Crack Mitigation Strategies for Concrete Bridge Decks

A TIDC/MDOT Research Project

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Team Members

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- Linfei Li, Assistant Research Professor
- Eric Landis, Professor
- (Former member: Amir Haddad Kolour, Postdoc; Maedeh Orouji, PhD student)

The Problems



(Ohio DOT, 2017)



(NJ DOT, 2015)

Mitigation Strategies

- Better aggregate grading/packing (Tarantula curve) => lower cementitious content
- Internal curing (LWFA) => Internal curing

Timeline

02/27/23 – 05/24/23: Specimens from six mix designs were cast and tested

- Aggregate adsorption capacity
- 28 days compressive strength and flexural strength
- Slump measurement
- Shrinkage measurement

05/25/23-07/25/23: Supplementary tests were conducted; LWFA was introduced

- LWFA adsorption capacity
- 15% LWFA replacement
- 7/14/28 days compressive strength; 28 days flexural strength
- Slump measurement
- Shrinkage measurement
- Bulk resistivity test

07/25/23-11/06/23: Internal curing purpose

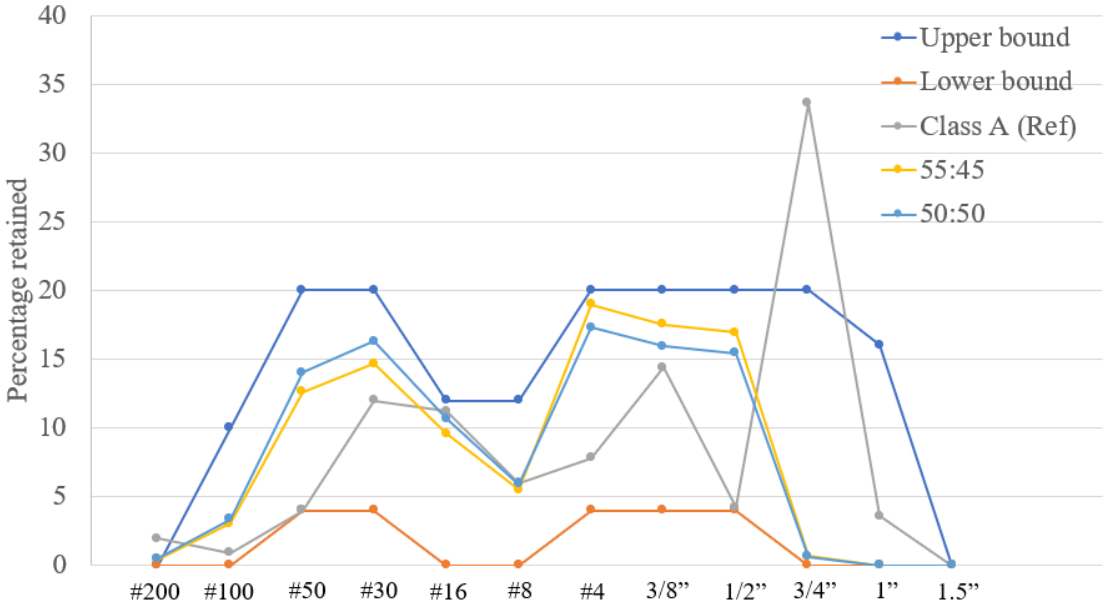
- Four mix designs with 5%, 10% LWFA replacement were cast and tested.
- Paper drafting.

Experiment 1: Aggregate size gradation

Step 1: Proportionally mix the aggregate to meet the requirement from the Tarantula curve



Source of the aggregate: Jason Folsom



- Class A concrete that is currently used with a **rock:sand=68:32** (reference from MDOT); Yellow and light blue are the adjusted aggregate ratio that can meet the requirement of the Tarantula curve.
- The reason we further change the aggregate ratio from 55:45 to 50:50 is because of the **low workability** provided. The coarse aggregate is in an angular shape, decreasing the slump (slump requirement 3-5”). As a result, we decreased the amount of coarse aggregate in the mix and added more fine aggregate instead.

Step 2: Mix design and sample preparation

Cement to Agg.	Cement(lb/yd3)	Slag(lb/yd3)	Water(lb/yd3)	Coarse (lb/yd3)	Fine (lb/yd3)	HRWR(oz/yd3)	AE(oz/yd3)	Paste (%)
0.21 (Type II)	320	320	288	1639	1341	25.6	1.92	22.71
0.21 (PLC)	320	320	288	1639	1341	25.6	1.92	22.71
0.18 (PLC)	268	268	241.5	1639	1341	30.72	1.92	20.47
0.165 (PLC)	246	246	221.4	1639	1341	38.4	1.92	19.04
0.15a (PLC)	224	224	201.5	1639	1341	43.52	1.92	17.51
0.15b (PLC)	224	224	201.5	1490	1490	43.52	1.92	17.51

- Water-to-binder ratio: 0.45
- 0.15a: 55% coarse aggregate vs. 45% fine aggregate
- 0.15b: 50% coarse aggregate vs. 50% fine aggregate
- All the samples were cast in 1 batch and cured in the moisture room with 85% R.H. and 78 °F
- 3-4 identical samples were cast for each.







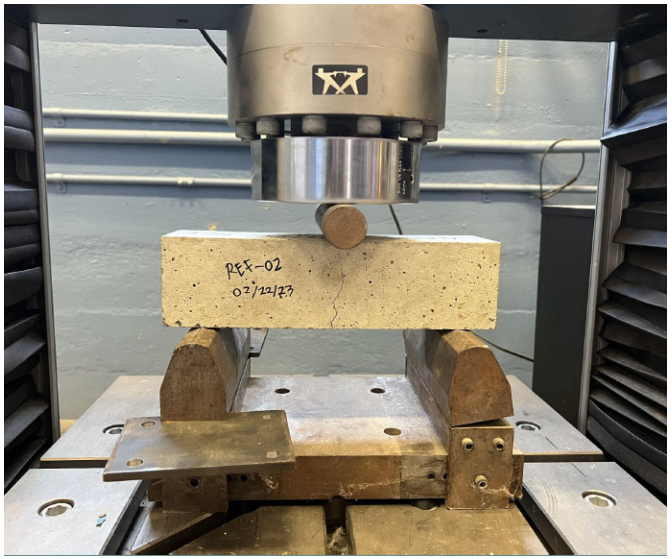









LUBRICATE SPHERICAL HEAD OFTEN

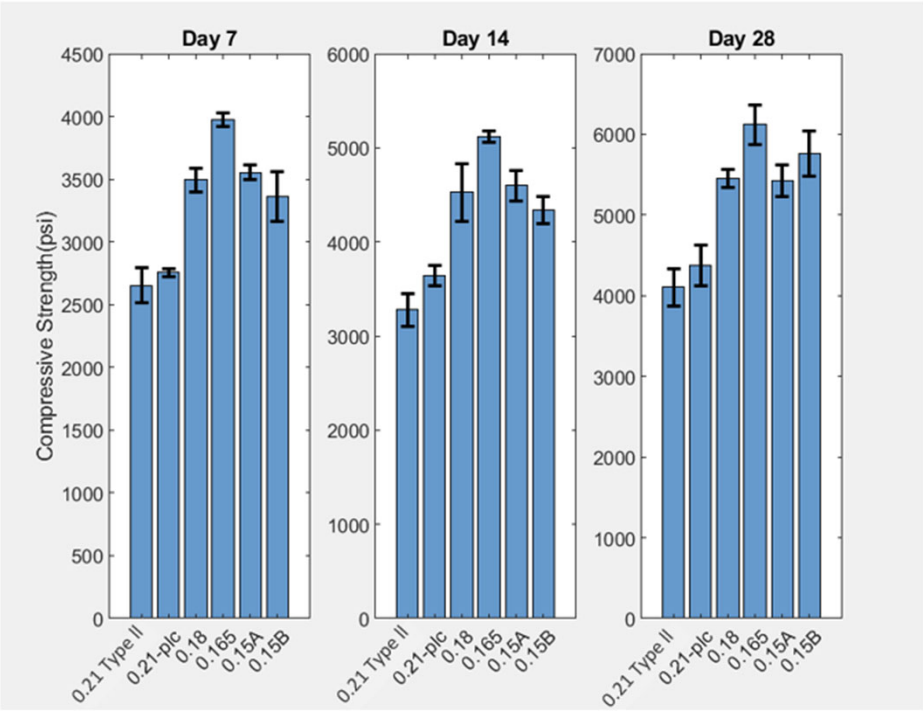

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02/12/23

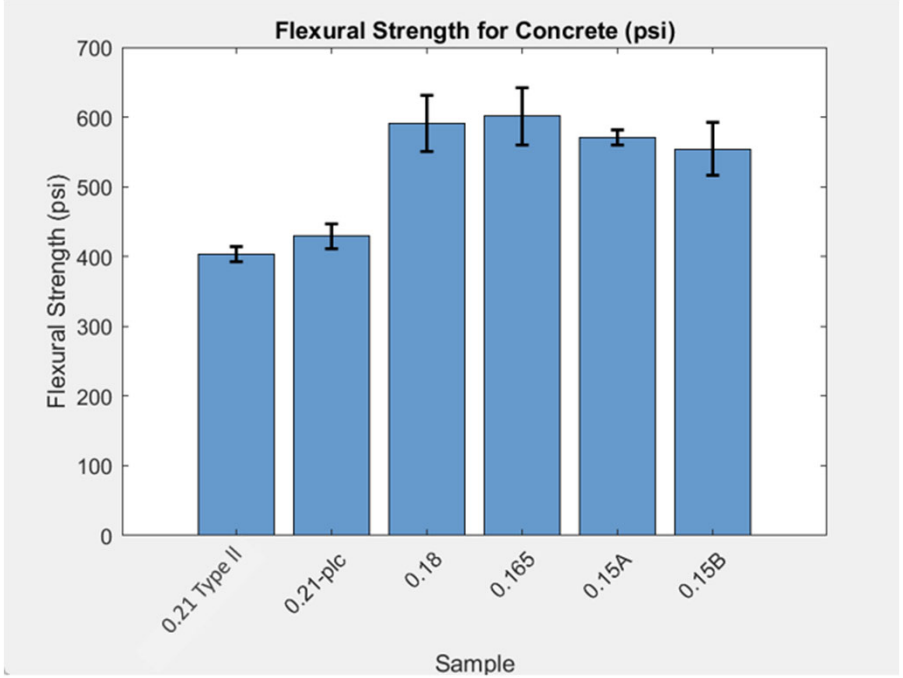

RCON
Concrete


H-3250.3
.001"
400 RANGE
HUMBOLDT
MADE IN USA

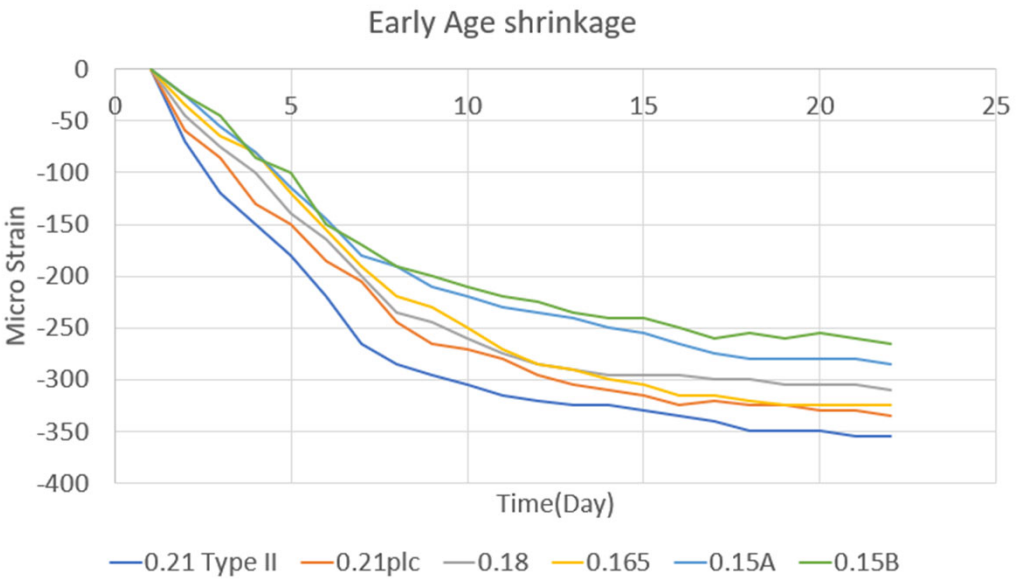
Step 3: Testing results

Cement to Agg.	0.21 (Type II)	0.21 (PLC)	0.18 (PLC)	0.165 (PLC)	0.15a (PLC)	0.15b (PLC)
Slump (in)	5.2	5.5	5	4.5	2.9	3.5





The minimum compressive strength is 4000 psi and flexural strength is about 10 of compressive strength (400 psi)



Length Change measured in accordance with ASTM C157: 500 microstrain (0.05%) at 28 days of drying.

Chloride Penetration	56-Day Rapid Chloride Permeability Charge Passed (Coulombs)	28-Day Bulk Electrical Resistivity of Saturated Concrete (KΩ.CM)	28-Day Surface Resistivity Concrete (KΩ.CM) at 23° C
High	>4000	<4	<10
Moderate	2000-4000	4 - 8	10 - 15
Low	1000-2000	8 - 16	15 - 25
Very Low	100-1000	16 - 190	25 - 200
Negligible	<100	>190	>200

(www.giatecscientific.com)

Paste to Agg.	Bulk Resistivity(KΩ.cm) 56 days	Bulk Resistivity(KΩ.cm) 28 days
0.21 (Type II)	21.2	14.5
0.21 (PLC)	23.1	15.4
0.18 (PLC)	23.7	15.8
0.165 (PLC)	24.2	16
0.15a (PLC)	24.4	16.2
0.15b (PLC)	24.5	16.4

Conclusion & recommendation:

(1) Strength: B/A = **0.165** > 0.15 = 0.18 > 0.21 PLC > 0.21 Type II

(2) Durability: B/A = **0.15** > 0.18 > 0.165 = 0.21 PLC > 0.21 Type II

Experiments 2: Internal curing

Step 1: Introduce lightweight fine aggregate

Adsorption capacity of aggregate::

- Fine Aggregate (sand): ~0.68%
- Coarse Aggregate (3/4’’): ~0.61%

Source of the aggregate: Jason Folsom

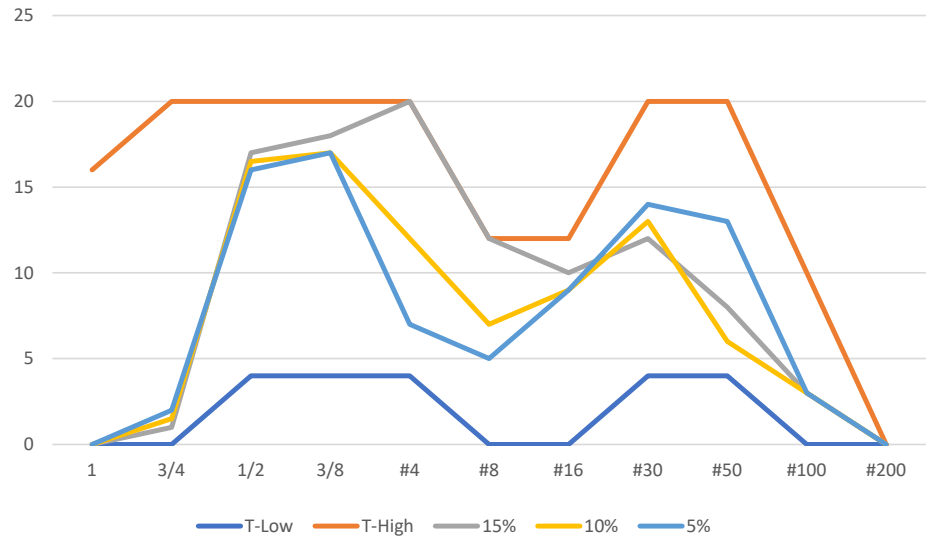
- Lightweight fine aggregate: ~24%

Source of the aggregate: Norlite aggregate



Step 2: Aggregate size gradation and mix design

Coarse Aggregate:55%
Fine Aggregate:40%; 35%; 30 %
Lightweight Aggregate: 5%; 10%; 15%

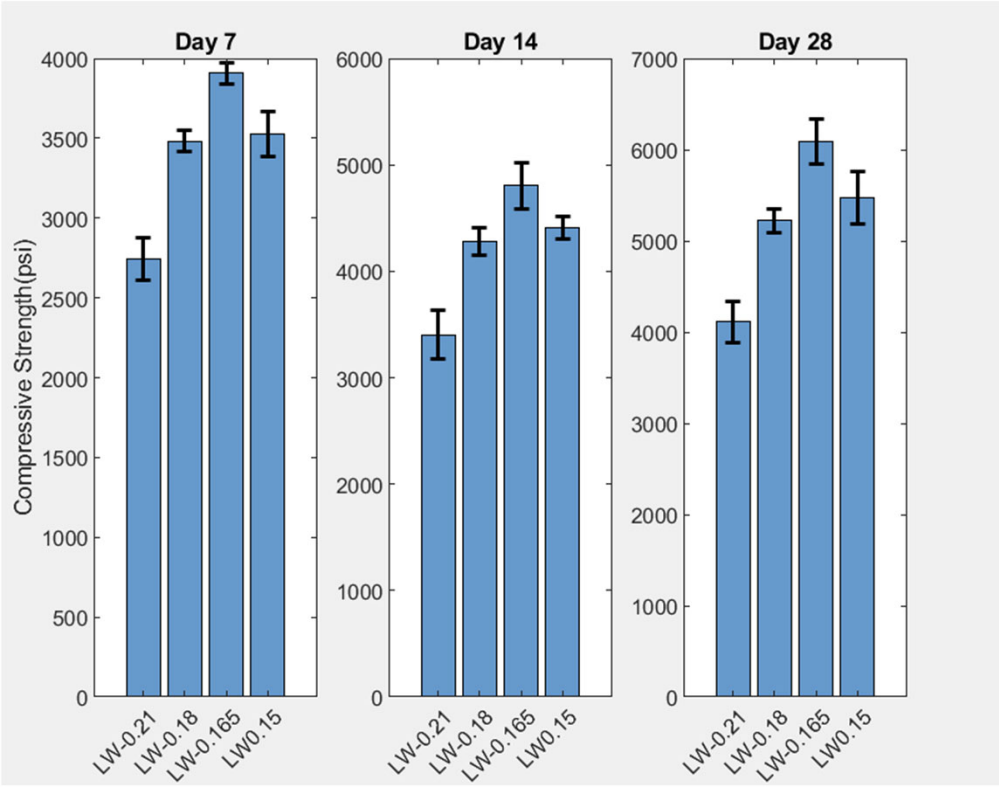


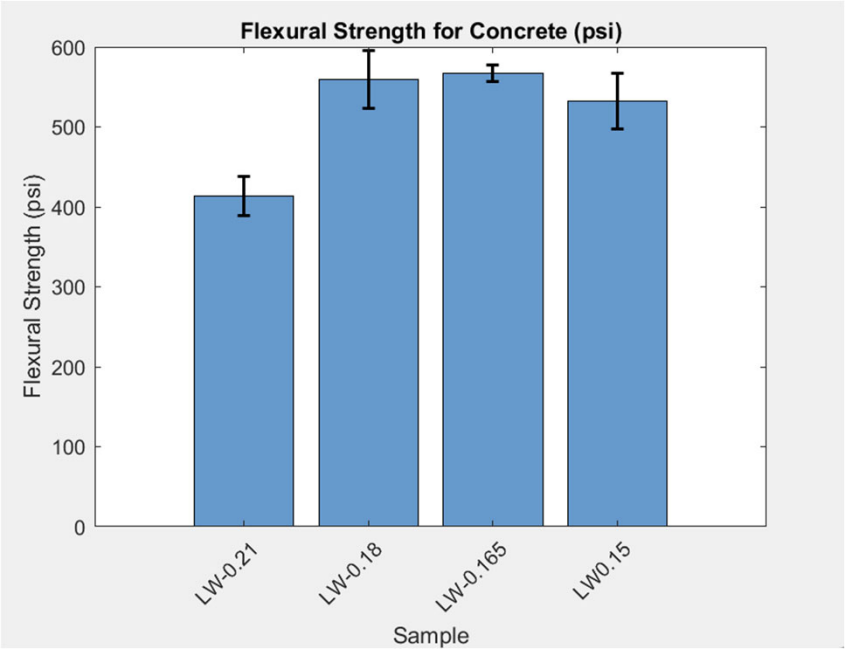
Cement to Agg.	Cement(lb/yd3)	Slag(lb/yd3)	Water(b/yd3)	Coarse (lb/yd3)	Fine (lb/yd3)	LWA (lb/yd3)	HRWR(oz/yd3)	AE(oz/yd3)	**Paste to all (%)**
0.21 (PLC)	320	320	244	1639	1192/1043/894	149/298/447	25.6	1.92	**22.71**
0.18 (PLC)	268	268	241.5	1639	1192/1043/894	149/298/447	30.72 (+20%)	1.92	**20.47**
0.165 (PLC)	246	246	221.4	1639	1192/1043/894	149/298/447	38.4 (+50%)	1.92	**19.04**
0.15a (PLC)	224	224	201.5	1639	1192/1043/894	149/298/447	43.52 (+70%)	1.92	**17.51**

Cement to Agg.	Slump (in) 15% rep	10%	5%
0.21 (PLC)	5.7	5.5	5.3
0.18 (PLC)	5.4	5.3	5.1
0.165 (PLC)	4.9	4.7	4.8
0.15a (PLC)	3.6	3.4	3.4

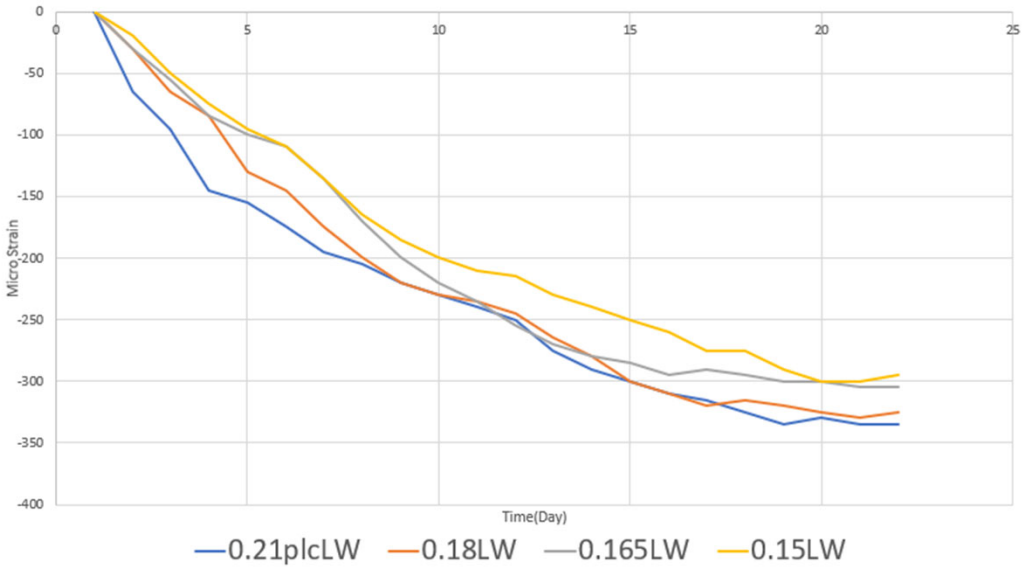
Step 3: Testing results

5% LWA replacement:





The minimum compressive strength is 4000 psi and flexural strength is about 10 of compressive strength (400 psi)

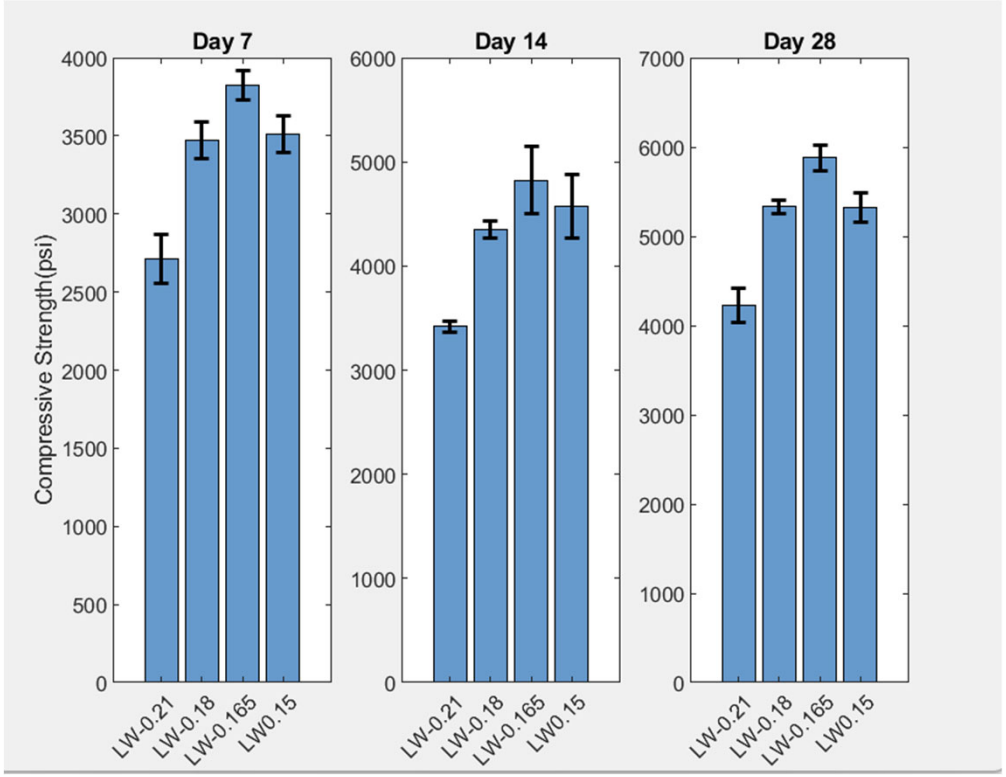


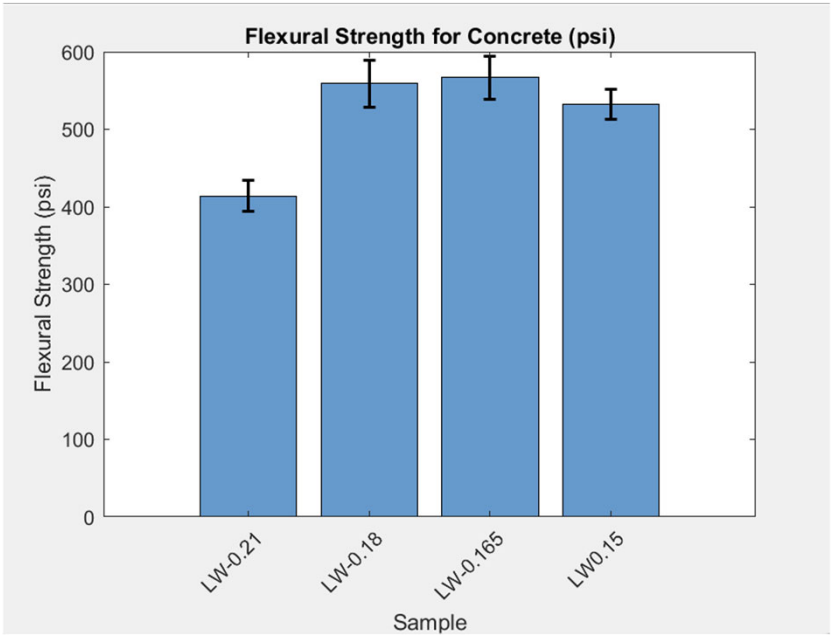
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Paste to Agg.	Bulk Resistivity(KΩ.cm) 56 days	Bulk Resistivity(KΩ.cm) 28 days
0.21 (PLC)	20.2	14.4
0.18 (PLC)	20.9	14.8
0.165 (PLC)	21.8	15.3
0.15a (PLC)	22.1	15.1

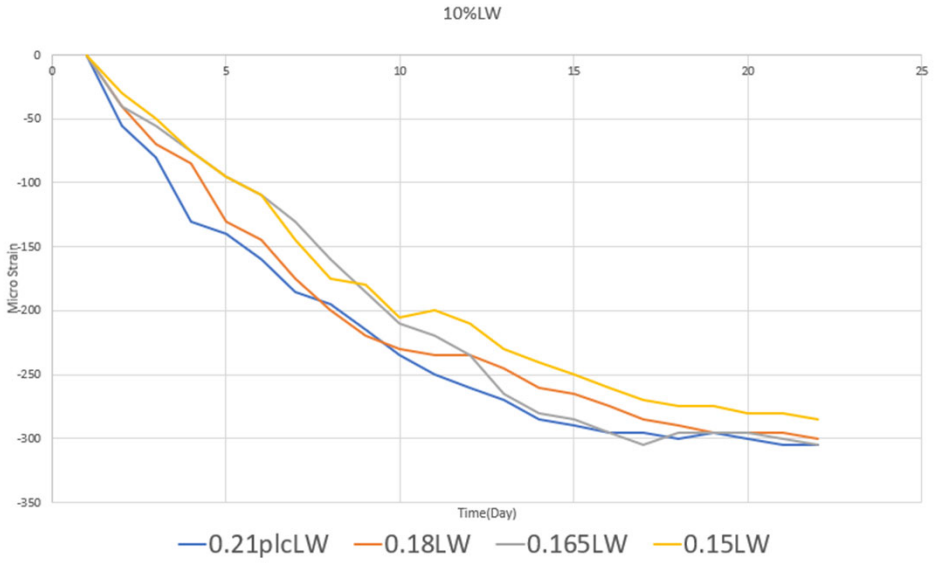
Length Change measured in accordance with ASTM C157: 500 microstrain (0.05%) at 28 days of drying.

10% LWA replacement:





The minimum compressive strength is 4000 psi and flexural strength is about 10 of compressive strength (400 psi)

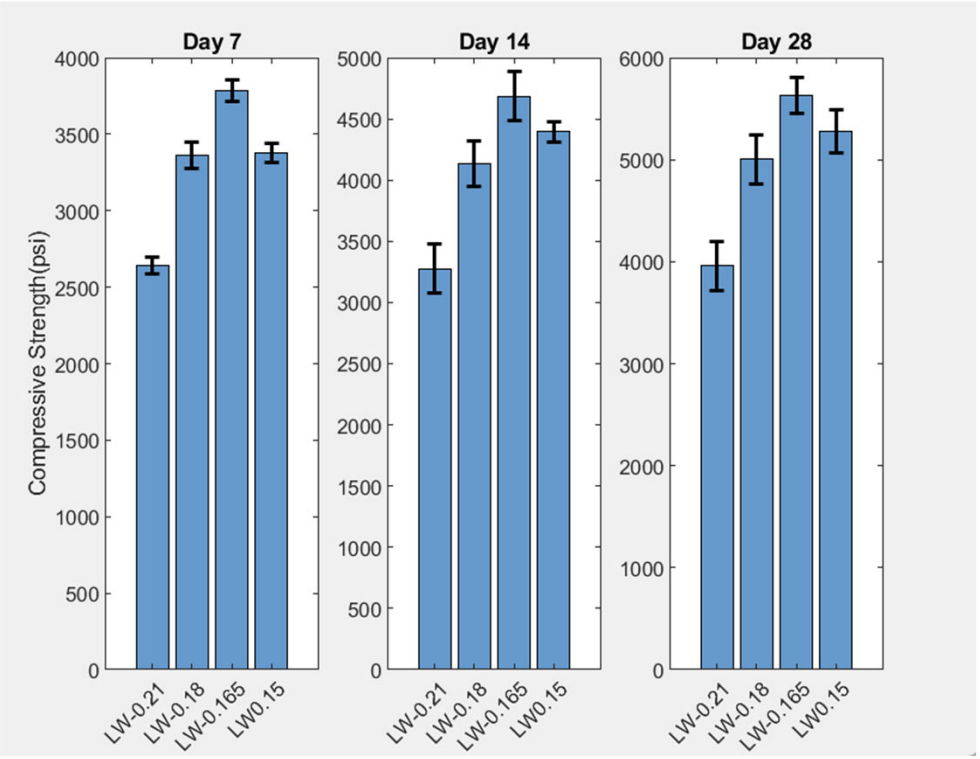


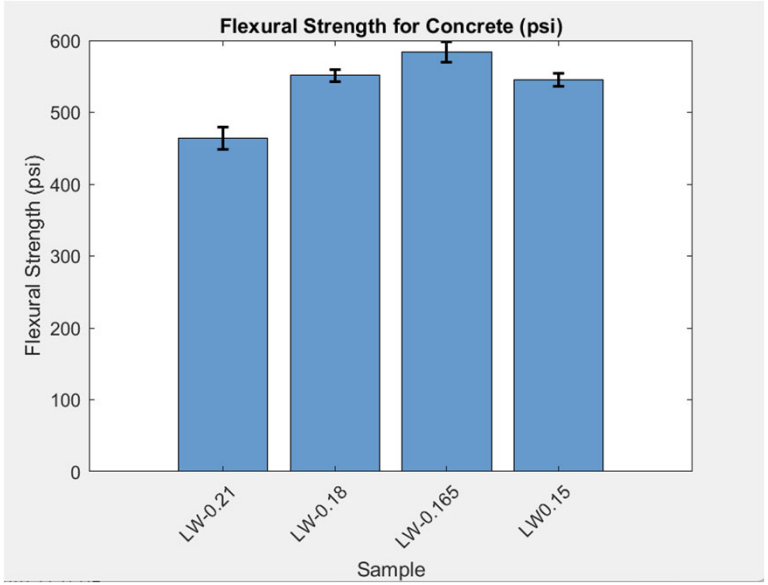
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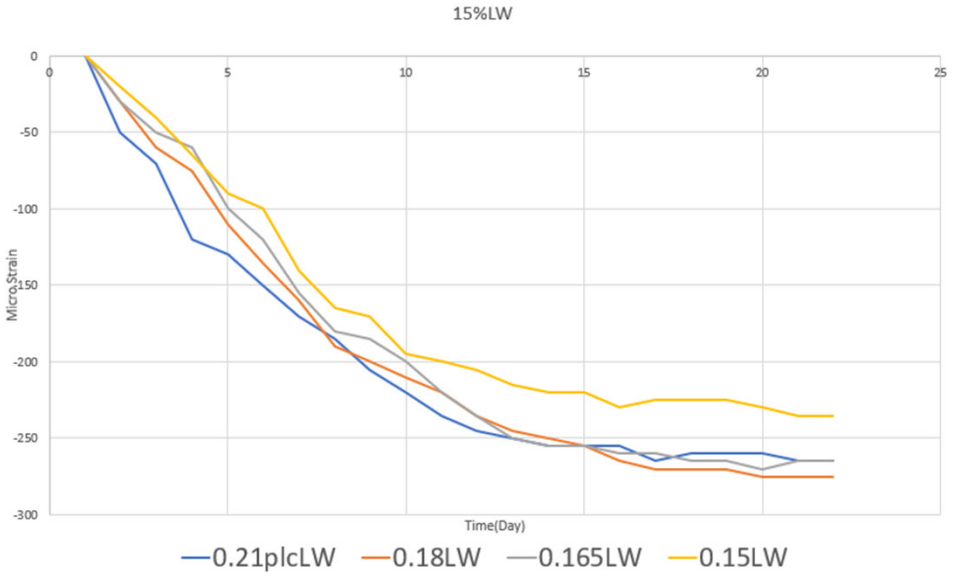
Paste to Agg.	Bulk Resistivity(KΩ.cm) 56 days	Bulk Resistivity(KΩ.cm) 28 days
0.21 (PLC)	20.1	14.1
0.18 (PLC)	21.2	15.3
0.165 (PLC)	22.2	15.4
0.15a (PLC)	22.4	15.7

15% LWA replacement:





The minimum compressive strength is 4000 psi and flexural strength is about 10 of compressive strength (400 psi)



Length Change measured in accordance with ASTM C157: 500 microstrain (0.05%) at 28 days of drying.

Chloride Penetration	56-Day Rapid Chloride Permeability Charge Passed (Coulombs)	28-Day Bulk Electrical Resistivity of Saturated Concrete (KΩ.CM)	28-Day Surface Resistivity Concrete (KΩ.CM) at 23° C
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Moderate	2000-4000	4 - 8	10 - 15
Low	1000-2000	8 - 16	15 - 25
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Paste to Agg.	Bulk Resistivity(KΩ.cm) 56 days	Bulk Resistivity(KΩ.cm) 56 days
0.21 (PLC)	20.4	14.3
0.18 (PLC)	21.6	14.9
0.165 (PLC)	22.9	15.4
0.15a (PLC)	23.7	15.7

Conclusion & Recommendation:

(1) With **5%** LWA replacement, **B/A=0.15 or 0.165** show similar shrinkage mitigation.
(2) With **10%** LWA replacement, **B/A=0.15** shows the best result, no different between 0.165 and 0.18.
(3) With **15%** LWA replacement, **B/A=0.15** still shows the best result, no difference between 0.165 and 0.18.
(4) The more LWA introduced, the lower the strengths are.
(5) The more LWA introduced, the bulk resistivity is better, and the shrinkage is lower.

B/A=0.15:

Type of Concrete	Compressive strength	Flexural strength	Last day shrinkage	56 days bulk resistivity
Regular	5424	571	290	24.5
5% LW	5279	545	285	22.1
10% LW	5136	530	265	22.4
15% LW	5084	518	230	23.7

Conclusion:

(1) Applying the Tarantula curve can lower the cement amount in the mix (**23% binder reduction**). Both strength and durability can be improved. The highest strength reached from **B/A=0.165**. The most durable mix is from **B/A=0.15**.
(2) Introducing LWFA can further mitigate the shrinkage. However, with more fine aggregate replaced by LWFA, the strength was reduced. From durability concerns, **15% replacement** is recommended with the Tarantula curve applied.

Next step:

(1) MDOT can help us find the demonstration project.
(2) Publication preparation (ongoing).
(3) Thermal cracking modeling development (ongoing).
(4) Further investigate the internal curing strategy (compare with other available technologies).

Questions and Comments?