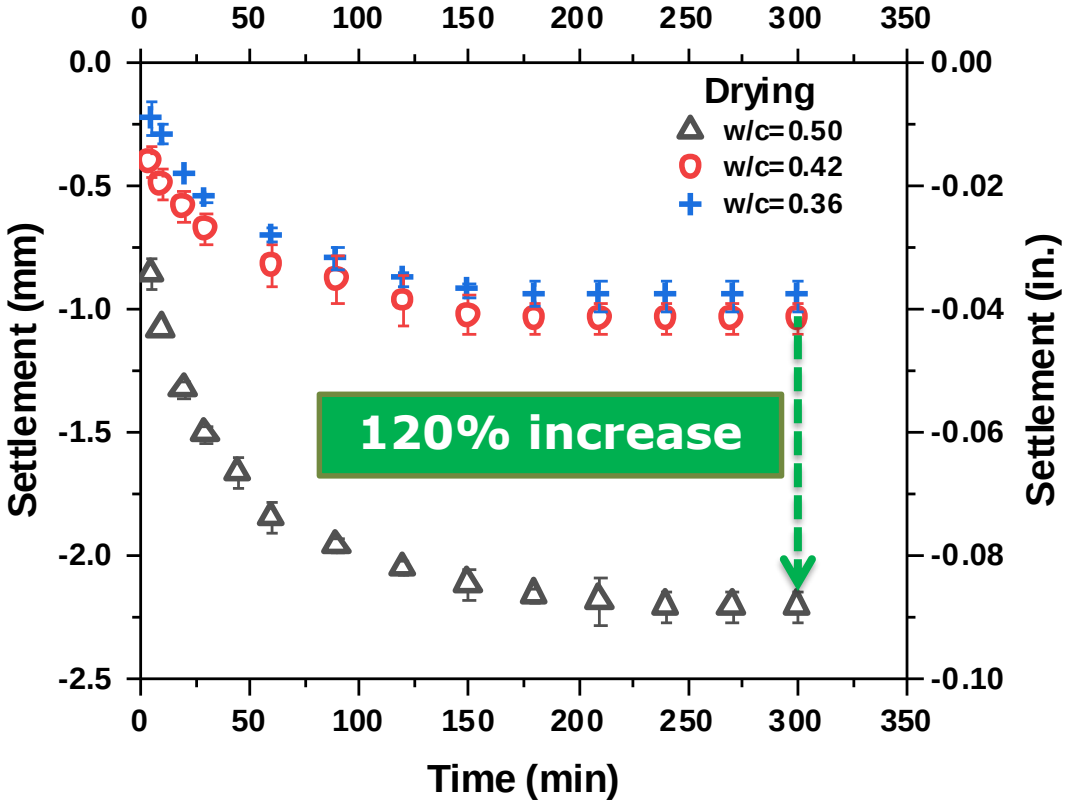
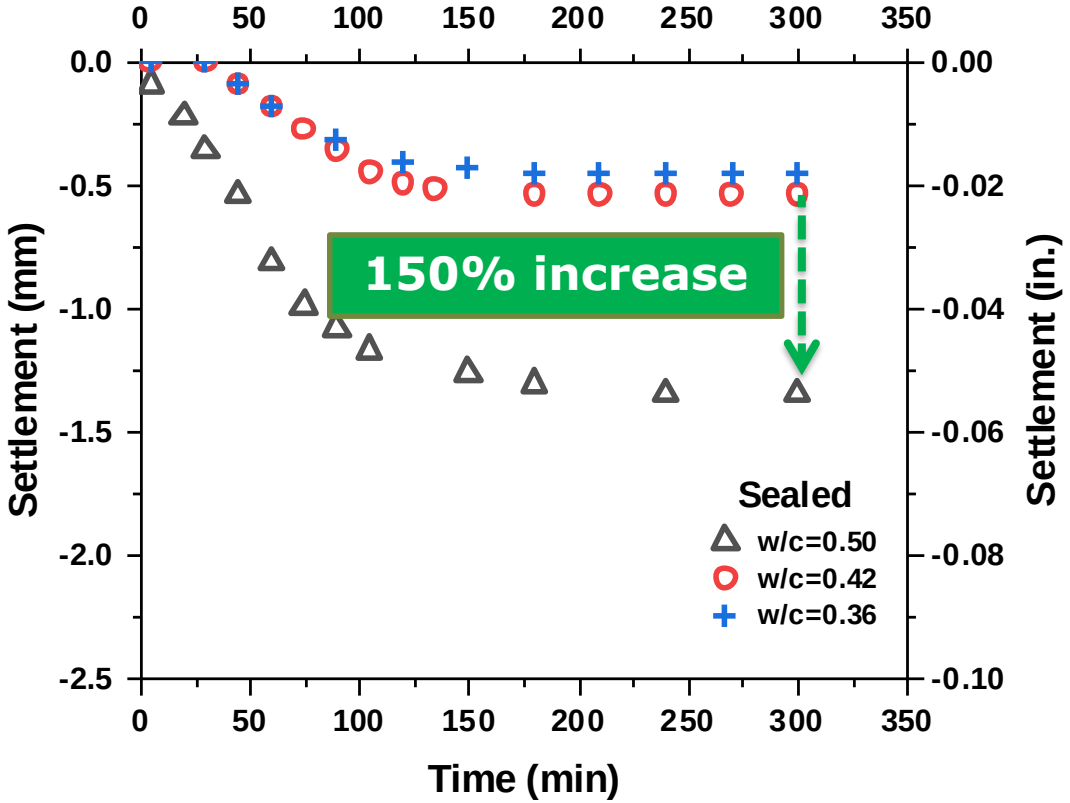
Impact of w/c



Drying



Sealed

Results – Settlement

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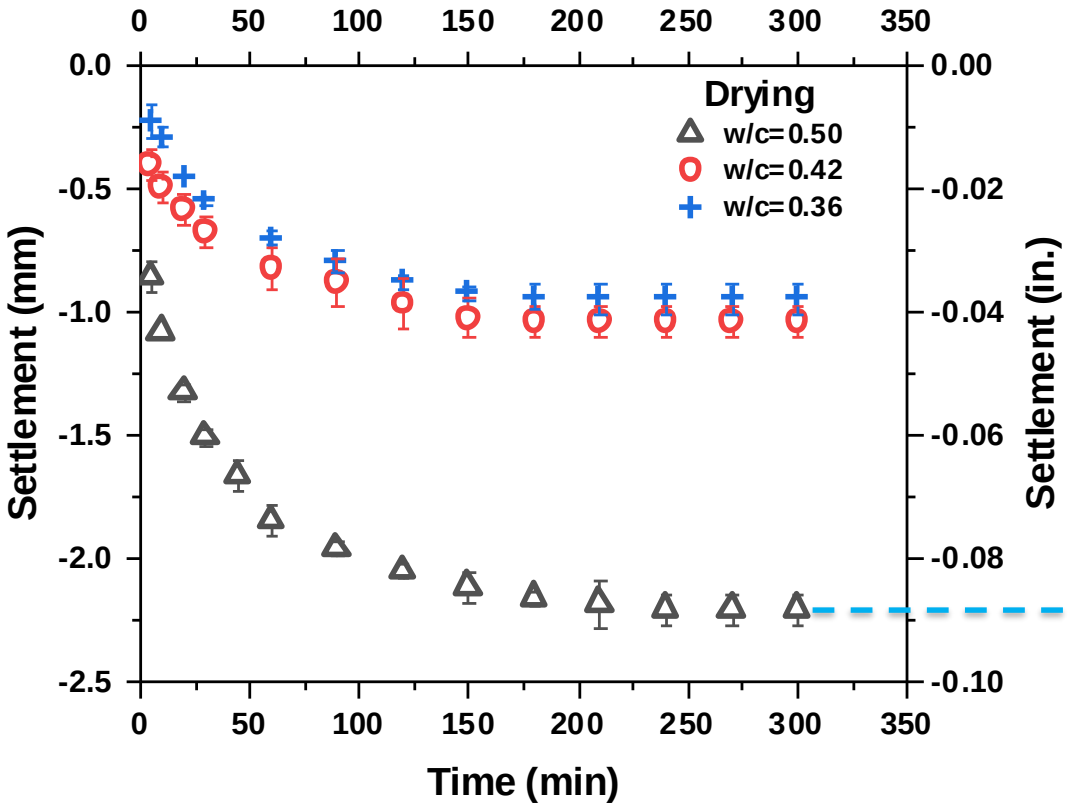
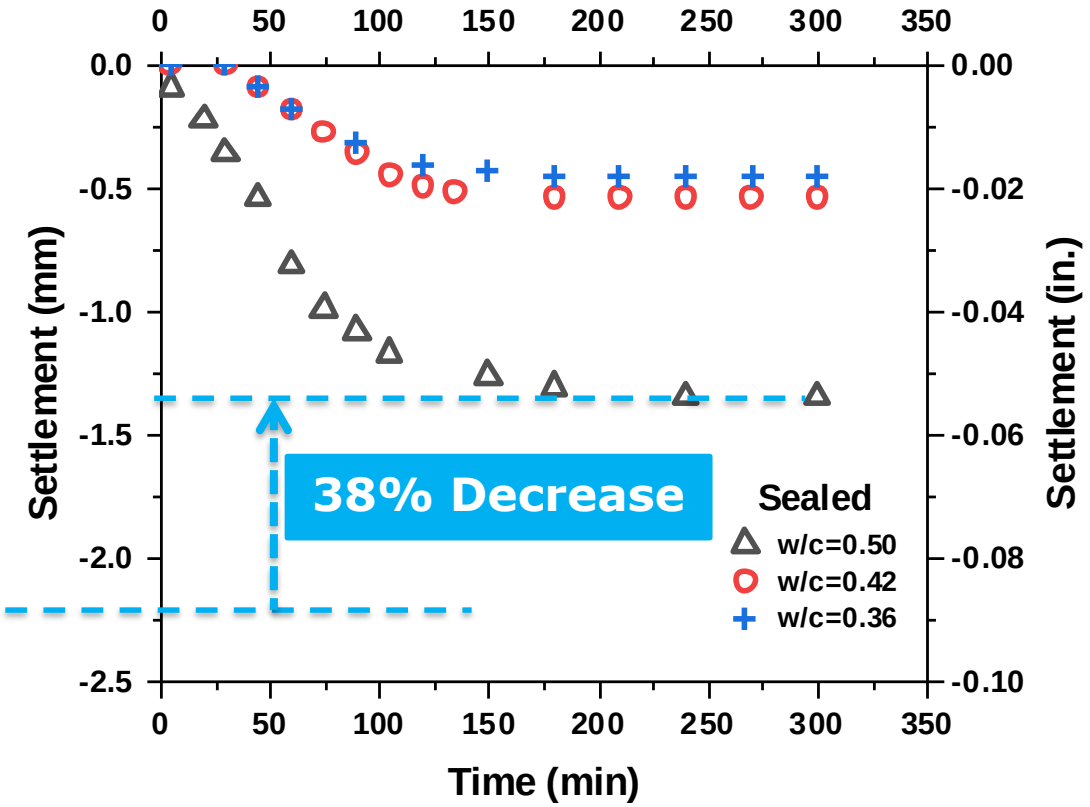
Impact from conditioning





Drying

Sealed

Results – Cumulative Mass loss

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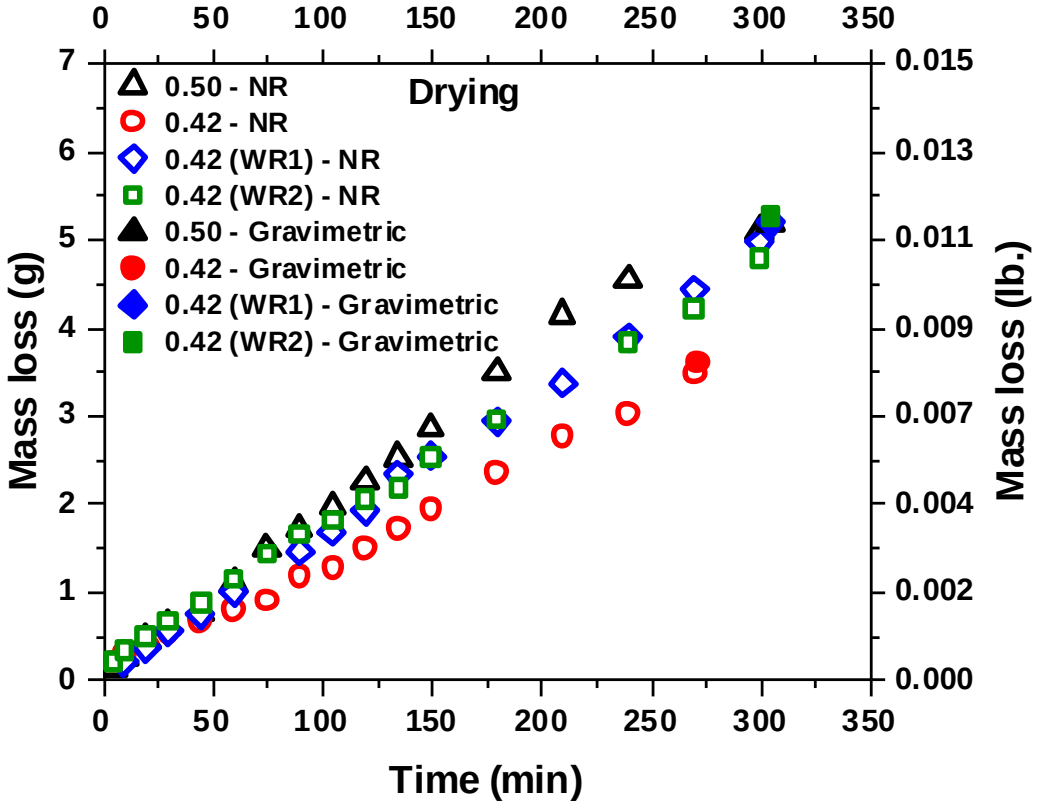
Impact of Water Reducer



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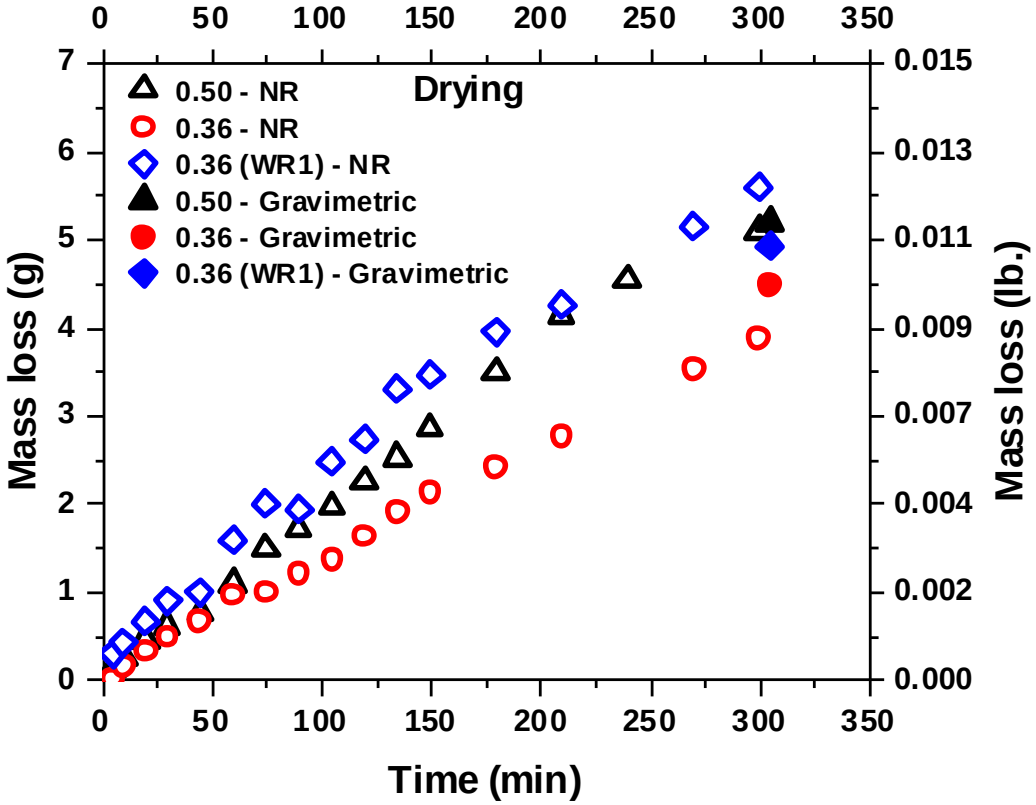

w/c=0.36

Results – Settlement

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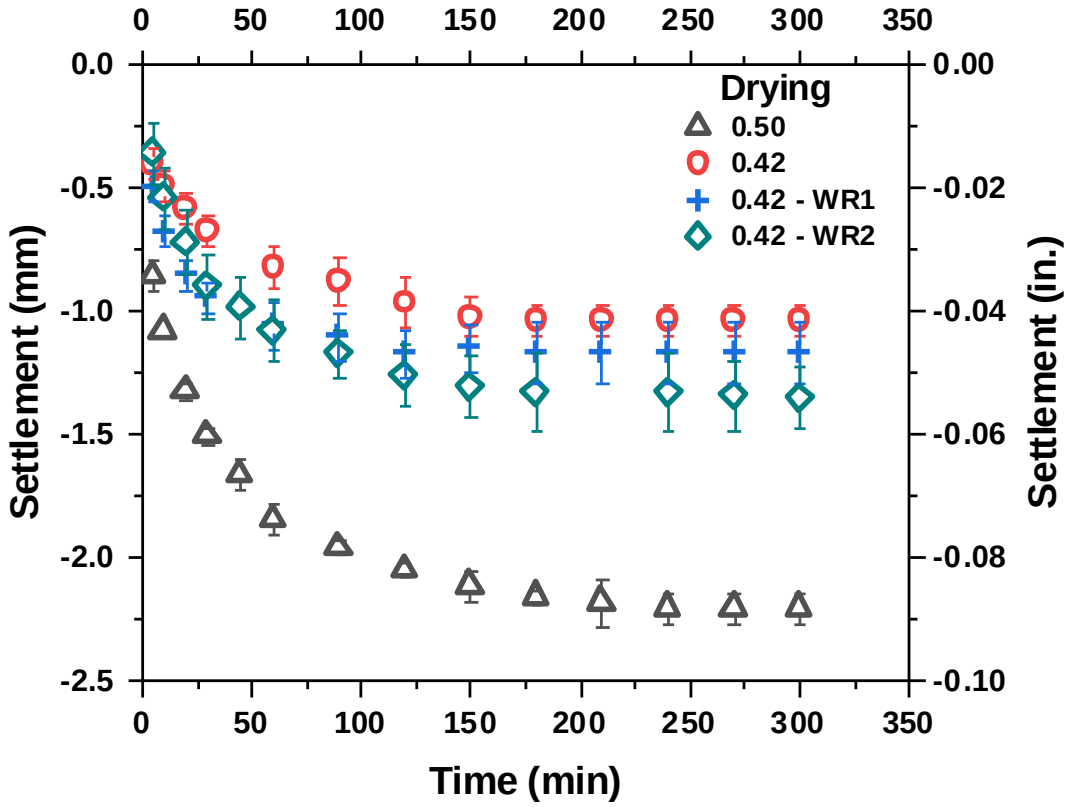
Impact of Water Reducer - Drying



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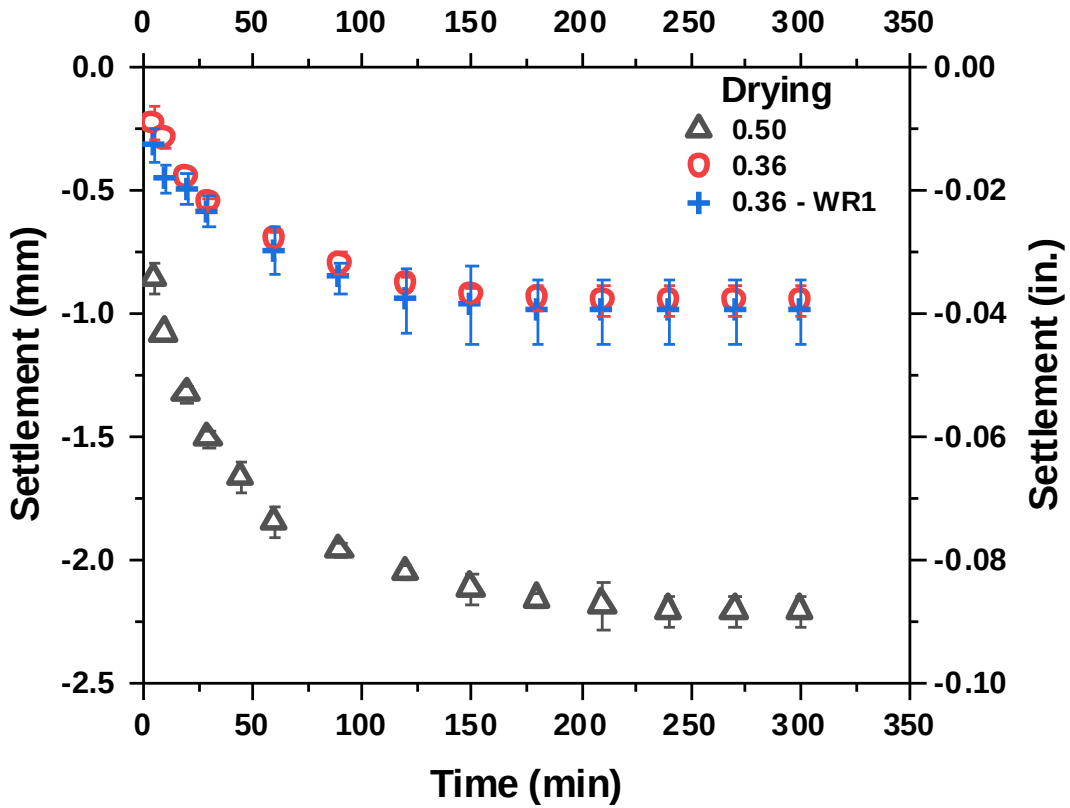

w/c=0.36

Results – Settlement

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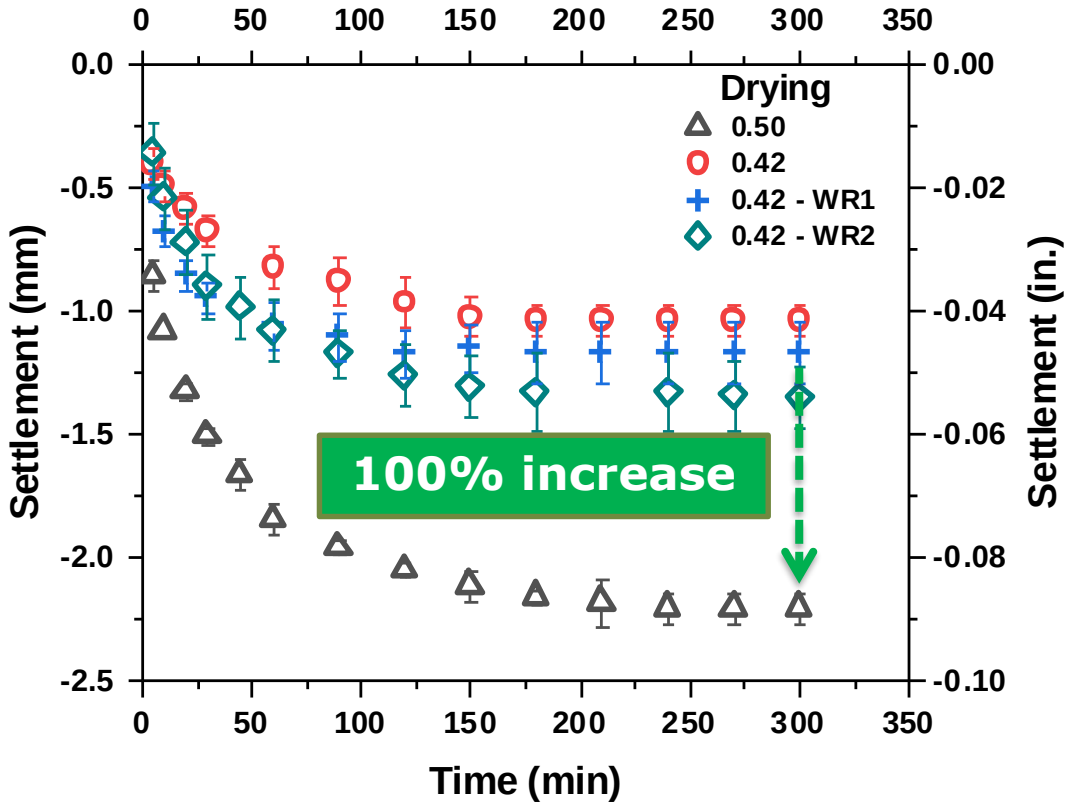
Impact of Water Reducer - Drying



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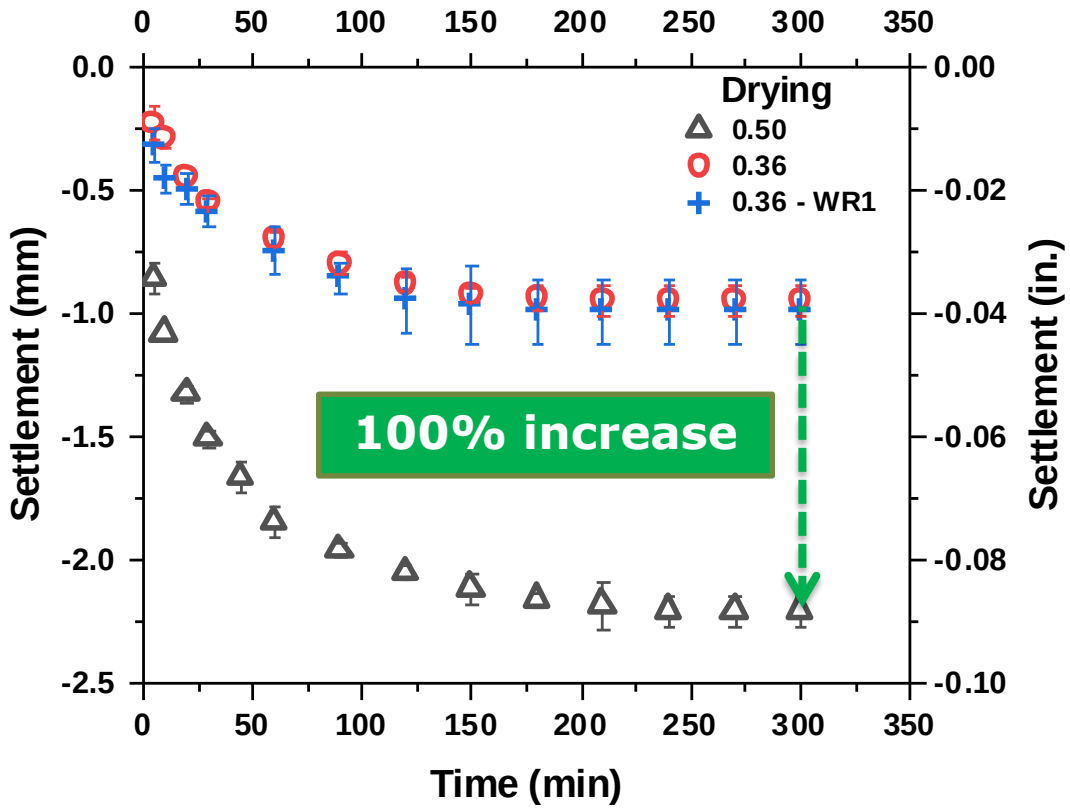

w/c=0.36

Results – Settlement

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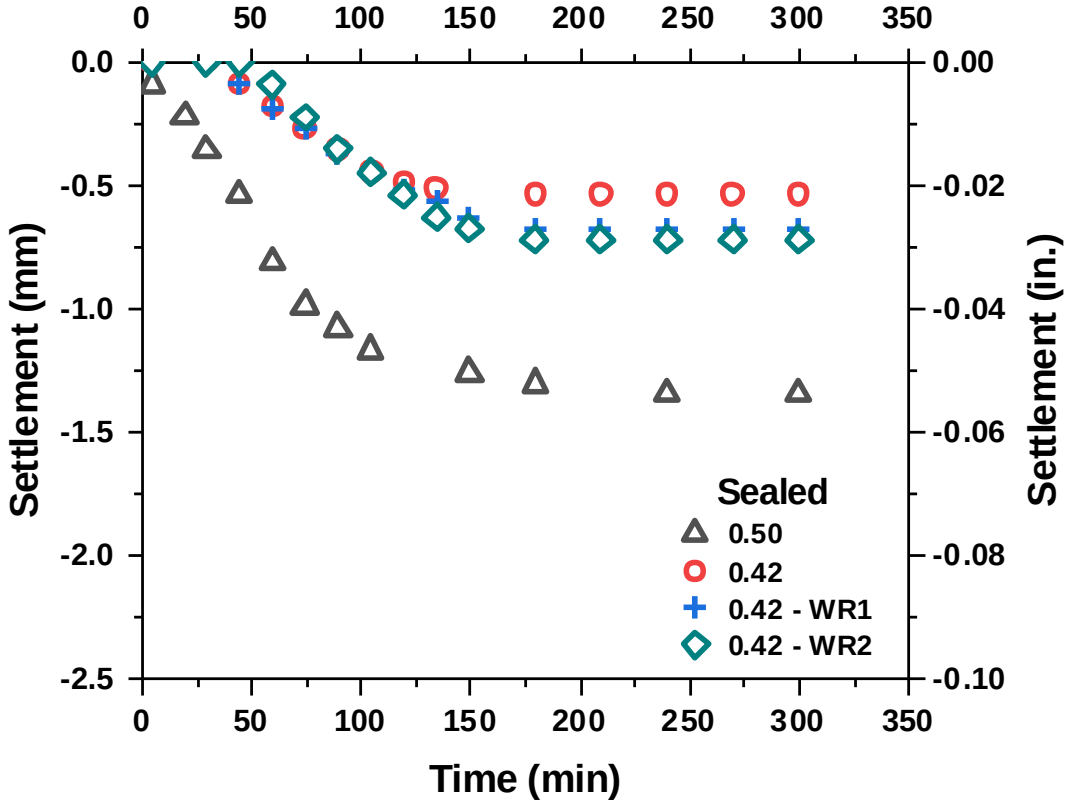
Impact of Water Reducer - Sealed



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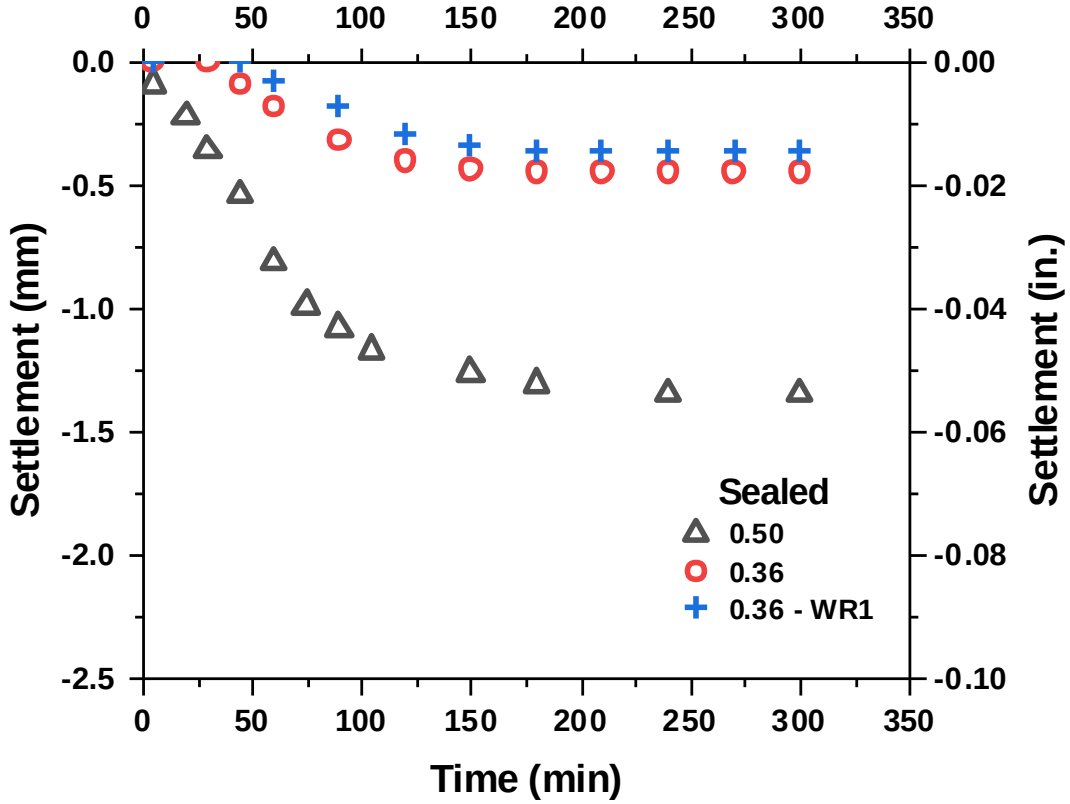

w/c=0.36

Discussion – Settlement

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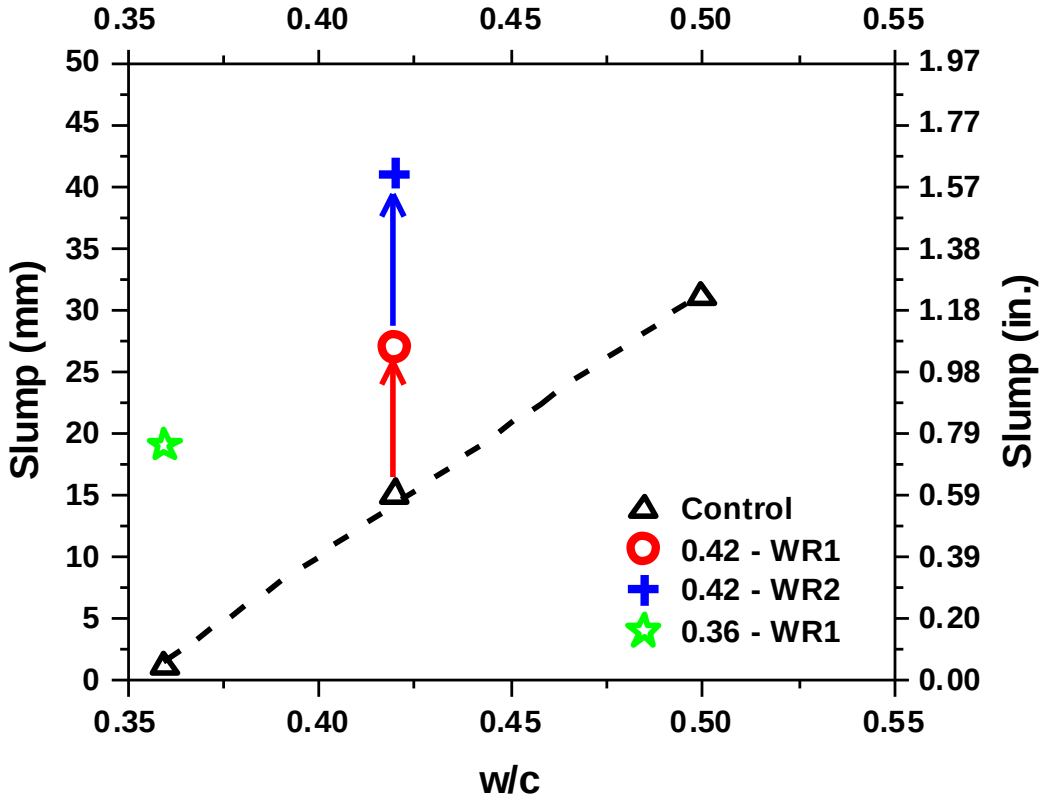
Impact of Water Reducer - Drying



Slump vs. w/c

Discussion – Settlement

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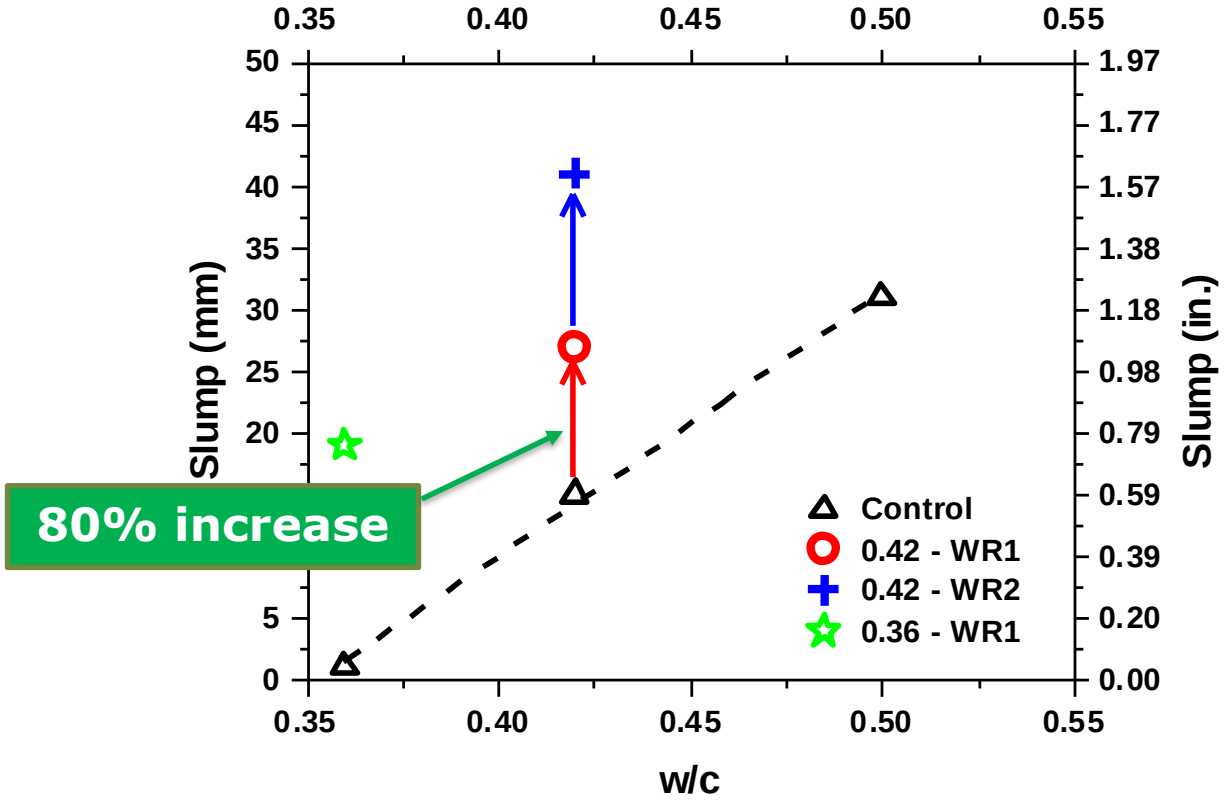
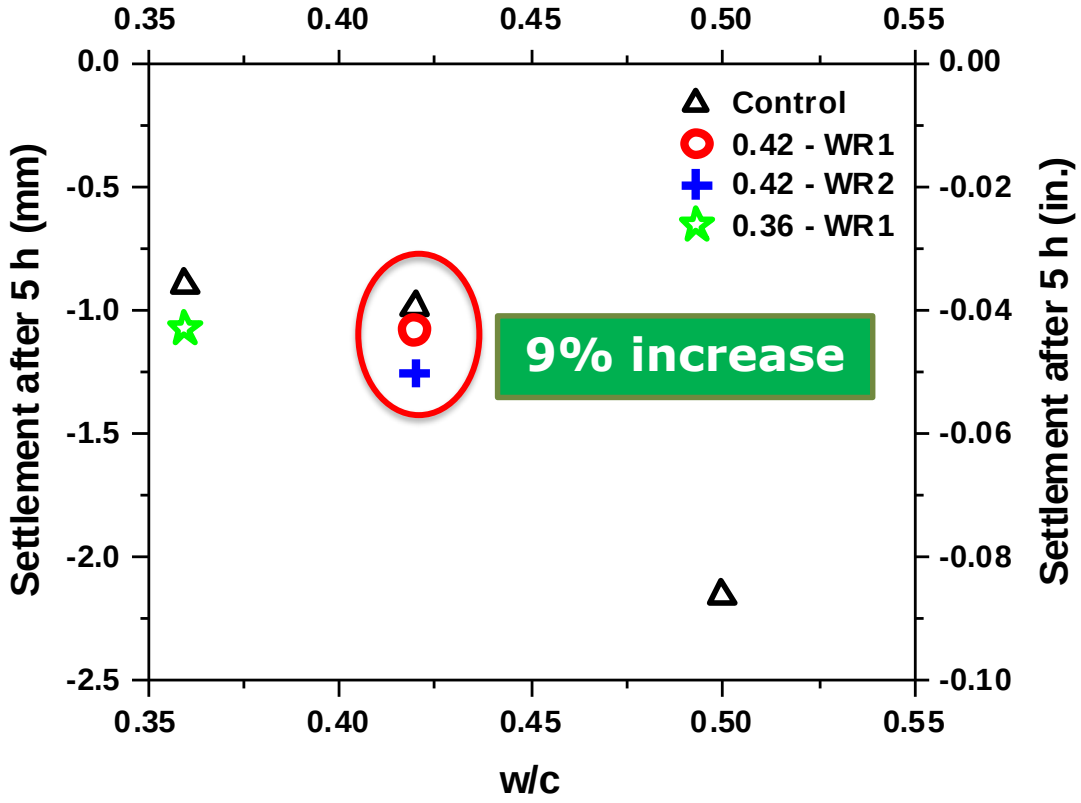
Impact of Water Reducer - Drying



Slump vs. w/c



Settlement vs. w/c

Discussion – Settlement

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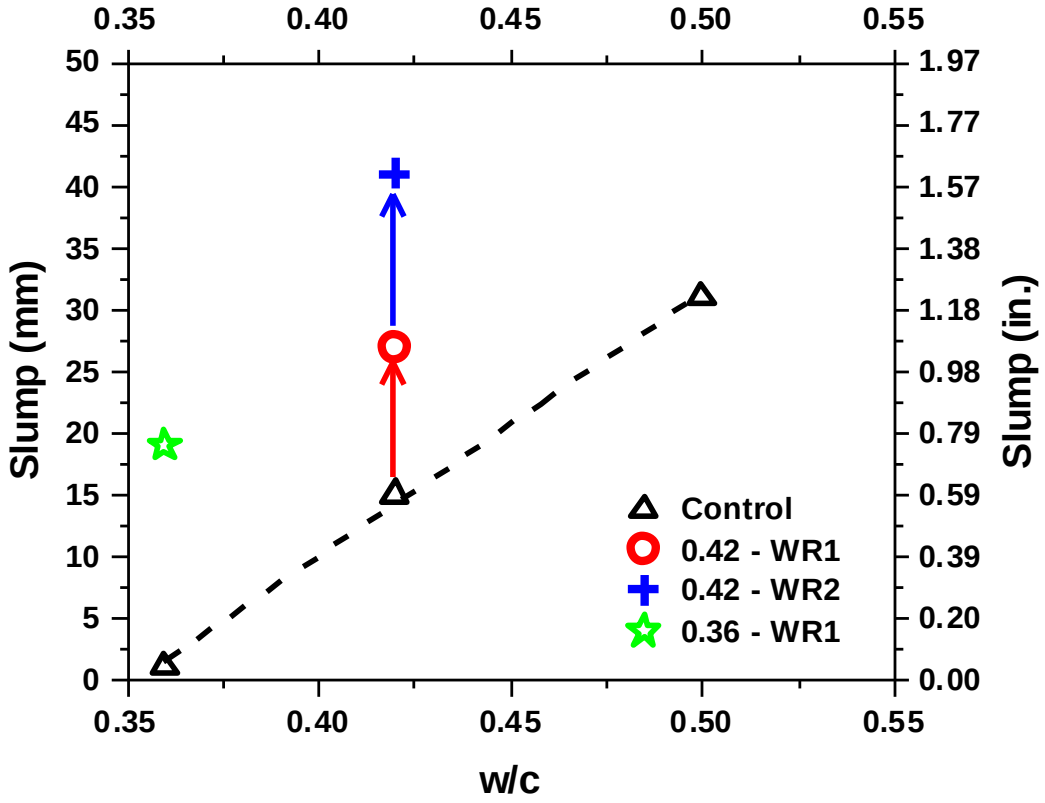
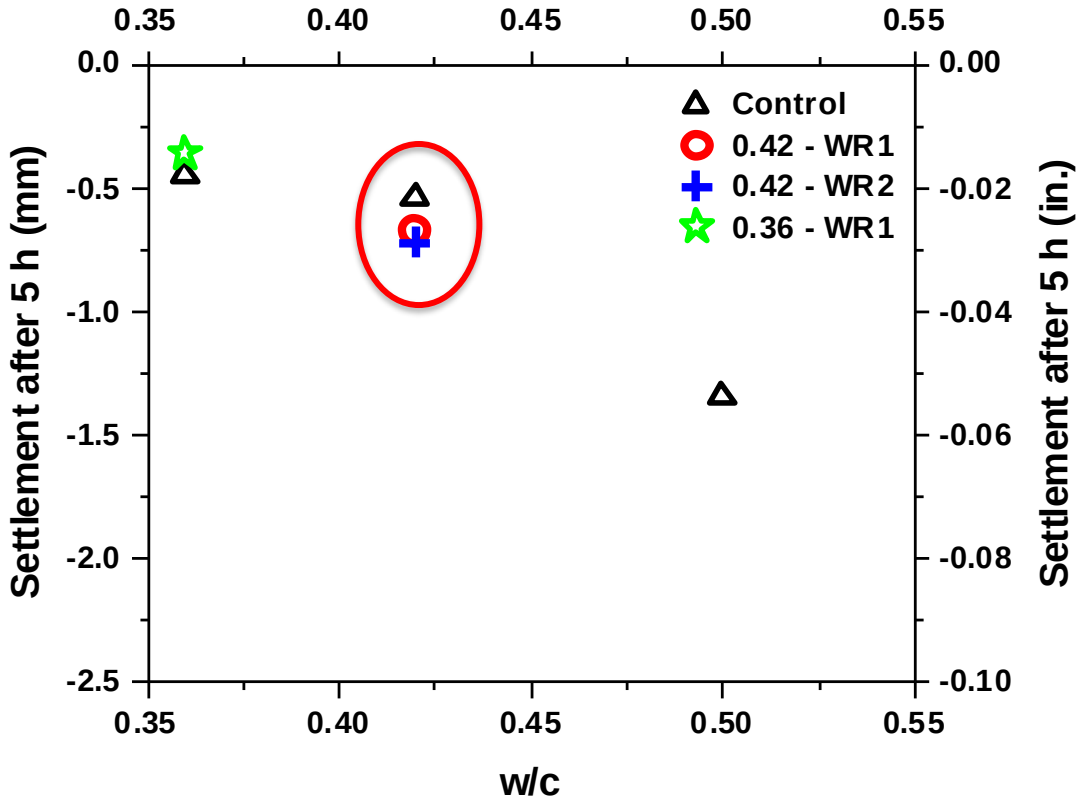
Impact of Water Reducer - Sealed



Slump vs. w/c



Settlement vs. w/c

Discussion – Settlement

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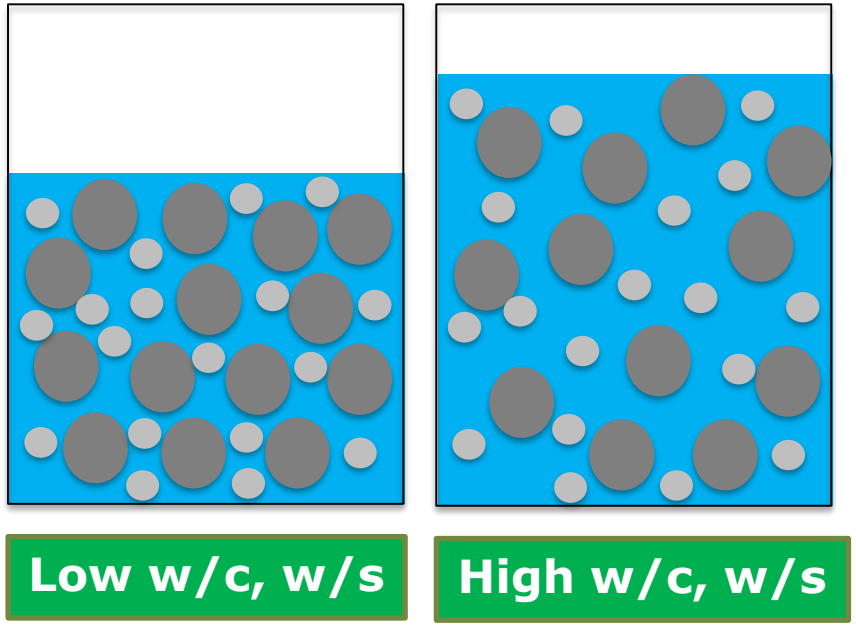


Cement
Sand
Water

$$Settlement = f(Permeability) = f(\frac{w}{c}, \frac{w}{s})$$

Terzaghi's one-dimensional small strain consolidation theory

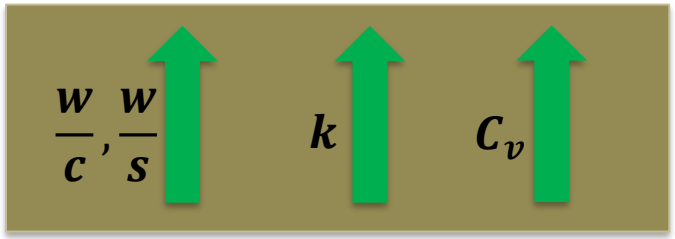
$$\frac{\partial p}{\partial t} = C_v \frac{\partial^2 p}{\partial x^2}$$

Pore pressure

Coefficient of consolidation

$$C_v = \frac{k}{\gamma_w m_v}$$

Coefficient of permeability



Kwak et al., 2010

Results – Impact of Rebar

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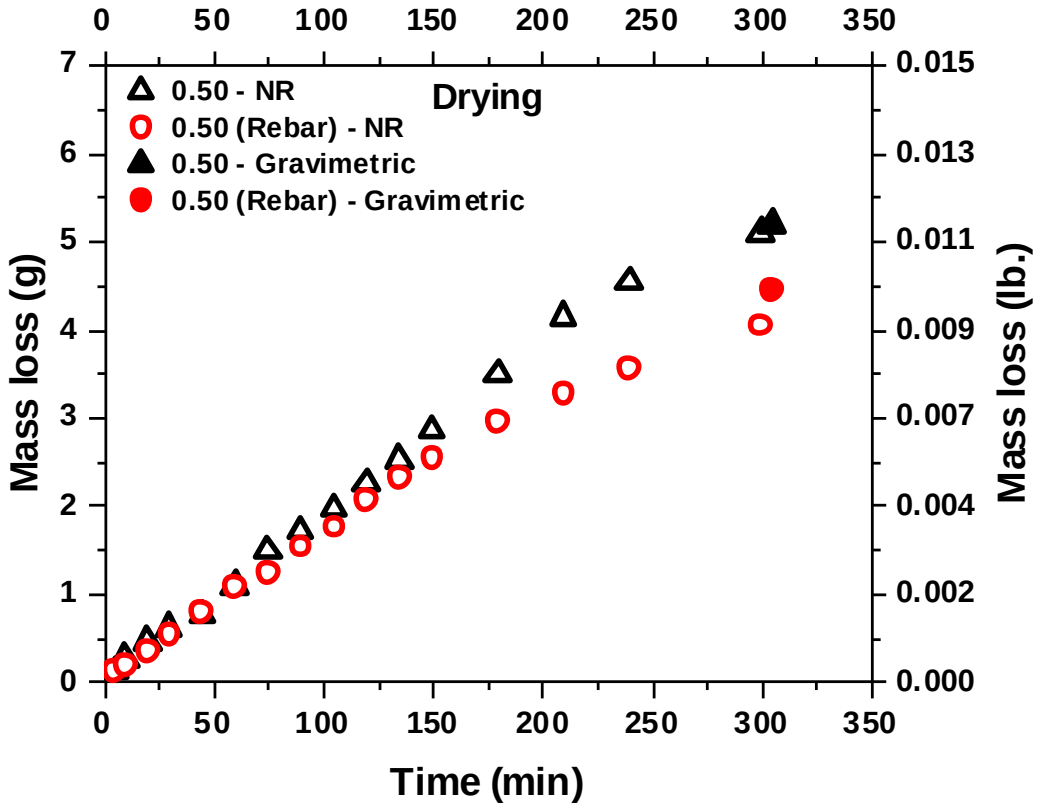
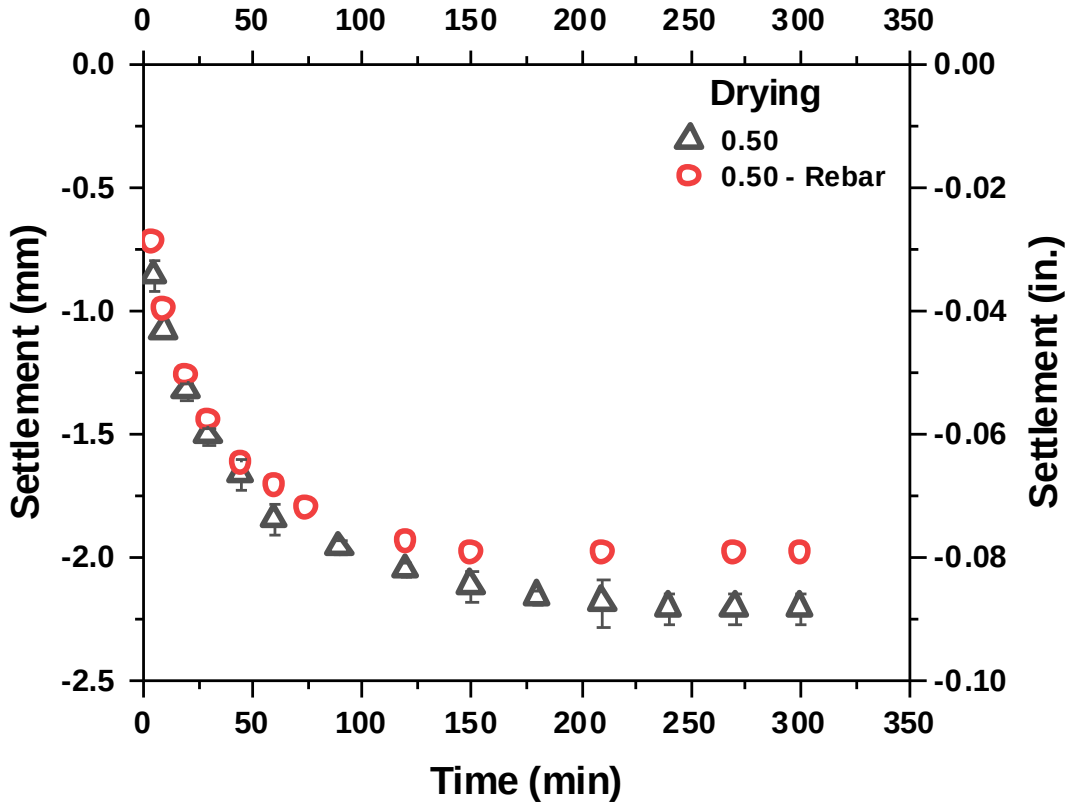
w/c=0.50



Mass loss



Settlement

Water accumulation around rebar (w/c=0.50)

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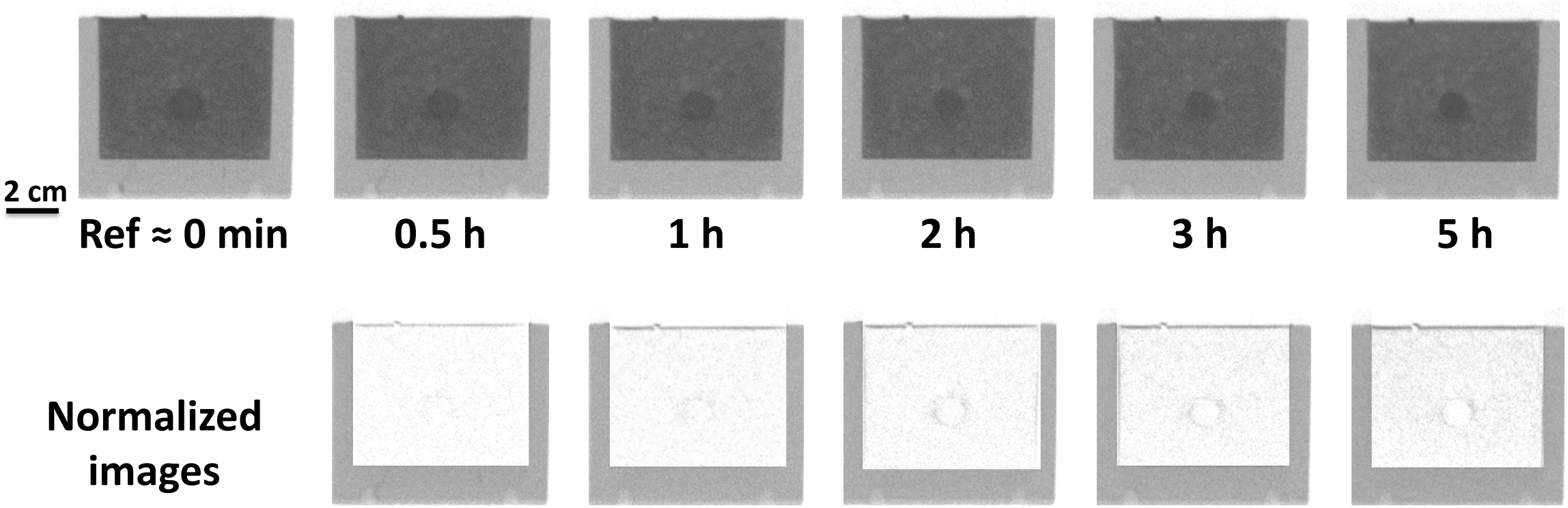

Water accumulation around rebar (w/c=0.50)

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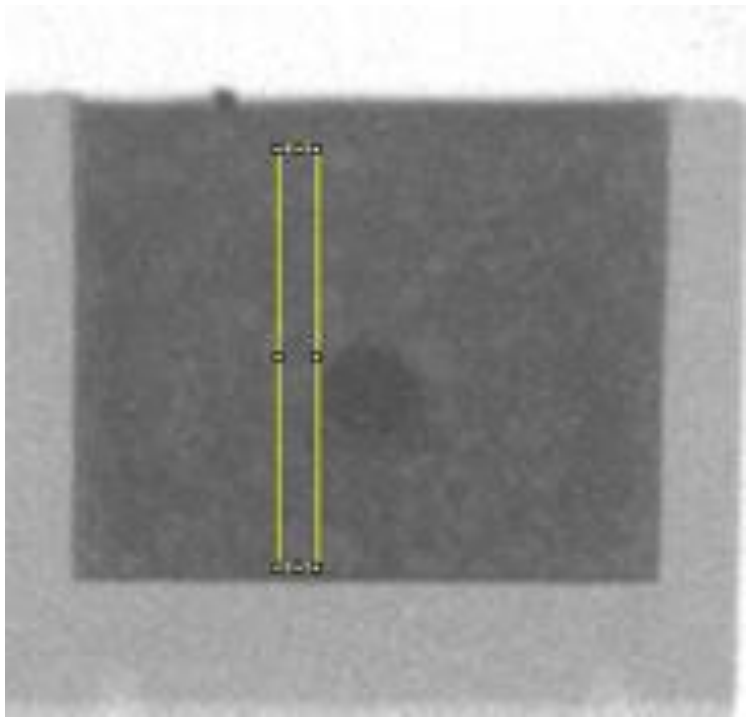

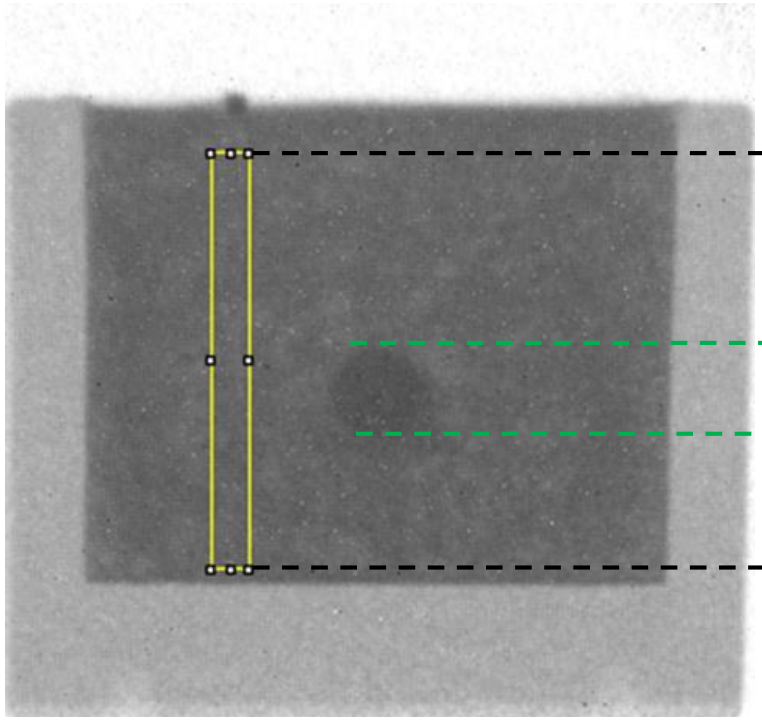

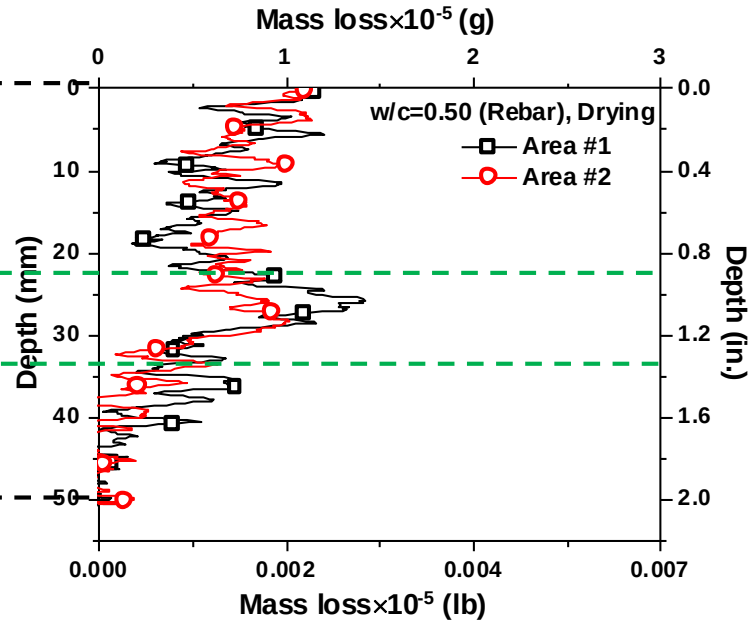

Area #1

Area #2

5 h Measurement

Summary & Conclusions

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- ✓ Settlement Increased by 120% by increasing w/c from 0.42 to 0.50. This happens because of higher permeability of matrix in mixture with w/c of 0.50.

- ✓ Sealed samples showed about a 40% decrease in settlement compared to the samples were tested in drying condition. This improvement can be attributed to reabsorption of bleeding water to the pores and the subsequent reduction in the pore pressure and tensile stresses.

Neuwald et al., 2003

Summary & Conclusions

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- ✓ Adding WR (to increase the workability) has no significant impact on mortar settlement.
- ✓ Free water accumulates around the rebar when the mortar is in a fresh state. This water seems to move to the pores over the time.
- ✓ Neutron Radiography can be used to measure the fresh concrete settlement with high spatial and temporal resolution and can quantify the volume of water change over time.

Acknowledgment

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College of Engineering

Thank You!

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