Bridge Deck Cracking Initiatives

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Background

- Not reaching service life 20 yrs.
- Early age shrinkage cracking observed using current mix design (A45)
- Design and construction practices also influence cracking

Research Goals

3

- Develop 1-2 mix designs that increase service life of bridge decks
- Identify potential construction practice changes and shrinkage parameters through a nation-wide survey

Autogenous Shrinkage Cracking

4

- Volumetric change caused by self desiccation when insufficient water is available for the reaction with the cement paste.
- More likely to occur in high performance concrete with low w/cm ratios <0.42
- Effective mitigation techniques:
  1) Use higher w/cm ratio
  2) Eliminate highly reactive SCM's
  3) Internal curing

Drying Shrinkage Cracking

5

- Volumetric change from the movement and loss of water in hardened concrete from environmental conditions.
- Effective mitigation techniques:
  1) Use lower w/cm ratio
  2) Decrease paste volume
  3) Use shrinkage reducing admixture

6

SDDOT A45 Bridge Deck Mix Design

Minimum Cement Content[1] (lb/yd^3)	Max W/CM	Slump (in)	Entrained Air Content (%)	Minimum Coarse Aggregate Content (%)	Minimum 28-Day Compressive Strength (psi)
650 615 if well graded[2]	0.45	1-4.5	5.0-7.5	55	4500

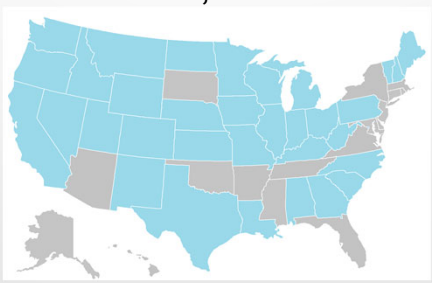
[1]The maximum cementitious content including cement and SCMs shall be 800 lb/yd^3. Class F fly ash can replace between 20-25% percent by weight of cement

[2]0.45 Power Gradation is used to conform to a well graded concrete mix

7

Nationwide DOT Survey

- 33 states responded (16 states require shrinkage testing)
- Drying shrinkage limits (ASTM C157 or AASHTO T 160)
- Slump 0-9 in. (1-3 in. typ.)
- W/cm ratio 0.32-0.50
- 0.45 power, Tarantula curve, Shilstone box, Compass software



8

Nationwide DOT Survey cont.

- Maximum cementitious content 560-718 lb/yd^3
- SCM replacement 10%-70%
  - **Fly ash** 10%-40%
  - **Slag** 10%-50%
  - **Silica fume** maximum 5%

General Changes

9

- Aggregate Type
- Aggregate Gradation
- Cement Content
- Water Content
- Admixtures
- Fly Ash Content

Aggregate Types

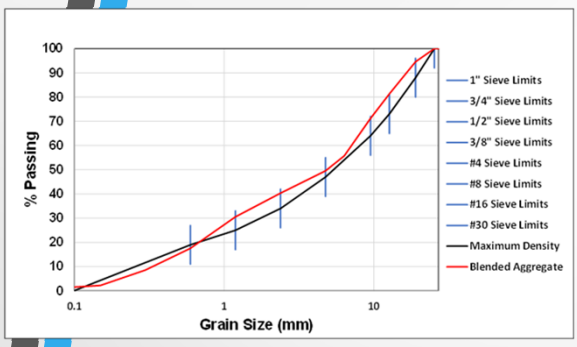
10

- Limestone aggregate (Rapid City, SD)
- Quartzite aggregate (Spencer, SD)
- Expanded shale lightweight aggregate (Boulder, CO)
  - Lightweight aggregates are used to provide internal curing

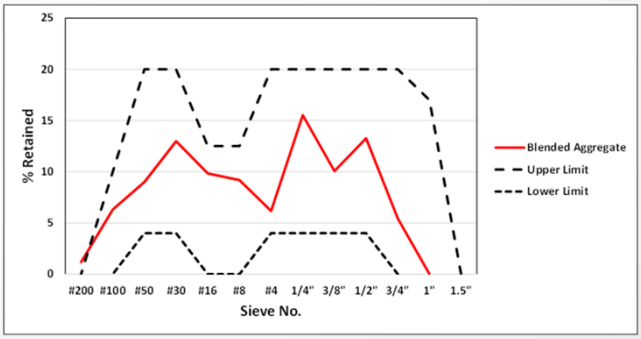
11

Aggregate Gradation

0.45 Power Curve



Tarantula Curve



Blend (wt%)

34% #57

21% #8

45% sand

12

Cement Content

- Type I/II portland cement (required by SDDOT)
  - Moderate heat of hydration
  - Moderate sulfate resistance
- Current content 650 lb/yd^3 or 615 lb/yd^3 (well graded)
- Maintain a paste volume of 27% or lower

13

Water to Cementitious Materials Ratio

- SDDOT mixes use a range of 0.39 to 0.45 as allowed by the A45 specifications.
- Higher water content supplies more water for chemical reaction
- Lower water content reduces volume that can be lost to the environment

14

Admixtures

- *Air-entraining admixtures (AEA)* used for freeze-thaw protection
- *Superplasticizers (SP)* used for increasing workability at a constant w/cm ratio
- *Shrinkage Reducing Admixtures (SRA)* used for reducing autogenous and drying shrinkage

15

Supplemental Cementitious Materials

- 20-25% Class F fly ash is required by SDDOT
- Class F (≤ 18% CaO) recommended
- Improved workability, durability, and compressive strength

16

Experimental Mix Design

Description	w/cm	Water	Cement	Fly Ash	Coarse Aggregate	Fine Aggregate	Paste Volume	Admixtures	SP Dosage	SRA Dosage	Theoretical Yield
	-	lb/yd^3	lb/yd^3	lb/yd^3	lb/yd^3	lb/yd^3	%	type	fl oz/cwt	gal/yd^3	ft^3/yd^3
Baseline w/o FA or SP	0.4	260	650	**0** [1*]	1735	1421	28.2	-	0	0	27.0
Baseline w/o FA	0.4	260	650	0	1735	1421	28.2	**SP** [2*]	6-20	0	27.0
DOT Baseline	0.4	260	520	130	1735	1396	29.1	SP	6-20	0	27.0
Baseline W/AEA	0.4	260	520	130	1735	1194	31.1	**AEA, SP** [3*]	6-20	0	27.0
Baseline / Quartzite	0.4	260	520	130	**1735** [4*]	**1349** [4*]	29.5	SP	6-20	0	27.0
Gradation	0.4	260	520	130	**1735** [5*]	**1396** [5*]	29.1	SP	6-20	0	27.0
Cement Content 1	0.4	245	**490** [6*]	122.5	1775	1430	26.8	SP	6-20	0	27.0
Cement Content 2	0.4	230	**460** [6*]	115	1805	1473	24.6	SP	6-20	0	27.0
Cement Content 3	0.4	215	**430** [6*]	107.5	1810	1540	22.5	SP	6-20	0	27.0
SCM 1	0.4	246	460	**155** [7*]	1772	1421	27.0	SP	6-20	0	27.0
FLA Replacement 1	0.4	260	520	130	1735	**993/248** [8*#]	30.6	SP	6-20	0	27.0
FLA Replacement 2	0.4	260	520	130	1735	**671/447** [9*#]	31.9	SP	6-20	0	27.0
FLA Replacement 3	0.4	260	520	130	1735	**407/610** [10*#]	33.1	SP	6-20	0	27.0
W/CM 1	**0.42** [11*]	273	520	130	1735	1362	29.8	SP	6-20	0	27.0
W/CM 2	**0.38** [12*]	247	520	130	1750	1415	28.3	SP	6-20	0	27.0
SRA 1	0.4	260	520	130	1735	1396	29.1	**SP, SRA** [13*]	6-20	1.5	27.0
SRA 2	0.4	260	520	130	1735	1396	29.1	**SP, SRA** [14*]	6-20	3	27.0
SRA 3	0.4	260	520	130	1735	1194	31.1	**AEA, SP, SRA** [15*]	6-20	1.5	27.0

# Denotes quantity of fine aggregate and fine lightweight aggregate (fa/fLWA)

[illegible] lb/yd^3.

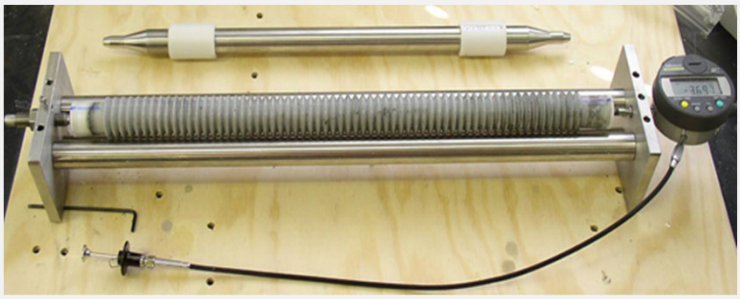
17

Autogenous Shrinkage (ASTM C1698)

- Limited to the cement paste and mortar
- Evaluates effects of internal curing from the addition of the saturated LWA

Curing conditions:
- Sealed
- Temperature 73° ± 3 °F

Test length:
- 28 days



18

Drying Shrinkage (ASTM C157)

- Can be used for concrete mixes

Curing conditions:
- Air cured or water cured
- Temperature 73° ± 3 °F
- Relative humidity 50 ± 4%

Test length:
- 28 days
- 64 weeks

19

Restrained Shrinkage (ASTM C1581)

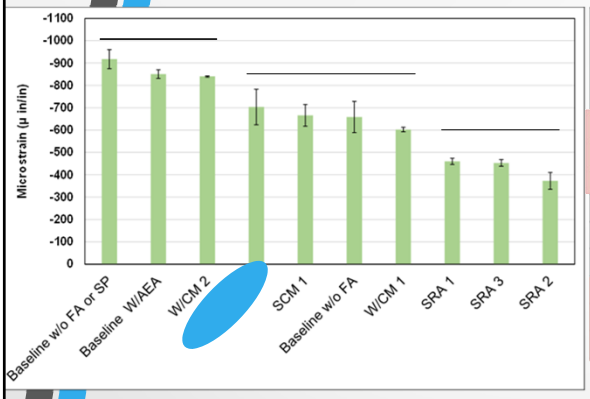
- Determine age at cracking of concrete under restrained shrinkage

Curing conditions:
- Moist cured
- Temperature 73.5°F ± 3.5 °F
- Relative humidity 50 ± 4%
- Coated with paraffin wax to prevent drying

Test length:
- 28 days (crack-free limit)
- Can extend longer

20

Paste Autogenous Shrinkage Results (28-day)

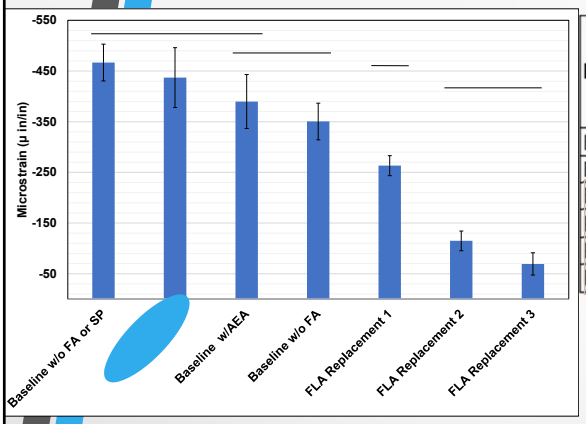


Mix Name	Percent Change in Mean Value (%)	Tukey-Kramer: P-value	Significant Difference (P<0.05)
Baseline w/o FA or SP	30.5	<0.001	Yes
Baseline W/AEA	21.0	<0.001	Yes
W/CM 2	19.4	0.01	Yes
SCM 1	-5.3	0.93	No
Baseline w/o FA	-6.3	0.83	No
W/CM 1	-14.3	0.16	No
SRA 1	-34.6	<0.001	Yes
SRA 3	-35.5	<0.001	Yes
SRA 2	-47.0	<0.001	Yes

Post-hoc testing of 28-day autogenous shrinkage means for paste samples compared to DOT Baseline (control)

21

Mortar Autogenous Shrinkage Results (28 Day)

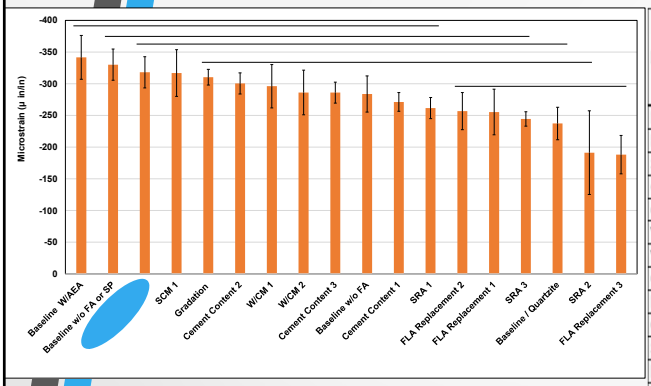


Mix Name	Percent Change in Mean Value (%)	Tukey-Kramer: P-value	Significant Difference (P<0.05)
Baseline w/o FA or SP	6.8	0.90	No
Baseline W/AEA	-10.8	0.68	No
Baseline w/o FA	-19.8	0.03	Yes
FLA Replacement 1	-39.7	<0.001	Yes
FLA Replacement 2	-73.7	<0.001	Yes
FLA Replacement 3	-84.2	<0.001	Yes

Post-hoc testing of 28-day autogenous shrinkage means for mortar samples compared to DOT Baseline (control)

22

Drying Shrinkage (28-day)

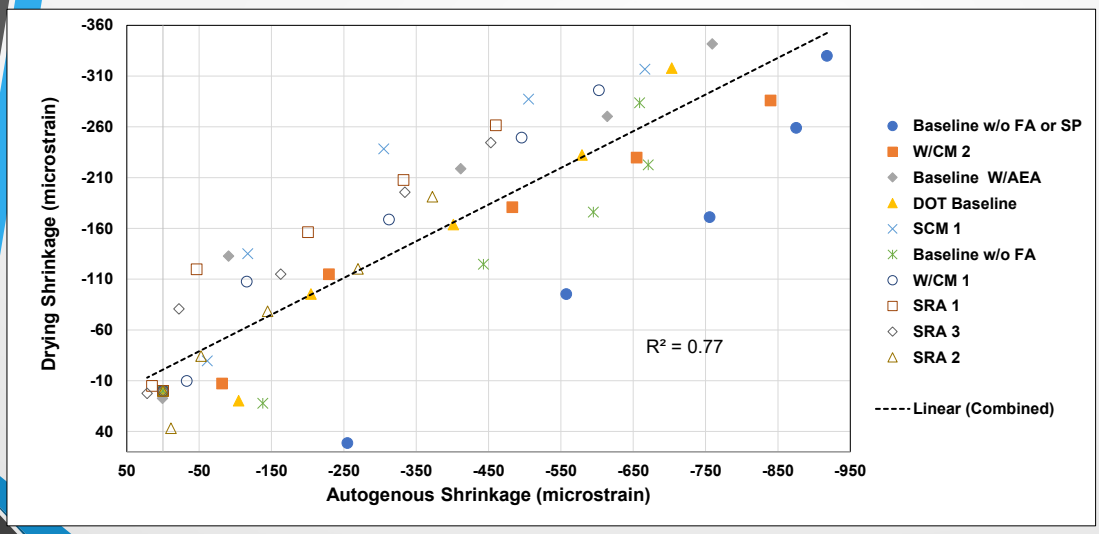


Mix Name	Percent Change in Mean Value (%)	Tukey-Kramer: P-value	Significant Difference (P<0.05)
Baseline W/AEA	7.4	0.99	No
Baseline w/o FA or SP	3.8	1.00	No
SCM 1	-0.3	1.00	No
Gradation	-4.7	1.00	No
Cement Content 2	-5.5	1.00	No
W/CM 1	-6.9	1.00	No
W/CM 2	-10.0	0.99	No
Cement Content 3	-10.1	0.99	No
Baseline w/o FA	-10.8	0.98	No
Cement Content 1	-14.7	0.76	No
SRA 1	-17.7	0.46	No
FLA Replacement 2	-19.3	0.32	No
FLA Replacement 1	-19.7	0.28	No
SRA 3	-23.1	0.09	No
Baseline / Quartzite	-25.4	0.04	Yes
SRA 2	-39.9	<0.001	Yes
FLA Replacement 3	-40.8	<0.001	Yes

Post-hoc testing of 28-day drying shrinkage means for concrete samples compared to DOT Baseline (control)

23

Autogenous and Drying Shrinkage Comparison



24

Summary of Findings:

Aggregate Type	• Quartzite aggregate reduced drying shrinkage more than limestone • FLA (LWA) significantly reduced shrinkage in both autogenous and drying shrinkage
Aggregate Gradation	• Optimized aggregate gradations did not significantly reduce drying shrinkage but did increase durability and compressive strength
Cement Content	• Lower paste volume did not show a significant reduction in shrinkage in this study, however it did increase durability and is still recommended from the literature
Water Content	• Change in w/cm had mixed results
Admixtures	• SRA significantly improved both autogenous and drying shrinkage
Fly Ash Content	• 25% fly ash (compared to 20%) did not change shrinkage but did improve workability and durability

25

Recommended Changes to Mix Design

Final Mix

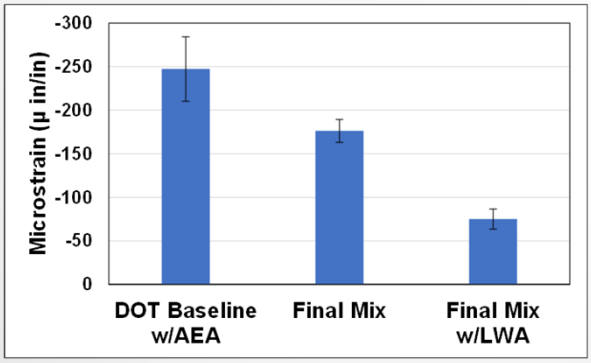
- 0.40 w/cm ratio
- Maintain slump requirements 1-4.5 inches
- Lower min cementitious content (615 lb/yd^3) with 20% fly ash
- Use of SRA at lower dosage (max 1.5 gal/yd^3)
- Use of improved aggregate gradation (meets tarantula and 0.45 power curves)

Final Mix w/ LWA

- Use of saturated LWA at lower dosage (20% replacement of fine aggregate)

26

28-Day Paste Autogenous Shrinkage Results

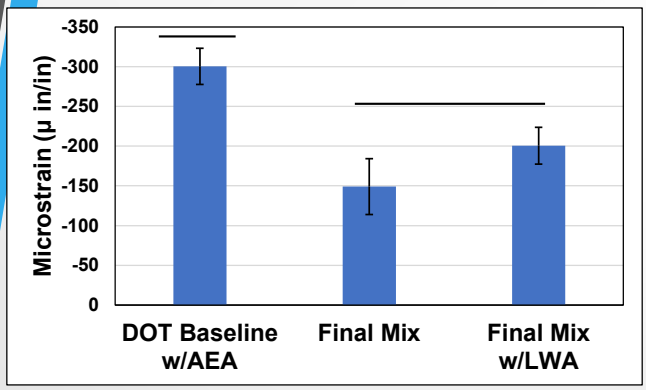


Mix Name	Percent Change in Mean Value (%)	Tukey-Kramer: P-value	Significant Difference (P<0.05)
Final Mix	-28.7	0.005	Yes
Final Mix w/LWA	-69.6	<0.001	Yes

Post-hoc testing of 28-day autogenous shrinkage means for paste samples compared to DOT Baseline (control)

27

Drying Shrinkage



Mix Name	Percent Change in Mean Value (%)	Tukey-Kramer: P-value	Significant Difference (P<0.05)
Final Mix	-50.4	<0.001	Yes
Final Mix w/LWA	-33.3	0.0016	Yes

Post-hoc testing of 28-day drying shrinkage means for concrete samples compared to DOT Baseline (control)

28

Restrained Shrinkage

Name	Number of Days Before Cracking
DOT Baseline w/AEA	31
Final Mix	Uncracked after 180 days
Final Mix w/LWA	Uncracked after 180 days

Low Shrinkage Bridge Deck Concrete

April 6, 2022

NC2 Nashville Meeting

Darin Hodges

SOUTH DAKOTA DEPARTMENT OF TRANSPORTATION

SDDOT Needs Solutions

Bridge Deck Cracking

- Stainless Steel Rebar in new Bridge Decks
  - 2021
- Girder Decks:
  - Reduced Service Life
  - Increased Maint. $

Figure 2. Underside of Route 123 Bridge Deck Showing Cracking (Sharp and Moruza, 2009

South Dakota Mines Recommendations

Change Mix Design for Bridge Decks to include:

- Optimized Aggregate (Tarantula Curve)
- Lower Cementitious
  - 615 lb max with 20% Fly Ash
- SRA
- SLWA (Sat. Lt. Wt. Agg.)
  - 20% of the Fine Agg.

South Dakota Mines Recommended Tests

Specify:

- Drying Shrinkage Test
  - ASTM C157
  - 285 Microstrain at 28day
    - Total Time of 56 days
- Consider changing to 56 day acceptance Str.
  - Due to Class F Fly Ash
  - Or a lower 28 day strength

- Continue to Look into Design and Construction Practices

Implementation

- Develop Special Provision
- Select Test Deck(s)
- Monitor Results
- Refine Special Provision

Special Provision

- Low Shrinkage Bridge Deck Special Provision
  - 1st draft written
  - review comments
- New Mix Design
  - Lab Mix
  - From other work
  - SDDOT may verify

Special Provision

- New Mix Requirements:
  - 4500 psi @ 56 Day
  - Cement 575 to 615max
  - Well Graded SDDOT size 15 rock – 50% min.
  - Well Graded total agg per 0.45 Power
  - ASTM C157 28 Day (56 total) Shrinkage Limit of 0.028% (280 microstrain)
  - Must Contain either SRA and/or Fine Lightweight Agg conform to C1761

Next Steps

- Select Test Decks
- Monitor in Place Deck(s)
  - More Research?
- Low Shrinkage Bridge Deck Special Provision
  - Shorter duration shrinkage limit
    - 28 day total time
    - More Research?
  - Tarantula Curve

QUESTIONS??

Want to work for SDDOT?

Darin Hodges

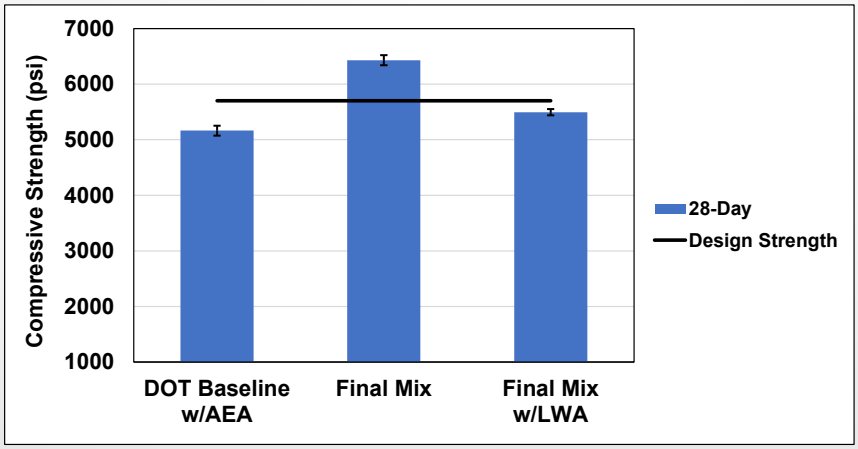
SOUTH DAKOTA DEPARTMENT OF TRANSPORTATION

Conclusions

- Shrinkage reducing admixture and saturated lightweight aggregates as a partial replacement of fine aggregate significantly reduced both autogenous shrinkage and drying shrinkage
- Other changed parameters including lowering the cement content, adjusting the fly ash content, using optimized aggregate gradation, and altering the w/cm also slightly improved autogenous and drying shrinkage performance compared to the control, but the shrinkage reduction was not statistically significant.
- Compared to the current SDDOT A45 mix, the final mixes exhibited significantly lower autogenous and drying shrinkage, improved resistivity, and improved strength. The recommended mix designs also significantly increased the time to cracking as measured by the ring test.

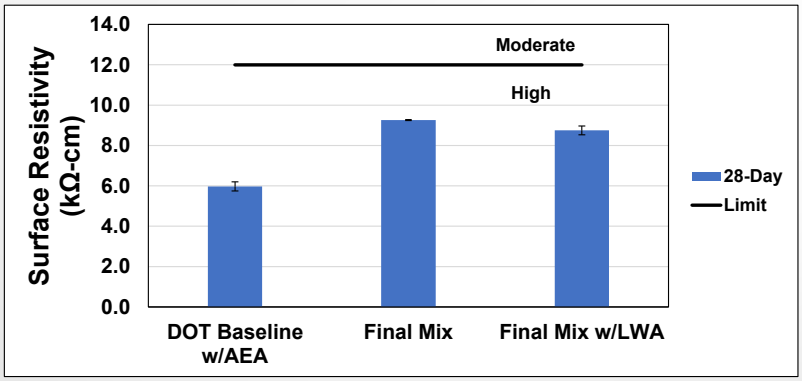
39

Concrete Compressive Strength (28-day)



40

Concrete Durability (28-day)



Surface Resistivity Test (4"x8" cylinder)	
Chloride Ion Penetration	kΩ-cm
High	<12
Moderate	12-21
Low	21-37
Very Low	37-254
Negligible	>254

AASHTO T358

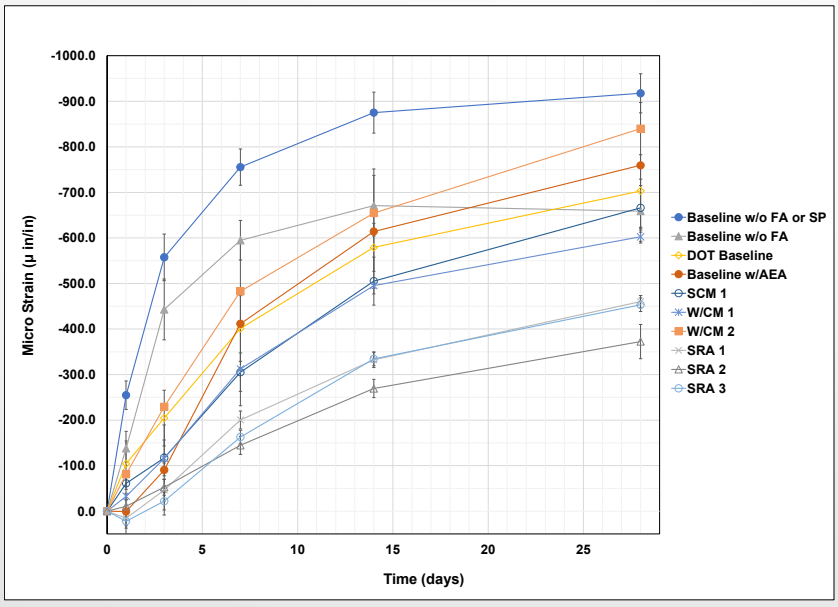
41

Other Concrete Shrinkage Types

- Plastic – associated with early moisture loss in plastic concrete
- Carbonation – from the reaction of concrete with carbon dioxide in the air
- Thermal- temperature changes (lower)
- Chemical – volumetric change from the reaction of water with cement

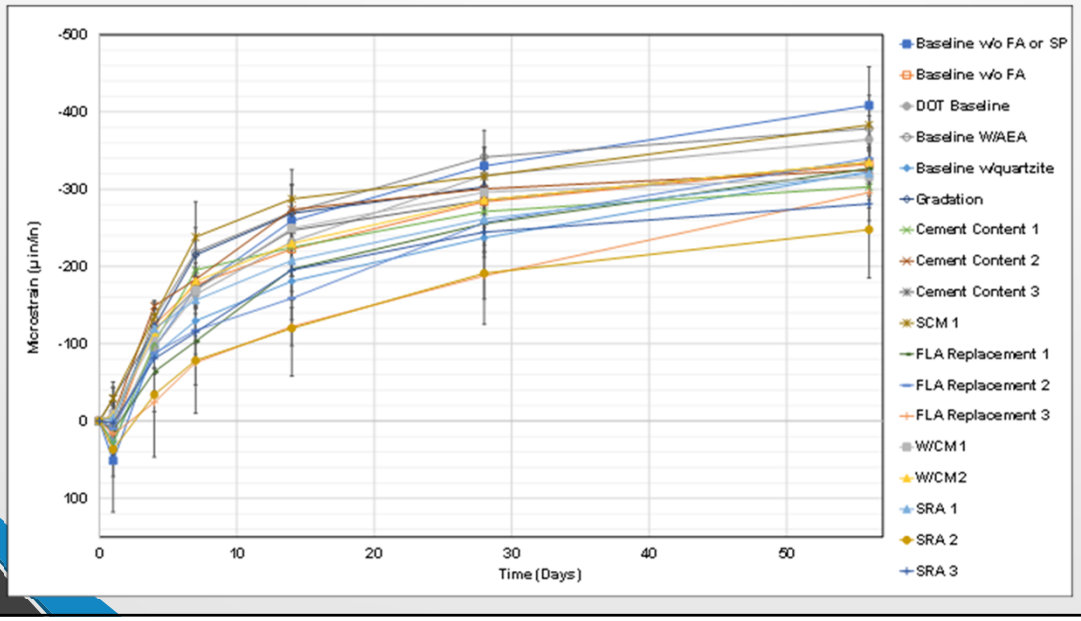
42

Autogenous Shrinkage (paste)



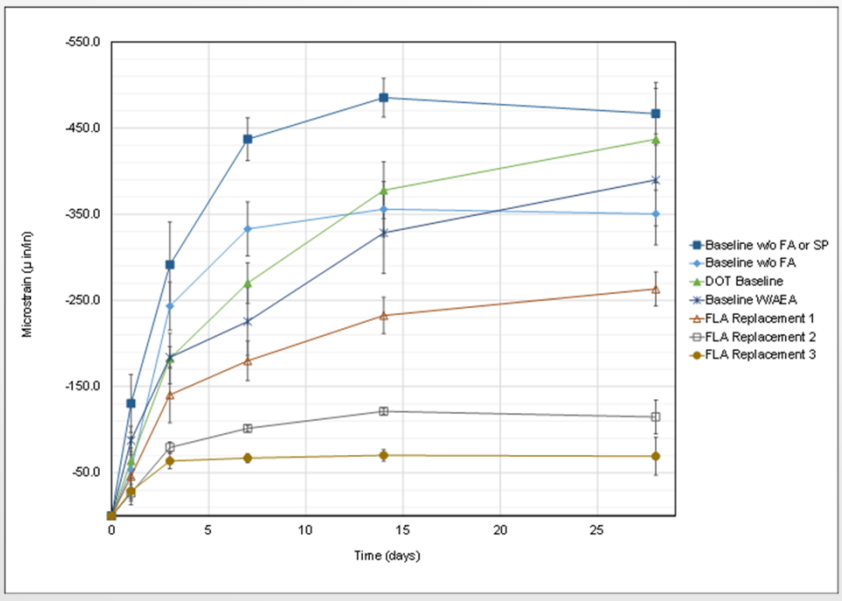
43

Drying Shrinkage (concrete)



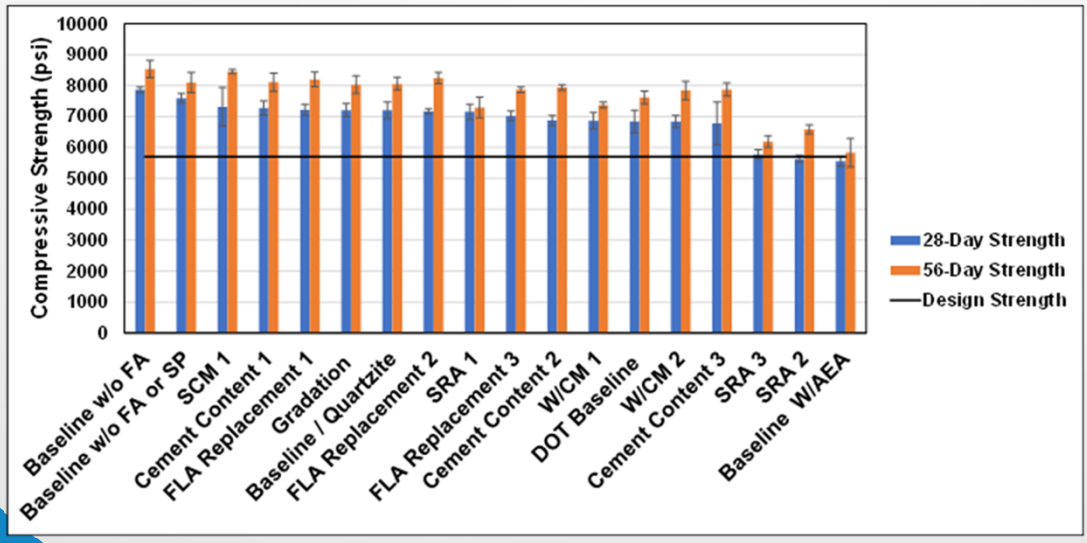
44

Autogenous Shrinkage (mortar)



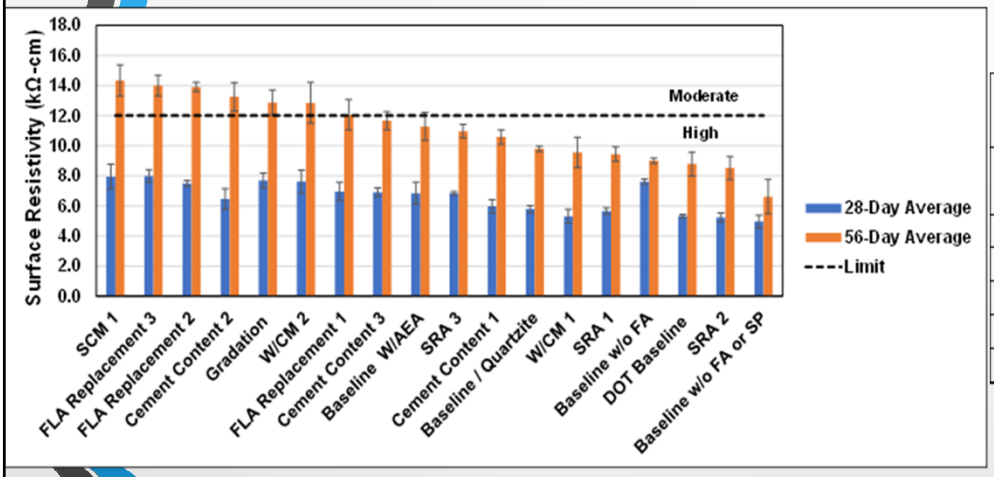
45

Concrete Compressive Strength



46

Concrete Durability



Surface Resistivity Test (4"x8" cylinder)	
Chloride Ion Penetration	kΩ-cm
High	<12
Moderate	12-21
Low	21-37
Very Low	37-254
Negligible	>254

AASHTO T358

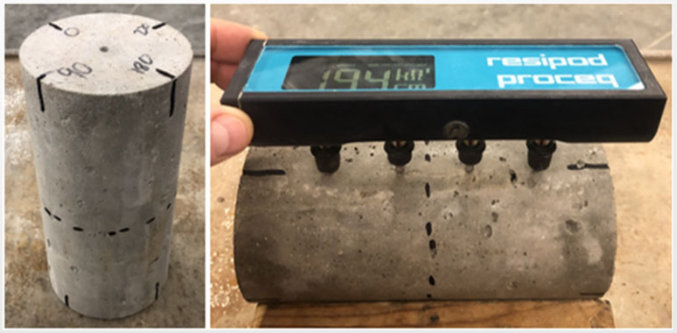
Surface Resistivity AASHTO T358

47

- Bulk Electrical Conductivity of Hardened Concrete (AASHTO T358). This test determines the bulk electrical conductivity of saturated specimens of hardened concrete to provide a rapid indication of the concrete's resistance to the penetration of chloride ions by diffusion. It is used to evaluate concrete mixture proportioning and can also aid in the design of cathodic protection systems.

Curing conditions:
- Moist cured
- Relative humidity 100%
- Temperature 73° ± 3 °F

Test length:
- 28 days



48

Statistical Analysis

Mixes w/avg 130 lb/cyd fly ash (20%)						
Data Type	Cement (lb/yd^3)	Rock (lb/yd^3)	Sand (lb/yd^3)	Water (lb/yd^3)	% Air	W/C
Average	534	1699	1167	273	6.5	0.41
Maximum	546	1734	1191	279	6.5	0.42
Minimum	533	1676	1129	268	6.5	0.40
Standard Deviation	3	21	20	4	0.0	0.00
Variance	80	1657	1929	34	0.0	0.00
1st Quartile	524	1661	1156	260	6.5	0.40
3rd Quartile	528	1727	1200	276	6.5	0.42
Mixes w/avg 168 lb/cyd fly ash (25%)						
Data Type	Cement (lb/yd^3)	Rock (lb/yd^3)	Sand (lb/yd^3)	Water (lb/yd^3)	% Air	W/C
Average	504	1715	1164	262	6.5	0.39
Maximum	504	1715	1164	262	6.5	0.39
Minimum	504	1715	1164	262	6.5	0.39
Standard Deviation	0	0	0	0	0.0	0.00
Variance	0	0	0	0	0.0	0.00
1st Quartile	491	1715	1165	263	6.5	0.39
3rd Quartile	495	1715	1165	265	6.5	0.40

49

Paste Results

Mix Name	Data Type	0 days μ-in/in	1 days μ-in/in	3 days μ-in/in	7 days μ-in/in	14 days μ-in/in	28 days μ-in/in
Baseline w/o FA or SP	Average	0.0	-254.8	-557.4	-755.4	-875.1	-917.6
	STDEV	0.0	31.3	51.0	39.8	45.0	42.7
W/CM 2	Average	0.0	-81.6	-229.2	-482.7	-654.6	-839.8
	STDEV	0.0	4.1	4.2	7.8	5.0	2.4
Baseline W/AEA	Average	0.0	0.7	-90.5	-411.5	-614.2	-759.3
	STDEV	0.0	89.1	98.9	180.0	137.1	138.0
DOT Baseline	Average	0.0	-104.4	-204.6	-401.3	-579.2	-703.1
	STDEV	0.0	49.7	61.2	72.0	52.7	79.6
SCM 1	Average	0.0	-61.3	-117.1	-305.1	-505.3	-666.0
	STDEV	0.0	13.6	39.3	42.1	52.6	48.7
Baseline w/o FA	Average	0.0	-138.0	-443.0	-594.8	-670.8	-658.9
	STDEV	0.0	37.4	66.8	43.4	66.6	70.1
W/CM 1	Average	0.0	-32.7	-115.7	-312.2	-495.5	-602.5
	STDEV	0.0	6.6	9.8	3.4	6.4	10.0
SRA 1	Average	0.0	15.4	-46.3	-200.3	-332.4	-460.0
	STDEV	0.0	16.5	24.0	19.8	16.8	13.8
SRA 3	Average	0.0	22.0	-22.0	-162.8	-334.4	-453.2
	STDEV	0.0	15.3	19.0	15.1	15.0	14.9
SRA 2	Average	0.0	-11.0	-52.6	-144.6	-269.5	-372.4
	STDEV	0.0	13.7	17.4	19.9	20.0	37.7

50

Mortar Results

Mix Name	Data Type	0 days μ-in/in	1 days μ-in/in	3 days μ-in/in	7 days μ-in/in	14 days μ-in/in	28 days μ-in/in
Baseline w/o FA or SP	Average	0.0	-130.4	-291.5	-437.1	-485.3	-466.8
	STDEV	0.0	33.6	49.8	24.7	22.5	36.4
DOT Baseline	Average	0.0	-63.9	-182.6	-270.3	-377.9	-437.1
	STDEV	0.0	27.4	29.5	23.5	33.0	59.0
Baseline W/AEA	Average	0.0	-87.6	-184.0	-225.6	-328.5	-389.8
	STDEV	0.0	16.5	12.6	39.2	47.0	53.3
Baseline w/o FA	Average	0.0	-53.4	-243.5	-333.0	-355.9	-350.5
	STDEV	0.0	25.3	27.8	31.4	32.1	36.2
FLA Replacement 1	Average	0.0	-46.1	-140.4	-179.9	-232.6	-263.4
	STDEV	0.0	28.7	32.4	22.9	21.0	19.8
FLA Replacement 2	Average	0.0	-26.5	-79.4	-101.5	-121.4	-114.8
	STDEV	0.0	6.5	6.3	3.5	3.4	19.5
FLA Replacement 3	Average	0.0	-28.6	-63.7	-67.0	-70.3	-69.2
	STDEV	0.0	15.4	9.0	5.1	6.8	22.0

51

Concrete Shrinkage Results

Name	Data Type	0 days μ in/in	1 days μ in/in	4 days μ in/in	7 days μ in/in	14 days μ in/in	28 days μ in/in
Baseline W/AEA	Average	0.0	7.4	-132.7	-218.7	-270.3	-341.6
	STDEV	0.0	12.4	23.5	31.6	36.4	34.6
Baseline w/o FA or SP	Average	0.0	51.3	-95.3	-171.1	-259.1	-330.1
	STDEV	0.0	20.1	56.1	25.9	25.9	24.5
DOT Baseline	Average	0.0	9.8	-95.4	-163.8	-232.3	-317.9
	STDEV	0.0	23.9	14.7	12.3	25.8	24.6
SCM 1	Average	0.0	-29.5	-135.1	-238.2	-287.3	-316.8
	STDEV	0.0	21.2	9.4	45.6	37.9	36.9
Gradation	Average	0.0	-4.9	-122.1	-215.0	-268.7	-310.3
	STDEV	0.0	16.9	23.3	17.7	36.2	12.4
Cement Content 2	Average	0.0	-7.3	-149.0	-183.2	-273.5	-300.4
	STDEV	0.0	12.3	4.9	12.3	13.9	16.7
W/CM 1	Average	0.0	-9.8	-107.6	-168.8	-249.5	-296.0
	STDEV	0.0	13.8	13.8	21.7	20.5	34.3
W/CM 2	Average	0.0	-7.3	-114.9	-180.9	-229.8	-286.1
	STDEV	0.0	25.7	31.3	23.3	42.7	35.2
Cement Content 3	Average	0.0	-29.3	-117.3	-171.0	-246.8	-285.9
	STDEV	0.0	13.8	21.1	16.9	16.7	16.6

Name	Data Type	0 days μ in/in	1 days μ in/in	4 days μ in/in	7 days μ in/in	14 days μ in/in	28 days μ in/in
Baseline w/o FA	Average	0.0	12.2	-124.7	-176.1	-222.6	-283.7
	STDEV	0.0	9.4	21.6	17.7	19.9	28.5
Cement Content 1	Average	0.0	29.3	-100.2	-195.5	-224.8	-271.2
	STDEV	0.0	8.0	16.7	0.1	13.8	14.7
SRA 1	Average	0.0	-4.9	-119.8	-156.4	-207.8	-261.5
	STDEV	0.0	18.7	9.3	17.8	20.1	16.7
FLA Replacement 2	Average	0.0	9.8	-88.0	-117.3	-158.9	-256.7
	STDEV	0.0	41.5	27.7	30.9	28.1	29.3
FLA Replacement 1	Average	0.0	12.3	-63.8	-103.1	-196.5	-255.4
	STDEV	0.0	31.4	26.0	26.0	29.0	35.9
SRA 3	Average	0.0	2.4	-80.7	-114.9	-195.5	-244.4
	STDEV	0.0	9.4	12.4	14.7	8.1	11.4
Baseline / Quartzite	Average	0.0	26.9	-85.6	-129.6	-181.0	-237.2
	STDEV	0.0	9.3	16.6	20.1	24.5	25.5
SRA 2	Average	0.0	36.9	-34.2	-78.4	-120.1	-191.2
	STDEV	0.0	80.7	80.6	68.3	62.0	66.0
FLA Replacement 3	Average	0.0	17.1	-24.4	-75.7	-122.1	-188.1
	STDEV	0.0	28.1	12.6	29.1	24.6	30.2

52

Shrinkage Tests

- ASTM C157 – length change for drying shrinkage
- ASTM C596 – length change for drying shrinkage
- AASHTO T160 – length change for drying shrinkage
- ASTM C1581 – cracking potential under restrained shrinkage
- AASHTO T334 – cracking potential under restrained shrinkage
- ASTM C1698 – length change for autogenous shrinkage
- AASHTO T363 – cracking potential from restrained shrinkage and temperature changes

53

Shrinkage Test Decision Matrix

Test	Description	Cost	Testing Time	Complexity of Test	Quantity of Material	Total
ASTM C1698	Autogenous Shrinkage	2	2	1	1	6
ASTM C157	Drying Shrinkage	1	3	1	2	7
AASHTO T160	Drying Shrinkage	1	3	1	2	7
ASTM C596	Drying Shrinkage	1	2	1	2	6
ASTM C1581	Restrained Shrinkage	2	2	2	2	8
AASHTO T334	Restrained Shrinkage	2	3	2	3	10
AASHTO T363	Restrained Shrinkage	3	1	3	3	10

54

Concrete Compressive Strength

Name	28-Day Strength AVG	28-Day Strength STDEV	56-Day Strength AVG	56-Day Strength STDEV
	psi	psi	psi	psi
Baseline w/o FA	7865	82	8536	281
SCM 1	7312	623	8455	65
FLA Replacement 2	7166	82	8249	184
FLA Replacement 1	7213	185	8201	240
Cement Content 1	7277	230	8109	296
Baseline w/o FA or SP	7596	154	8105	329
Baseline / Quartzite	7202	269	8060	209
Gradation	7208	212	8030	287
Cement Content 2	6869	168	7939	92
Cement Content 3	6778	695	7872	214
FLA Replacement 3	7018	156	7862	90
W/CM 2	6841	193	7840	301
DOT Baseline	6842	366	7618	203
W/CM 1	6865	261	7373	97
SRA 1	7154	247	7296	336
SRA 2	5635	116	6585	142
SRA 3	5778	152	6187	189
Baseline W/AEA	5548	149	5832	456

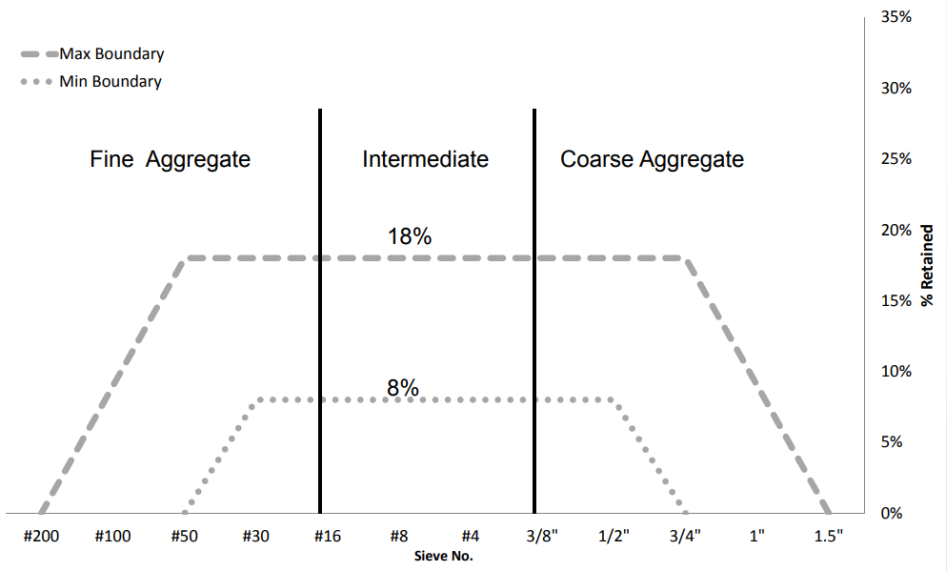
55

Concrete Durability

Name	28-day AVERAGE	28-day STDEV	56-day AVERAGE	56-day STDEV
	kΩ-cm	kΩ-cm	kΩ-cm	kΩ-cm
SCM 1	7.9	0.82	14.3	1.04
FLA Replacement 3	8.0	0.42	14.0	0.69
FLA Replacement 2	7.5	0.19	13.9	0.30
Cement Content 2	6.5	0.69	13.3	0.95
Gradation	7.7	0.49	12.9	0.82
W/CM 2	7.6	0.77	12.9	1.36
FLA Replacement 1	7.0	0.61	12.1	1.00
Cement Content 3	6.9	0.28	11.7	0.60
Baseline W/AEA	6.8	0.73	11.3	0.92
SRA 3	6.8	0.11	11.0	0.45
Cement Content 1	6.0	0.43	10.6	0.47
Baseline / Quartzite	5.8	0.23	9.8	0.18
W/CM 1	5.3	0.47	9.6	1.00
SRA 1	5.7	0.21	9.4	0.48
Baseline w/o FA	7.6	0.18	9.0	0.19
DOT Baseline	5.3	0.11	8.8	0.80
SRA 2	5.2	0.29	8.5	0.78
Baseline w/o FA or SP	5.0	0.42	6.6	1.15

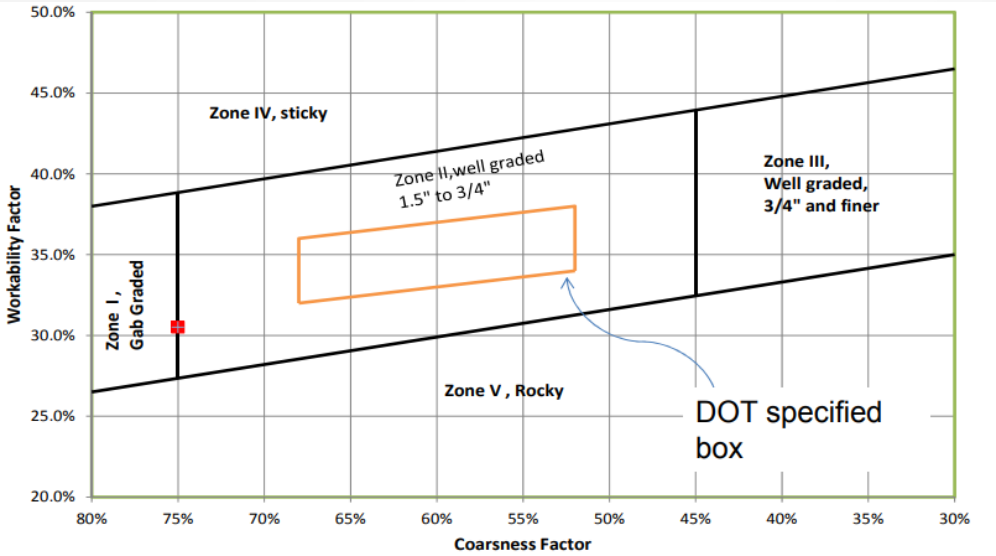
56

Shilstone Box Test



57

Shilstone Box Test



58

Experimental Testing Plan

Description	ASTM C39	ASTM C403	ASTM C138	AASHTO T358	ASTM C231	ASTM C157	ASTM C1698
	Compressive Strength	Setting Time	Density, Yield, Air-Content (G)	Electrical Resistivity	Air Content (P)	Length Change	Autogenous Shrinkage
Baseline w/o FA or SP	X	X	X	X	X	X	X (M&P)
Baseline w/o FA	X	X	X	X	X	X	X (M&P)
Baseline	X	X	X	X	X	X	X (M&P)
Baseline W/AEA	X	X	X	X	X	X	X (M&P)
Baseline / Quartzite	X	X	X	X	X	X	
Gradation 1	X	X	X	X	X	X	
Cement Content 1	X	X	X	X	X	X	X (P)
Cement Content 2	X	X	X	X	X	X	X (P)
Cement Content 3	X	X	X	X	X	X	X (P)
Change Aggregate Content	X	X	X	X	X	X	
Change Aggregate Content	X	X	X	X	X	X	
FLA Replacement	X	X	X	X	X	X	X (M)
FLA Replacement	X	X	X	X	X	X	X (M)
FLA Replacement	X	X	X	X	X	X	X (M)
SCM 1	X	X	X	X	X	X	X (P)
W/CM 1	X	X	X	X	X	X	X (P)
W/CM 2	X	X	X	X	X	X	X (P)
Shrinkage Reducing Admixture	X	X	X	X	X	X	X (P)
Shrinkage Reducing Admixture	X	X	X	X	X	X	X (P)
Shrinkage Reducing Admixture	X	X	X	X	X	X	X (P)
(M) = Mortar (P) = Paste							