Louisiana's Ternary Cementitious Combinations Research and Specifications

TTCC/NCC Fall Meeting
Rapid City, SD
September 13, 2011

Tyson Rupnow, Ph.D., P.E.
Concrete Research Engineer

Outline

- Background
- Objectives
- Materials
- Test methods
- Results
- Conclusions
- Recommendations and Specification Changes
- Acknowledgements

Background

- Benefits of ternary mixtures
  - Increased durability and strength
  - Reduced permeability, cost, and CO_2 emissions
- Drawbacks of ternary mixtures
  - Increased chance for incompatibilities
  - Early stiffening or delayed set times

Objective

- Characterize fresh and hardened characteristics of ternary mixtures

Materials

- Cementitious
  - Type I portland cement
  - Class C fly ash
  - Class F fly ash
  - Grade 100 Slag
  - Grade 120 Slag
- Aggregates
  - #67 Limestone
  - Natural sand

Test Methods

- ASTM C39 – compressive strength
- ASTM C78 – flexural strength
- ASTM C136 – sieve analysis
- ASTM C138 – unit weight
- ASTM C143 – slump
- ASTM C150 – portland cement
- ASTM C157/157M – length change
- ASTM C231 – air content (pressure meter)

Test Methods

- ASTM C403 – set time
- ASTM C469 – MOE
- ASTM C618 – fly ash
- ASTM C666 – freeze-thaw
- ASTM C989 – slag
- ASTM C1202 – rapid chloride permeability

Test Matrix

Mixture ID	Type I PC	Class C FA	Class F FA	G100S	G120S
100TI*	100				
80TI-20C*	80	20			
80TI-20F*	80		20		
50TI-50G100S*	50			50	
50TI-50G120S*	50				50
50TI-30G120S-20C	50	20			30
40TI-30G120S-30C	40	30			30
30TI-30G120S-40C	30	40			30
30TI-50G120S-20C	30	20			50
20TI-50G120S-30C	20	30			50
10TI-50G120S-40C	10	40			50
50TI-30G100S-20C	50	20		30	
40TI-30G100S-30C	40	30		30	
30TI-30G100S-40C	30	40		30	
30TI-50G100S-20C	30	20		50	
20TI-50G100S-30C	20	30		50	
10TI-50G100S-40C	10	40		50	
50TI-30G120S-20F	50		20		30
40TI-30G120S-30F	40		30		30
30TI-30G120S-40F	30		40		30
30TI-50G120S-20F	30		20		50
20TI-50G120S-30F	20		30		50
10TI-50G120S-40F	10		40		50
50TI-30G100S-20F	50		20	30	
40TI-30G100S-30F	40		30	30	
30TI-30G100S-40F	30		40	30	
30TI-50G100S-20F	30		20	50	
20TI-50G100S-30F	20		30	50	
10TI-50G100S-40F	10		40	50	
60TI-20C-20F	60	20	20		
40TI-30C-30F	40	30	30		
20TI-40C-40F	20	40	40		

Results

- Cementitious materials all meet specification

Oxide	Type I/II Portland Cement	Class C Fly Ash	Class F Fly Ash	Grade 100 GGBFS	Grade 120 GGBFS
SiO_2	20.24	35.04	60.74	38.59	34.77
Al_2O_3	4.45	19.30	19.41	7.61	10.73
Fe_2O_3	3.47	5.32	7.93	0.76	0.56
CaO	63.28	24.98	5.33	38.61	40.52
MgO	3.82	5.48	1.84	13.00	11.99
Na_2O	0.22	1.95	0.77	0.25	0.29
K_2O	0.44	0.46	1.19	0.38	0.38
TiO_2	0.28	1.36	1.01	0.36	0.60
SO_3	2.62	2.81	0.37	0.38	0.41
LOI	1.10	0.60	0.60	0.20	0.20

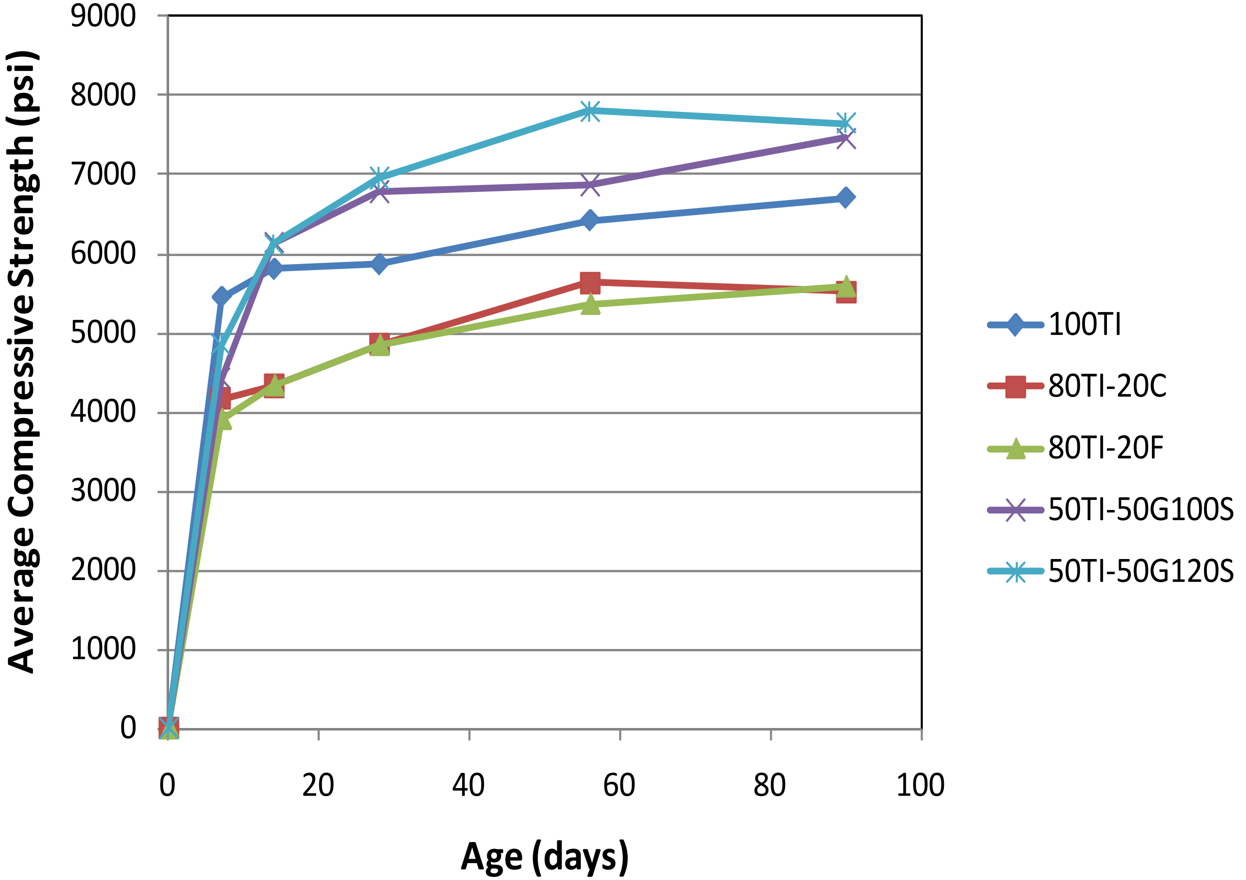
Results

Mixture ID	Slump (in)	Air Content (%)	Unit Weight (pcf)	Time to Initial Set (hrs:mins)	Time to Final Set (hrs:mins)
100TI	2.25	4.5	147.4	4:47	6:13
80TI-20C	5.00	6.0	144.0	7:14	8:45
80TI-20F	5.00	5.8	144.0	5:50	7:23
50TI-50G100S	2.50	4.4	146.6	5:38	7:45
50TI-50G120S	4.00	5.1	144.2	5:34	7:51
50TI-30G120S-20C	1.00	3.2	149.2	5:28	7:24
40TI-30G120S-30C	1.50	3.3	148.8	7:58	10:20
30TI-30G120S-40C	1.00	3.4	149.2	8:36	12:16
30TI-50G120S-20C	2.00	3.6	148.4	7:02	9:46
20TI-50G120S-30C	3.00	3.5	146.8	9:35	12:47
10TI-50G120S-40C	4.00	2.9	148.8	8:33	11:49
50TI-30G100S-20C	5.00	5.2	143.4	5:55	8:13
40TI-30G100S-30C	3.25	4.7	144.4	6:04	8:18
30TI-30G100S-40C	6.75	4.3	147.0	10:21	13:13
30TI-50G100S-20C	4.25	3.5	146.4	7:57	10:57
20TI-50G100S-30C	3.00	3.9	145.6	9:27	13:04
10TI-50G100S-40C	3.50	2.7	147.0	10:53	19:33
50TI-30G120S-20F	2.50	3.6	147.8	6:06	8:13
40TI-30G120S-30F	1.50	2.9	147.6	6:15	8:59
30TI-30G120S-40F	3.25	4.0	146.6	8:12	11:17
30TI-50G120S-20F	1.50	3.7	147.8	8:02	11:23
20TI-50G120S-30F	0.50	4.4	145.6	8:16	13:49
10TI-50G120S-40F	7.50	3.4	145.6	15:25	30:27
50TI-30G100S-20F	2.75	3.9	147.6	6:29	8:43
40TI-30G100S-30F	5.25	3.8	148.0	7:01	9:23
30TI-30G100S-40F	6.00	5.8	147.4	7:34	11:28
30TI-50G100S-20F	0.00	2.8	148.8	4:59	8:35
20TI-50G100S-30F	0.50	2.6	149.2	5:17	9:29
10TI-50G100S-40F	0.75	2.8	147.4	7:40	16:20
60TI-20C-20F	5.50	5.1	144.4	9:31	11:34
40TI-30C-30F	6.00	5.4	143.2	11:35	15:05
20TI-40C-40F	8.50	4.2	144.0	13:25	37:10

Results - Compressive Strength

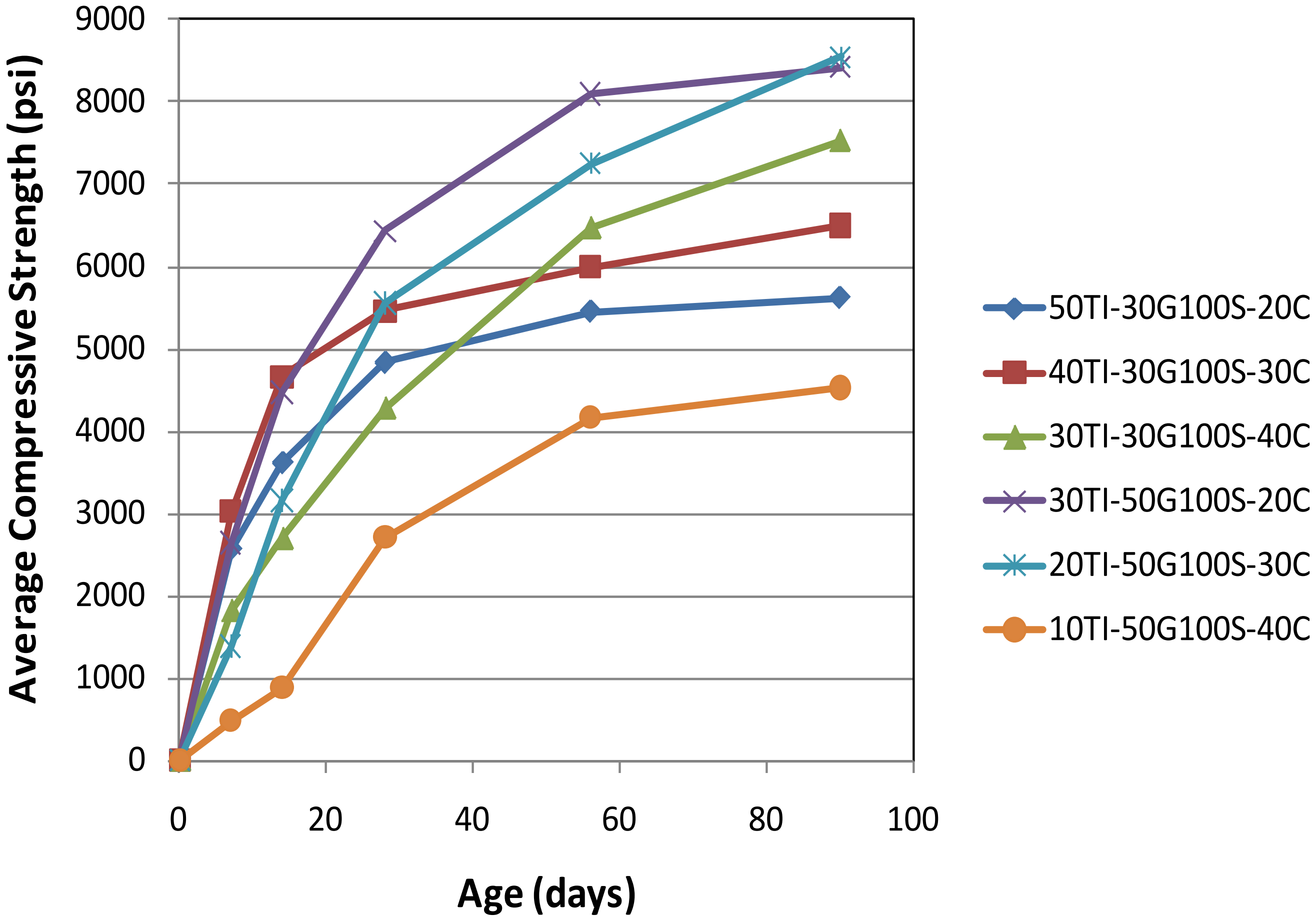
- A wide range of mixtures will meet and exceed current and proposed specifications
- 80% PC replacement generally meets 4000 psi at 28-days
- Compressive strength ratios range from 1.4 to 25.5, generally between 1.55 and 1.95
    - Allows for more creep at early ages leading to a potential reduction in early age shrinkage cracking

Results



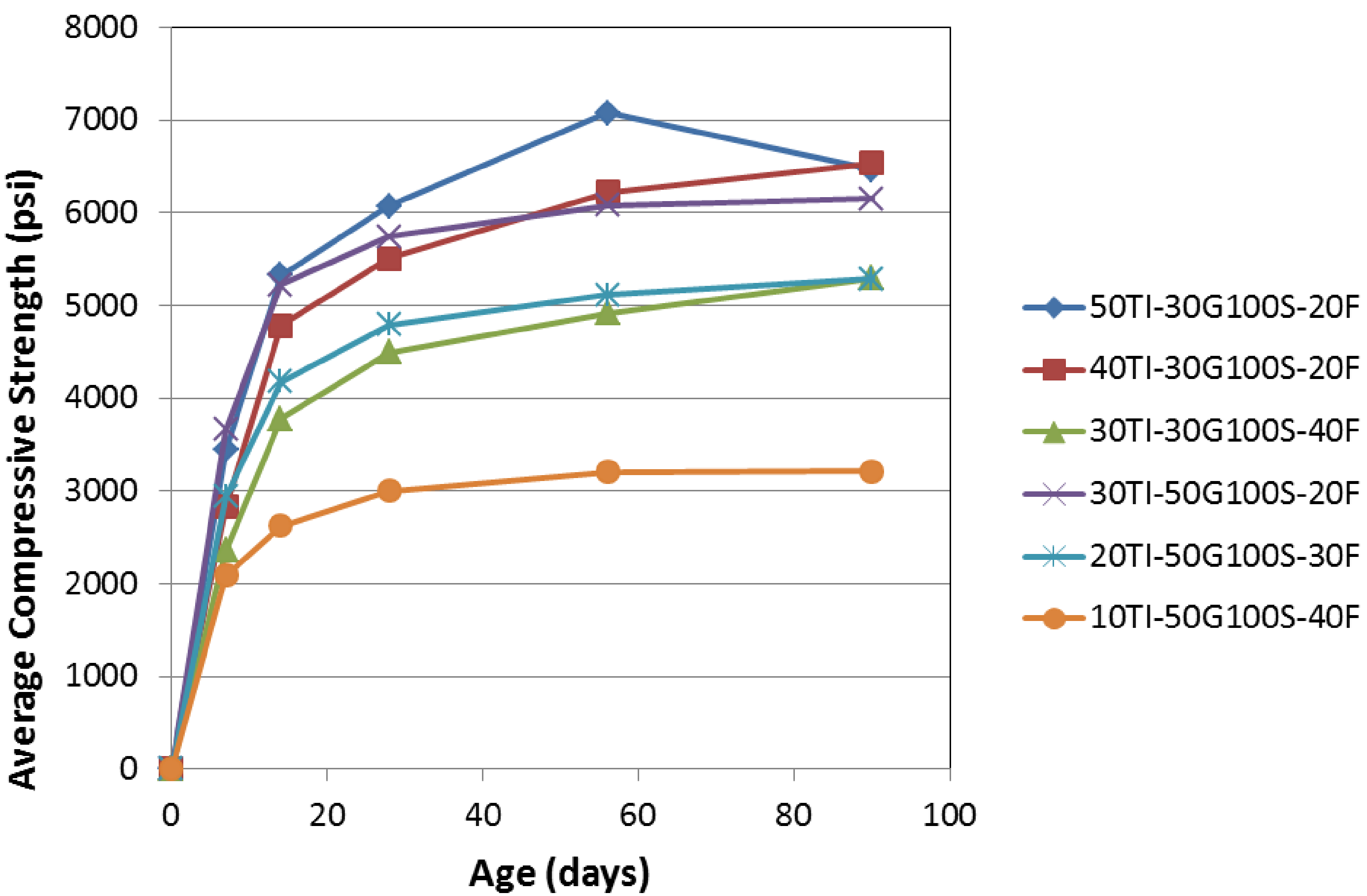
Average Compressive Strength (psi)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
Age (days)
100TI
80TI-20C
80TI-20F
50TI-50G100S
50TI-50G120S

Results



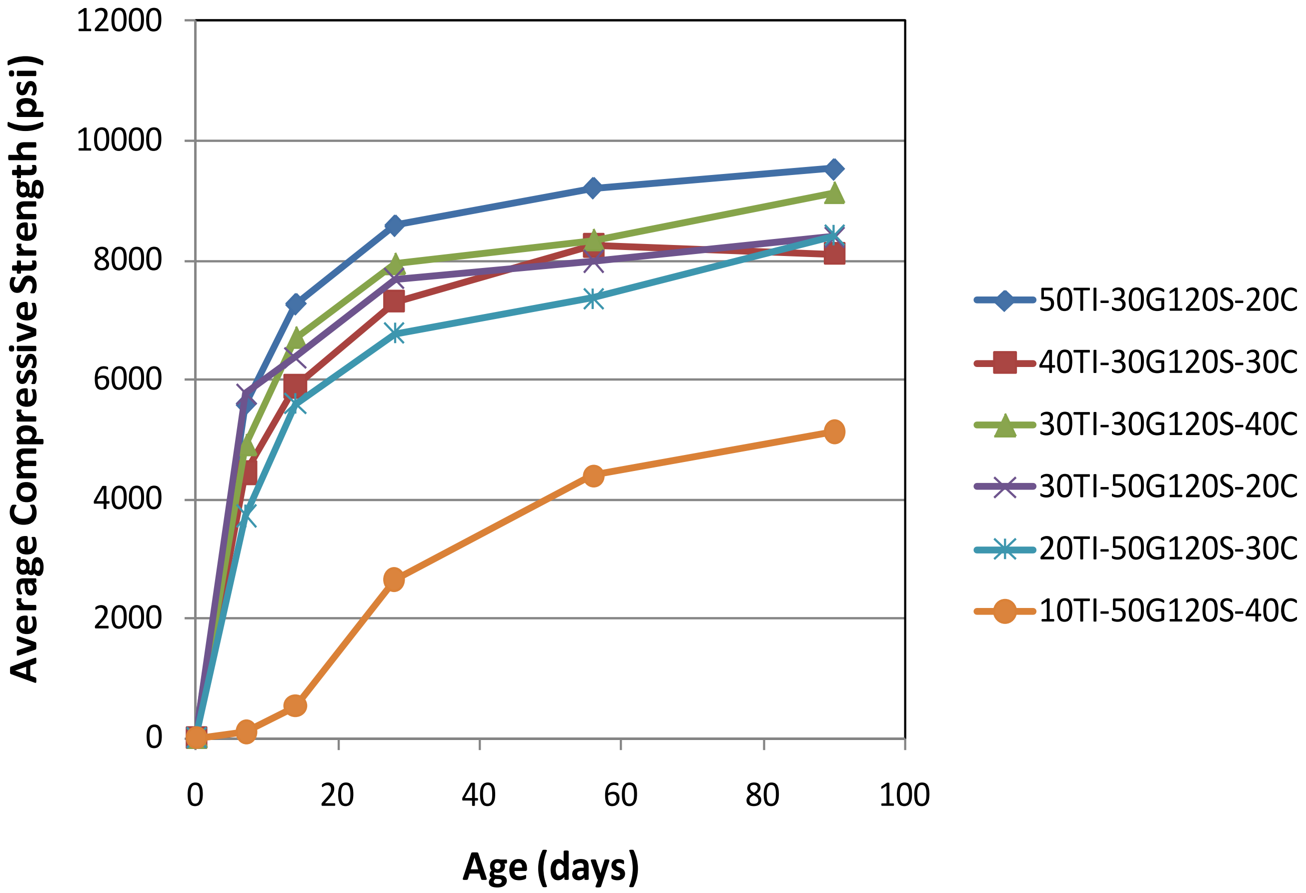
Average Compressive Strength (psi)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
Age (days)
50TI-30G100S-20C
40TI-30G100S-30C
30TI-30G100S-40C
30TI-50G100S-20C
20TI-50G100S-30C
10TI-50G100S-40C

Results



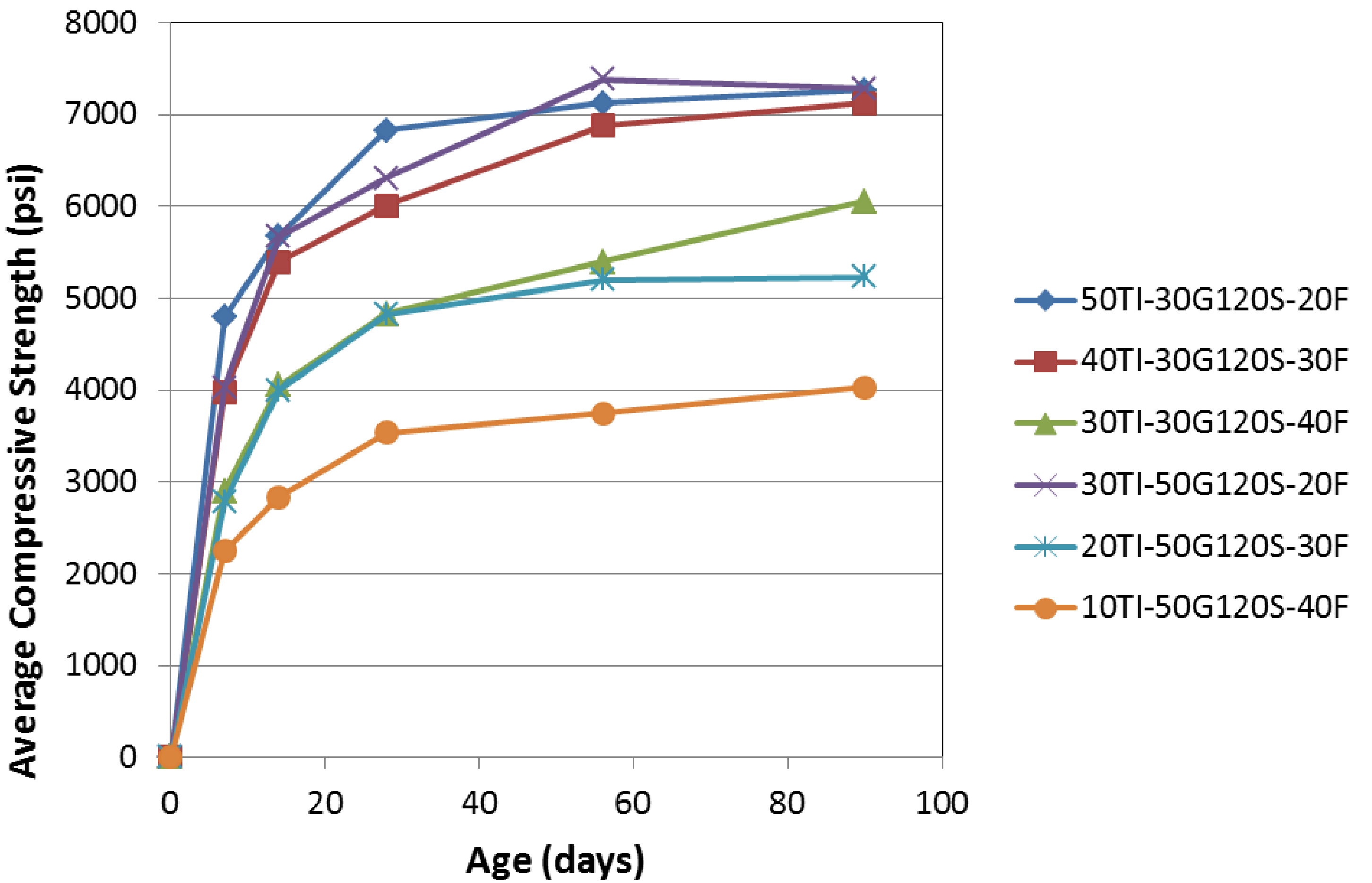
8000
7000
6000
5000
4000
3000
2000
1000
0
Average Compressive Strength (psi)
0
20
40
60
80
100
Age (days)
50TI-30G100S-20F
40TI-30G100S-20F
30TI-30G100S-40F
30TI-50G100S-20F
20TI-50G100S-30F
10TI-50G100S-40F

Results



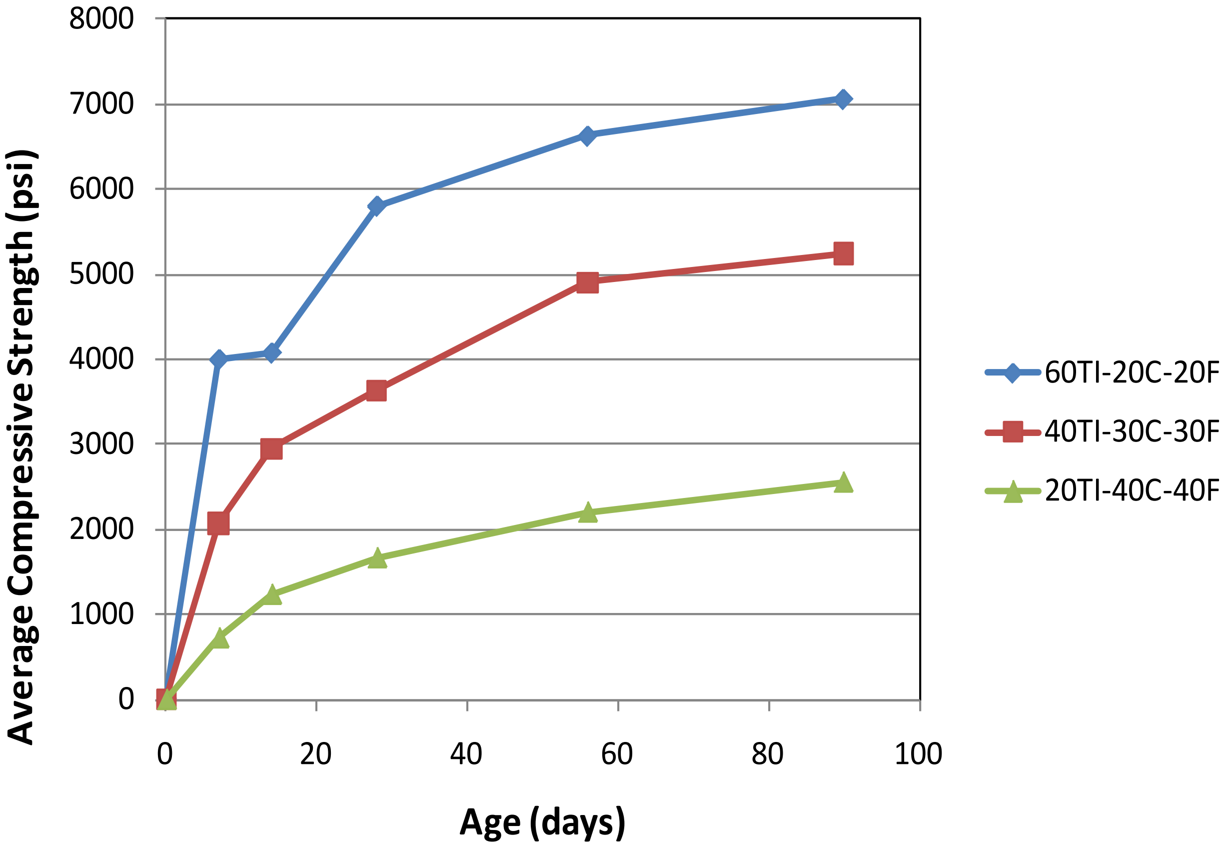
12000
10000
8000
6000
4000
2000
0
0
20
40
60
80
100
Average Compressive Strength (psi)
Age (days)
50TI-30G120S-20C
40TI-30G120S-30C
30TI-30G120S-40C
30TI-50G120S-20C
20TI-50G120S-30C
10TI-50G120S-40C

Results



8000
7000
6000
5000
4000
3000
2000
1000
0
Average Compressive Strength (psi)
0
20
40
60
80
100
Age (days)
50TI-30G120S-20F
40TI-30G120S-30F
30TI-30G120S-40F
30TI-50G120S-20F
20TI-50G120S-30F
10TI-50G120S-40F

Results

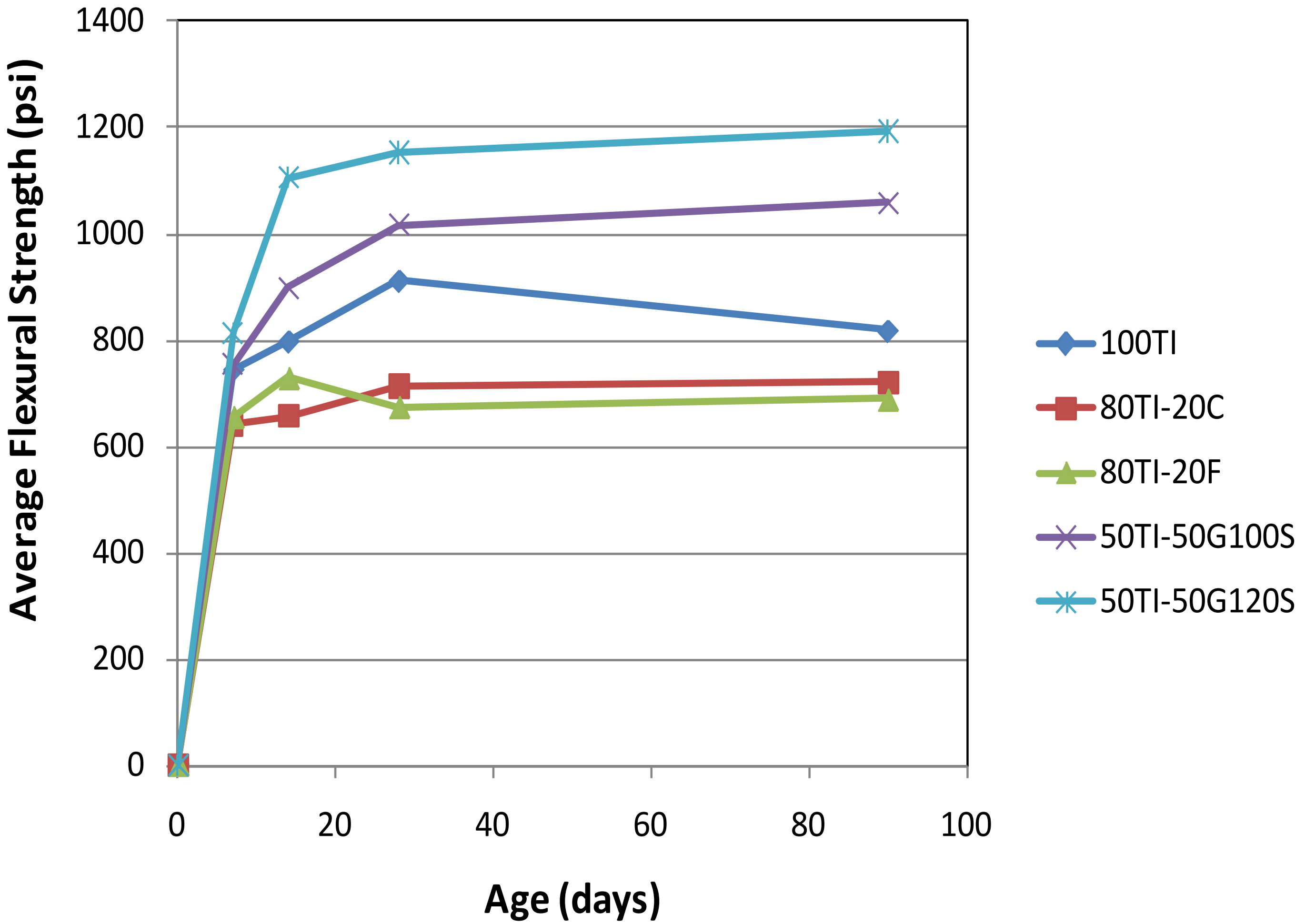


Average Compressive Strength (psi)
8000
7000
6000
5000
4000
3000
2000
1000
0
0
20
40
60
80
100
Age (days)
60TI-20C-20F
40TI-30C-30F
20TI-40C-40F

Results – Flexural Strength

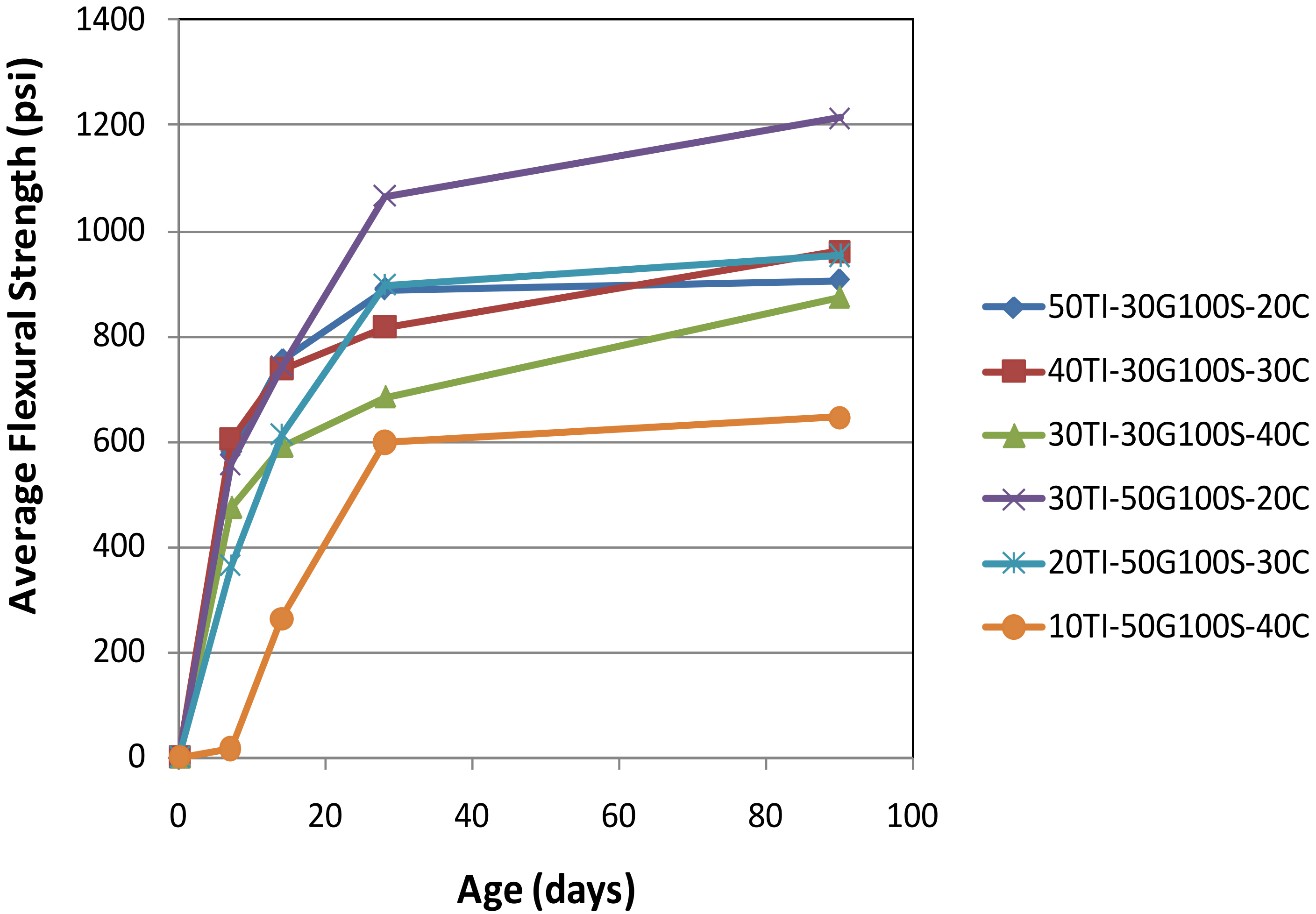
- Results tended to follow the same trend as the compressive strengths
- Increases in SCMs lowered initial strengths
- Very adequate with some flexural strengths exceeding 800 psi
- Potential to reduce pavement thicknesses

Results



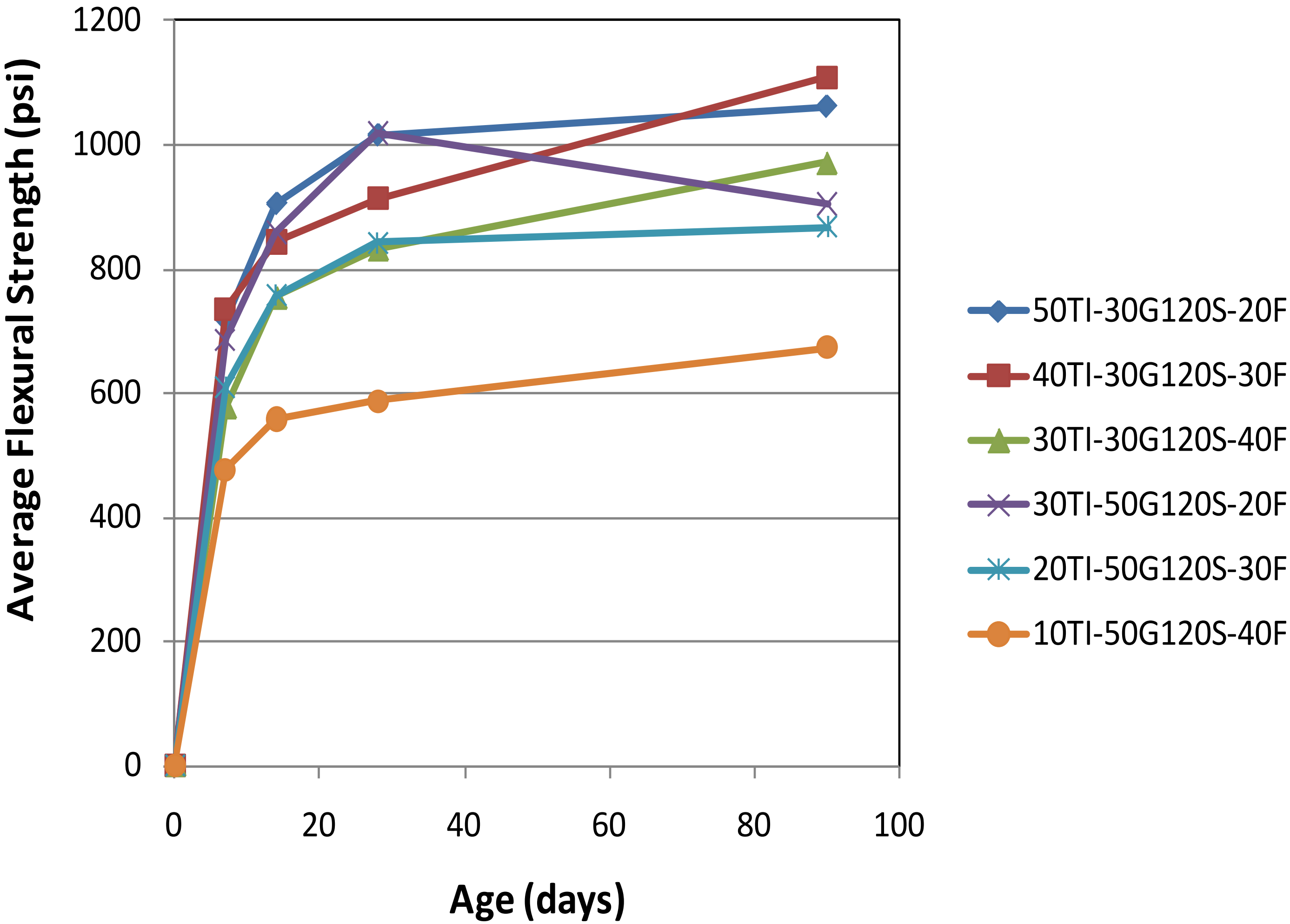
Average Flexural Strength (psi)
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
Age (days)
100TI
80TI-20C
80TI-20F
50TI-50G100S
50TI-50G120S

Results



Average Flexural Strength (psi)
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
Age (days)
50TI-30G100S-20C
40TI-30G100S-30C
30TI-30G100S-40C
30TI-50G100S-20C
20TI-50G100S-30C
10TI-50G100S-40C

Results



1200
1000
800
600
400
200
0
Average Flexural Strength (psi)
0
20
40
60
80
100
Age (days)
50TI-30G120S-20F
40TI-30G120S-30F
30TI-30G120S-40F
30TI-50G120S-20F
20TI-50G120S-30F
10TI-50G120S-40F

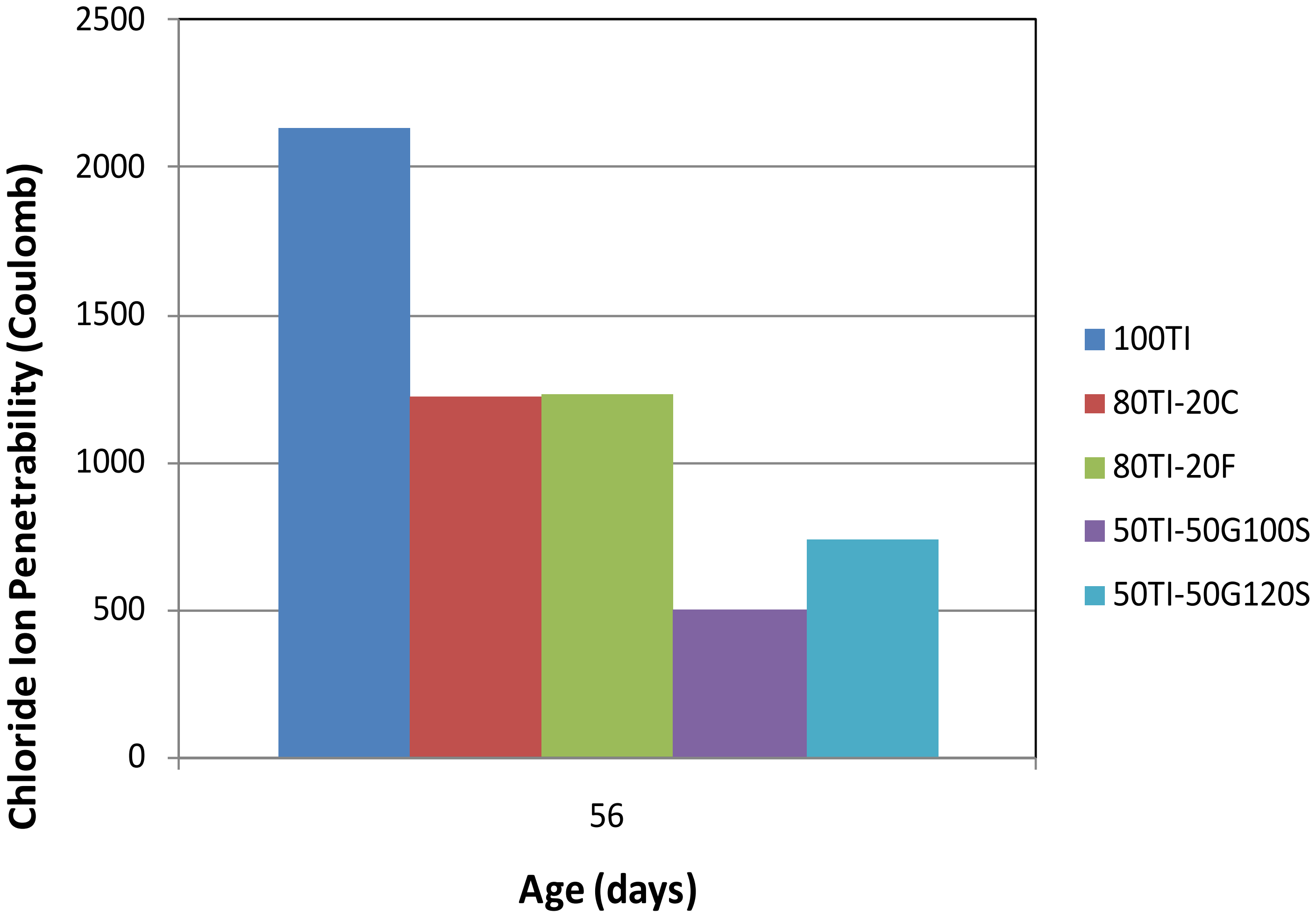
Results – Modulus of Elasticity

- Ternary mixtures performed equal to or better than the control mixtures at 90 days of age
- Lower 28-day results are attributed to pozzolanic action not being fully completed
- Mixtures fall within normal range of 4-6 million psi

Results – Permeability

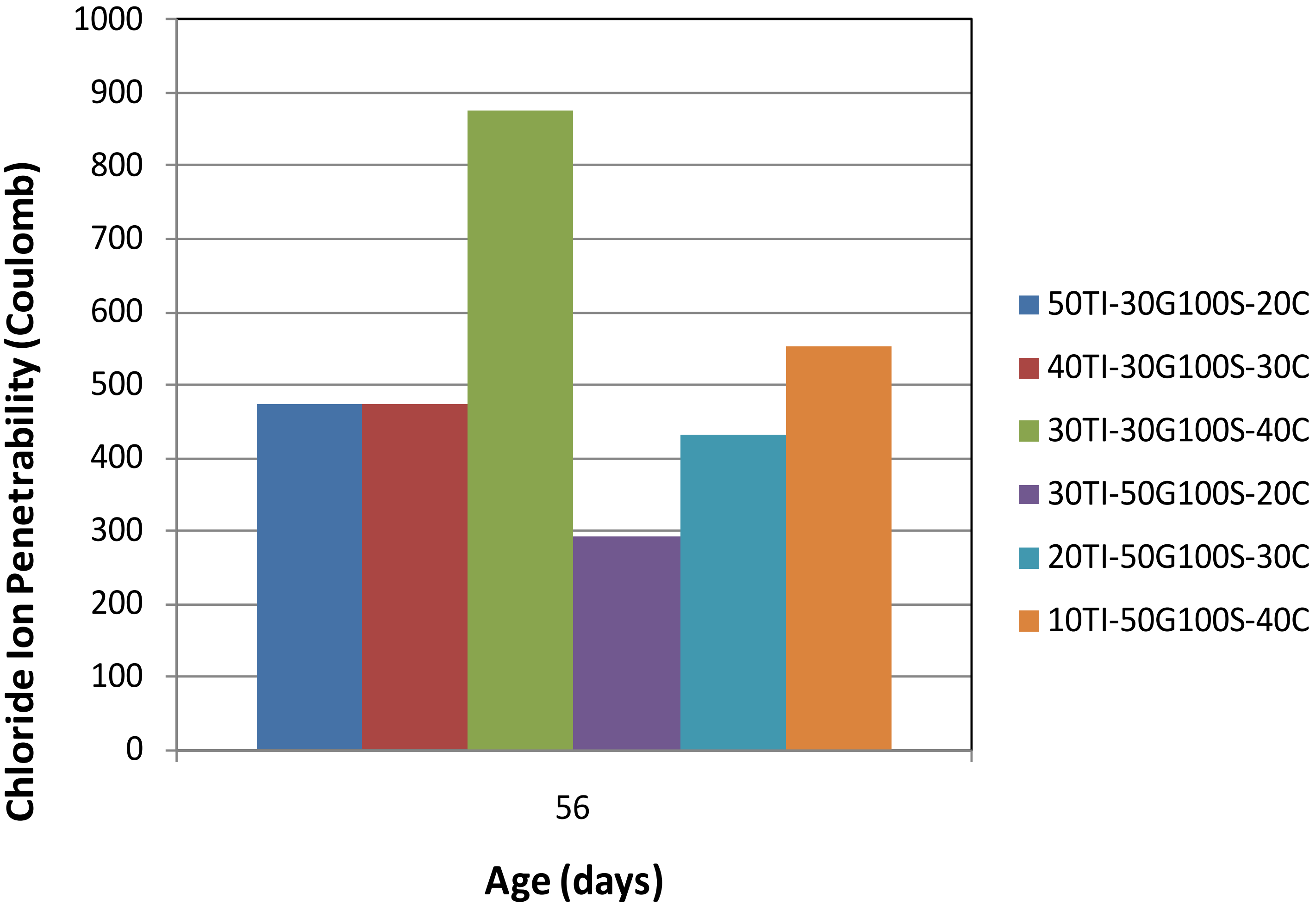
- Results are typical for mixtures containing high amounts of SCMs
- Surface resistivity test results are applicable for these mixtures
- All ternary mixtures fell under 900 Coulombs at 56-days of age
- Addition of class F fly ash tended to reduce the permeability more than class C fly ash
- Ternary mixtures are able to be tested with surface resistivity meter

Results



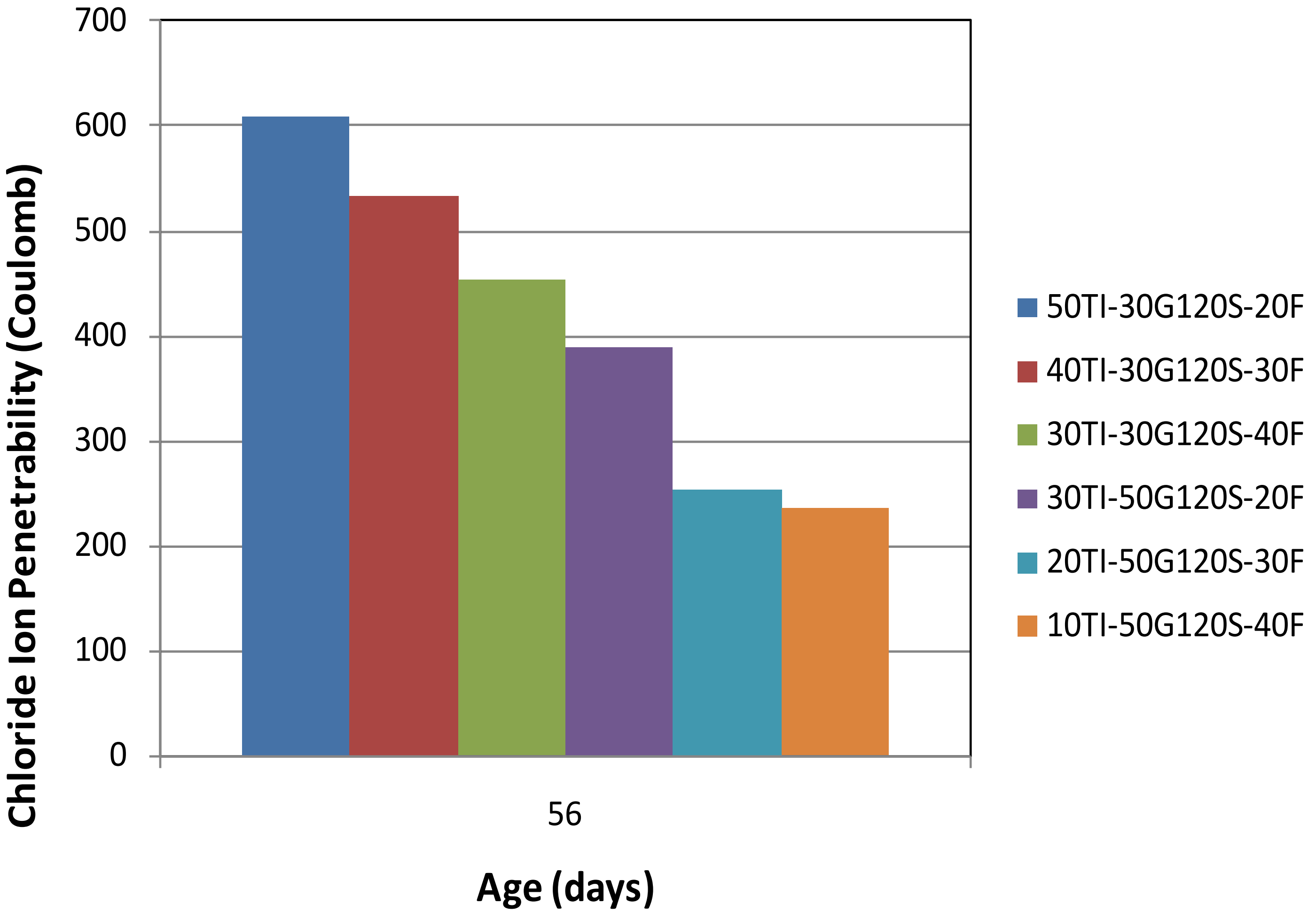
2500
2000
1500
1000
500
0
Chloride Ion Penetrability (Coulomb)
56
Age (days)
100TI
80TI-20C
80TI-20F
50TI-50G100S
50TI-50G120S

Results



Chloride Ion Penetrability (Coulomb)
1000
900
800
700
600
500
400
300
200
100
0
56
Age (days)
50TI-30G100S-20C
40TI-30G100S-30C
30TI-30G100S-40C
30TI-50G100S-20C
20TI-50G100S-30C
10TI-50G100S-40C

Results



700
600
500
400
300
200
100
0
Chloride Ion Penetrability (Coulomb)
56
Age (days)
50TI-30G120S-20F
40TI-30G120S-30F
30TI-30G120S-40F
30TI-50G120S-20F
20TI-50G120S-30F
10TI-50G120S-40F

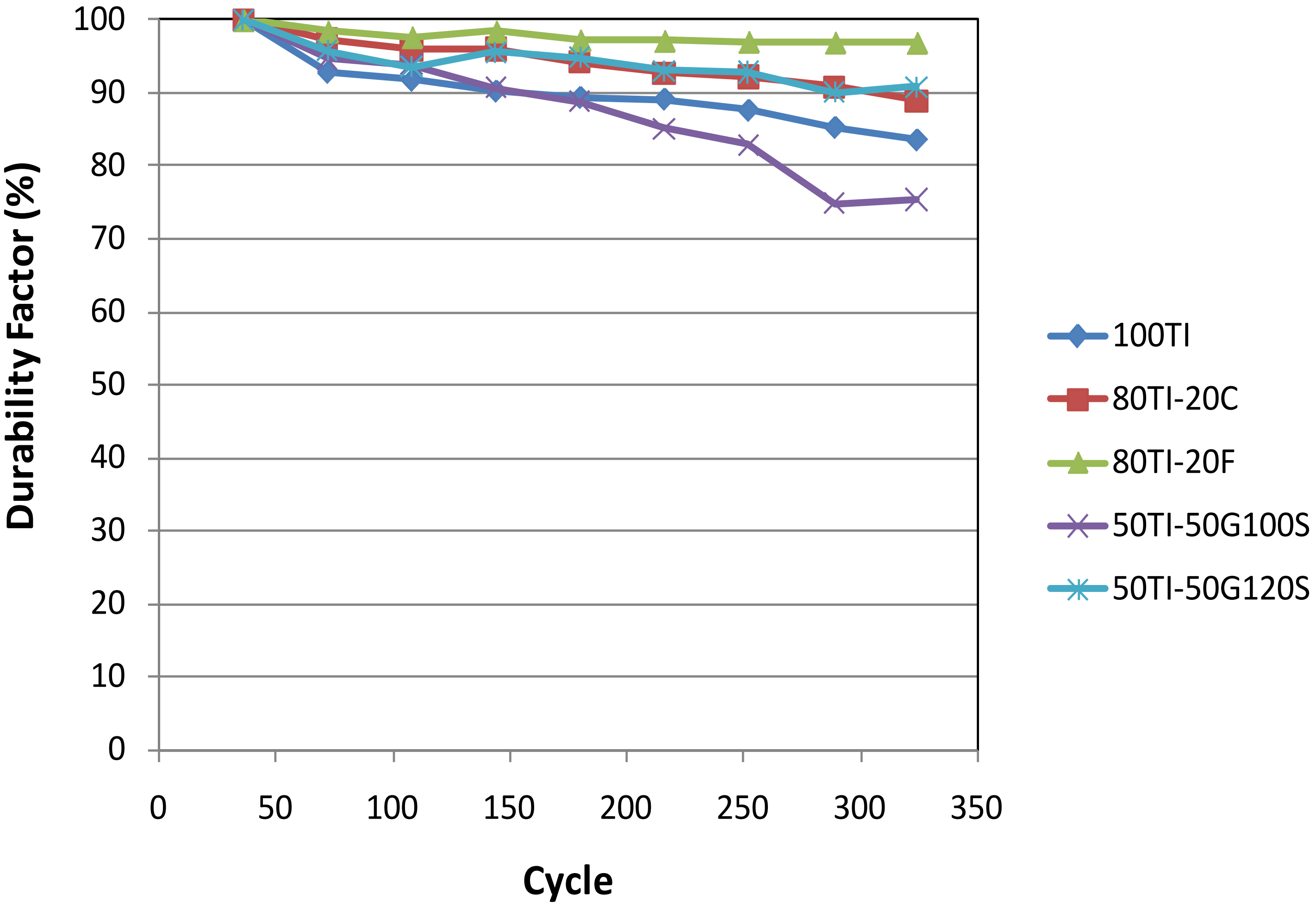
Results – Length Change

- Control mixtures averaged about 0.30 percent
- Ternary mixtures were comparable to or less than the control
  - Ternary mixtures no more prone to shrinkage cracking than the control mixtures
  - NOT more resistant to cracking

Results – Freeze-Thaw Durability

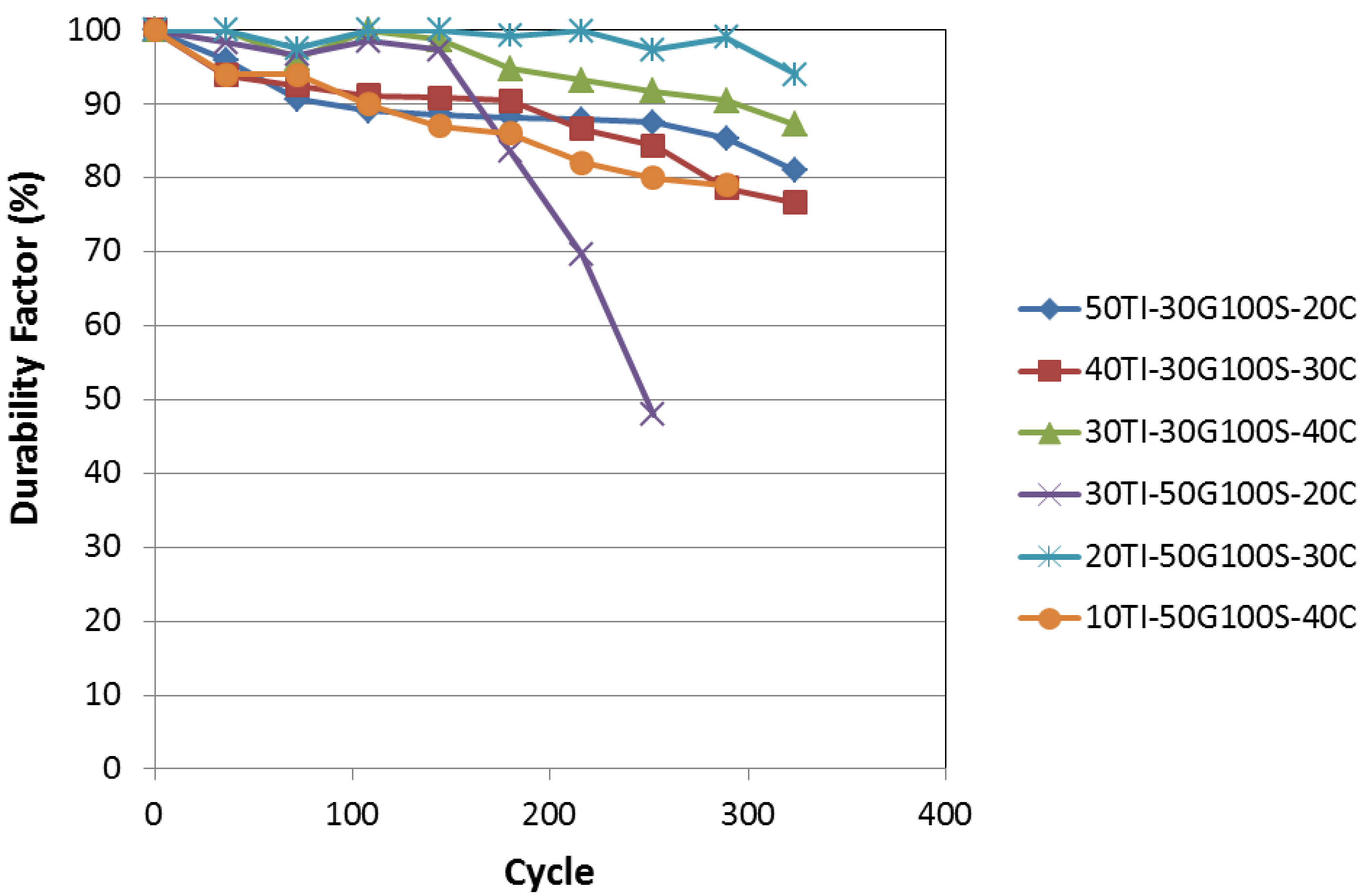
- Control mixtures performed well
- Ternary mixtures performed well providing the following two criteria were met
  - Proper air content
  - Adequate curing time

Results



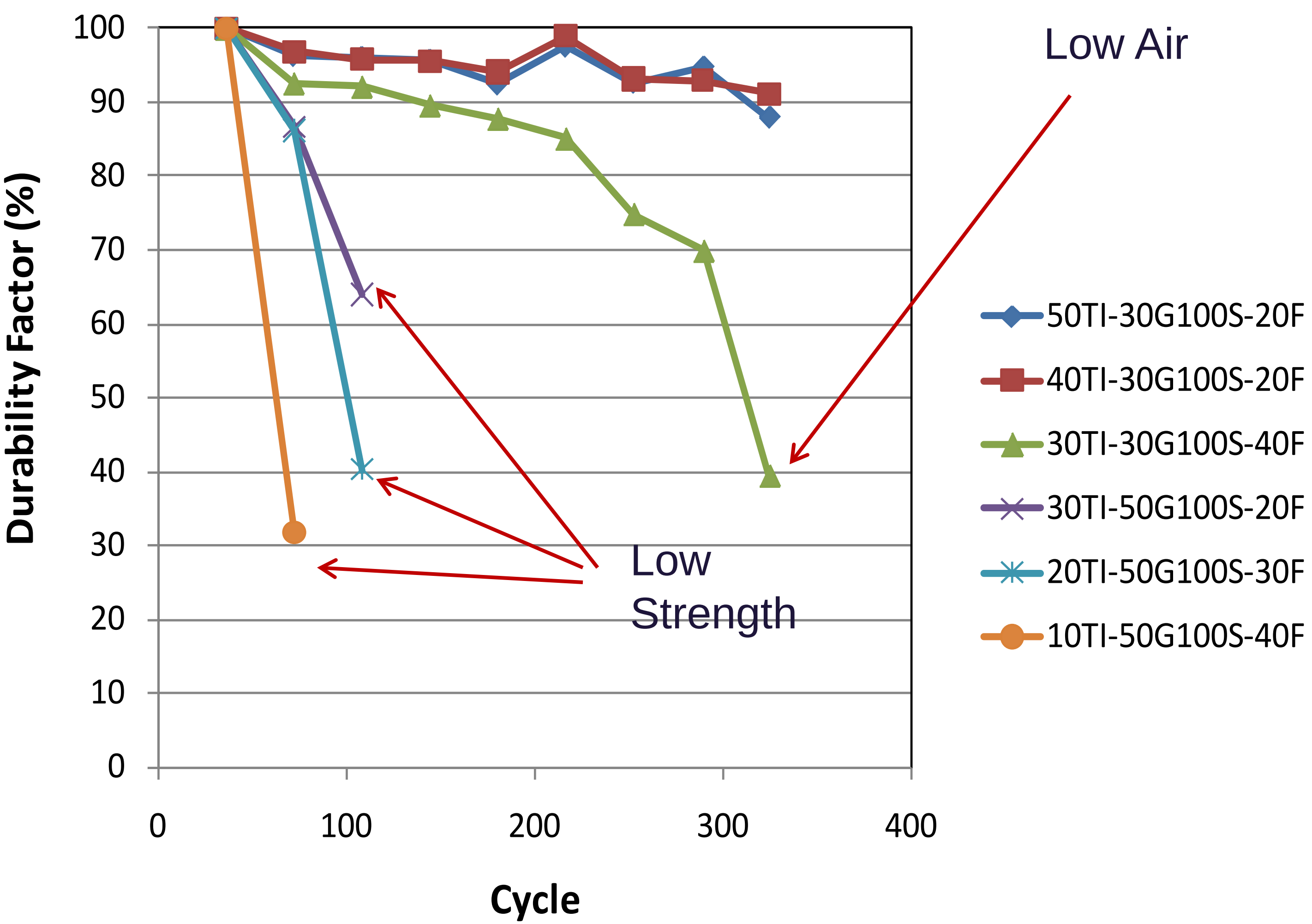
Durability Factor (%)
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
Cycle
100TI
80TI-20C
80TI-20F
50TI-50G100S
50TI-50G120S

Results



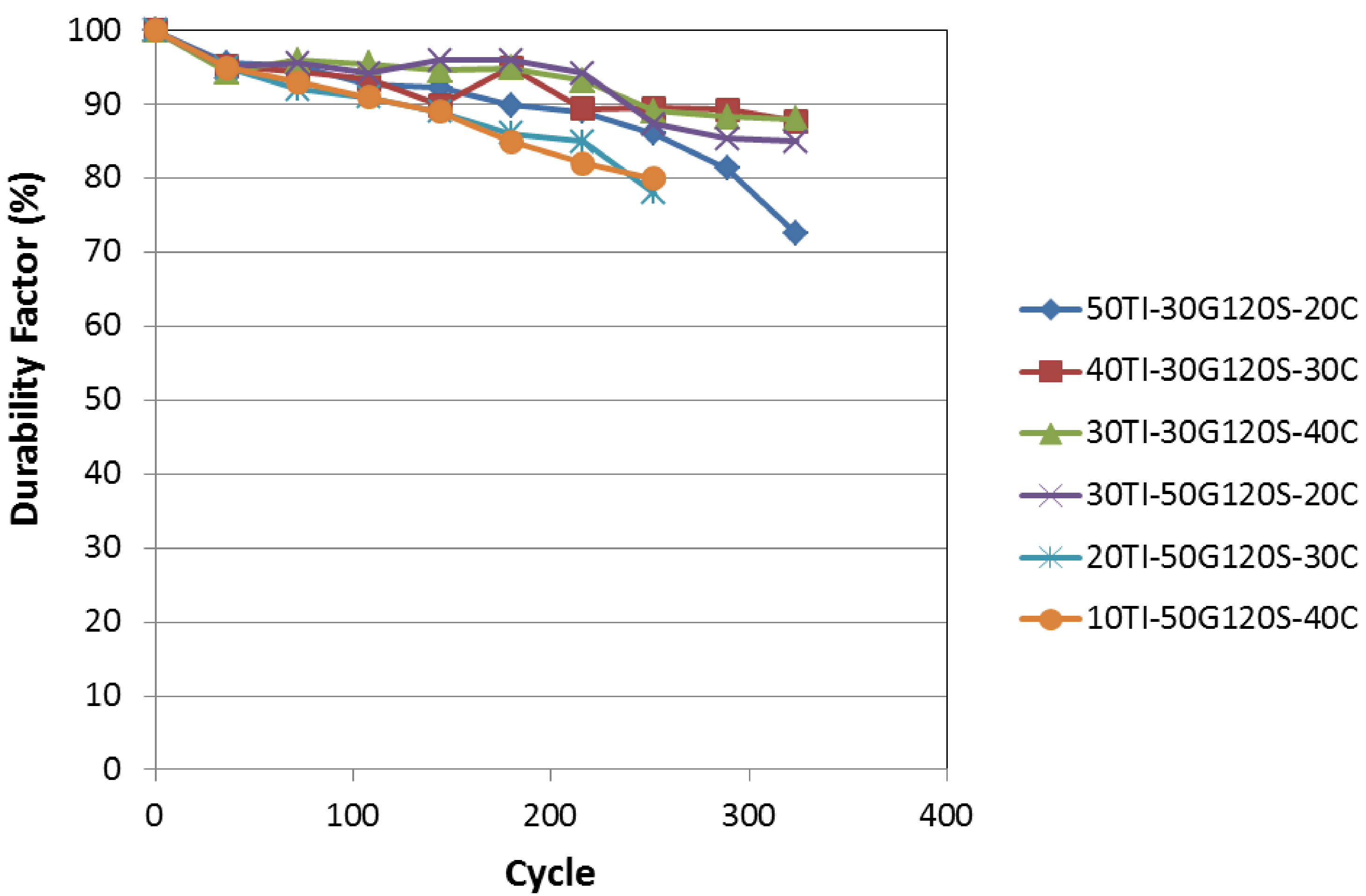
Durability Factor (%)
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
Cycle
50TI-30G100S-20C
40TI-30G100S-30C
30TI-30G100S-40C
30TI-50G100S-20C
20TI-50G100S-30C
10TI-50G100S-40C

Results



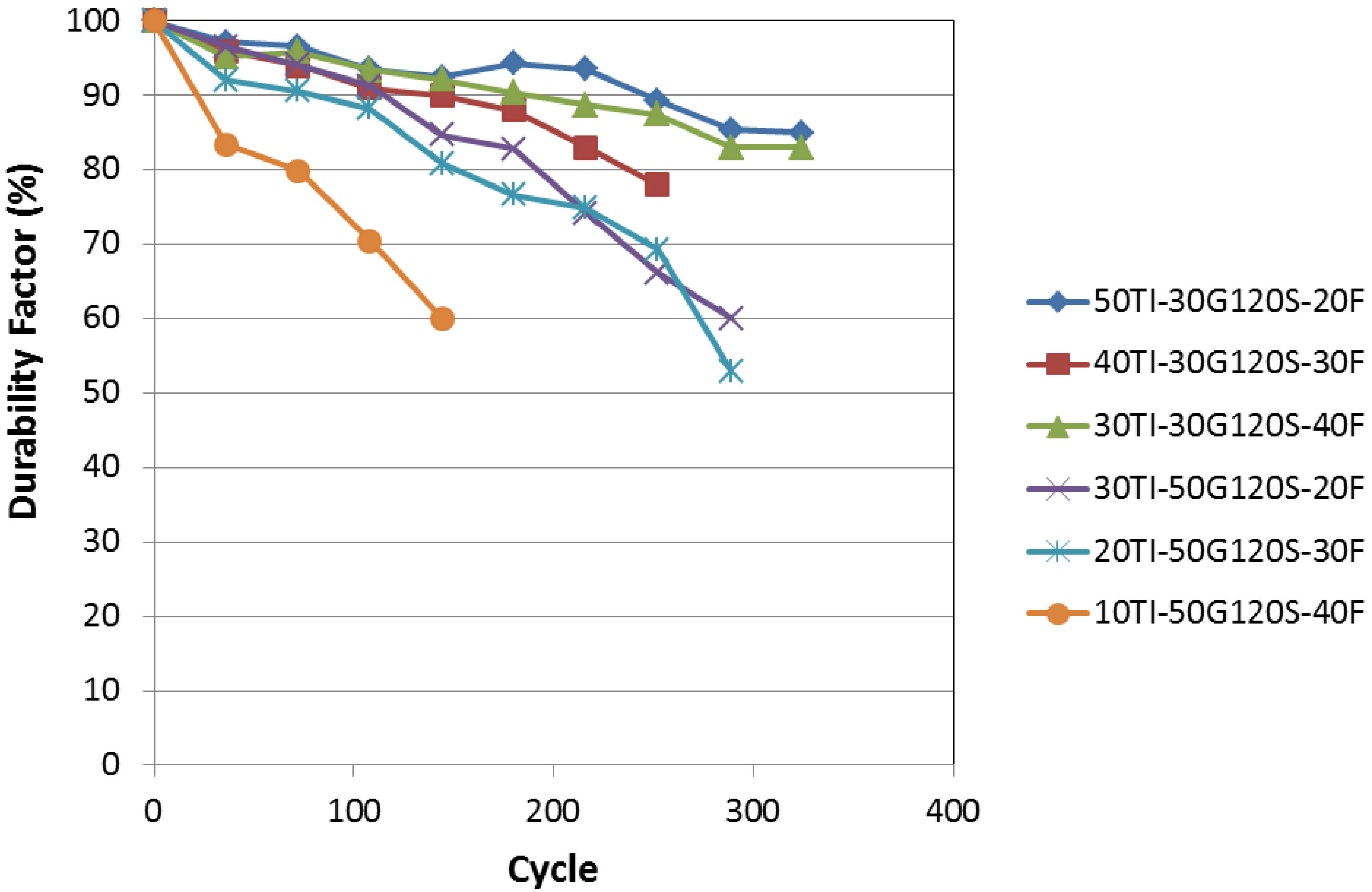
Low Air
Low
Strength
Durability Factor (%)
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
Cycle
50TI-30G100S-20F
40TI-30G100S-20F
30TI-30G100S-40F
30TI-50G100S-20F
20TI-50G100S-30F
10TI-50G100S-40F

Results



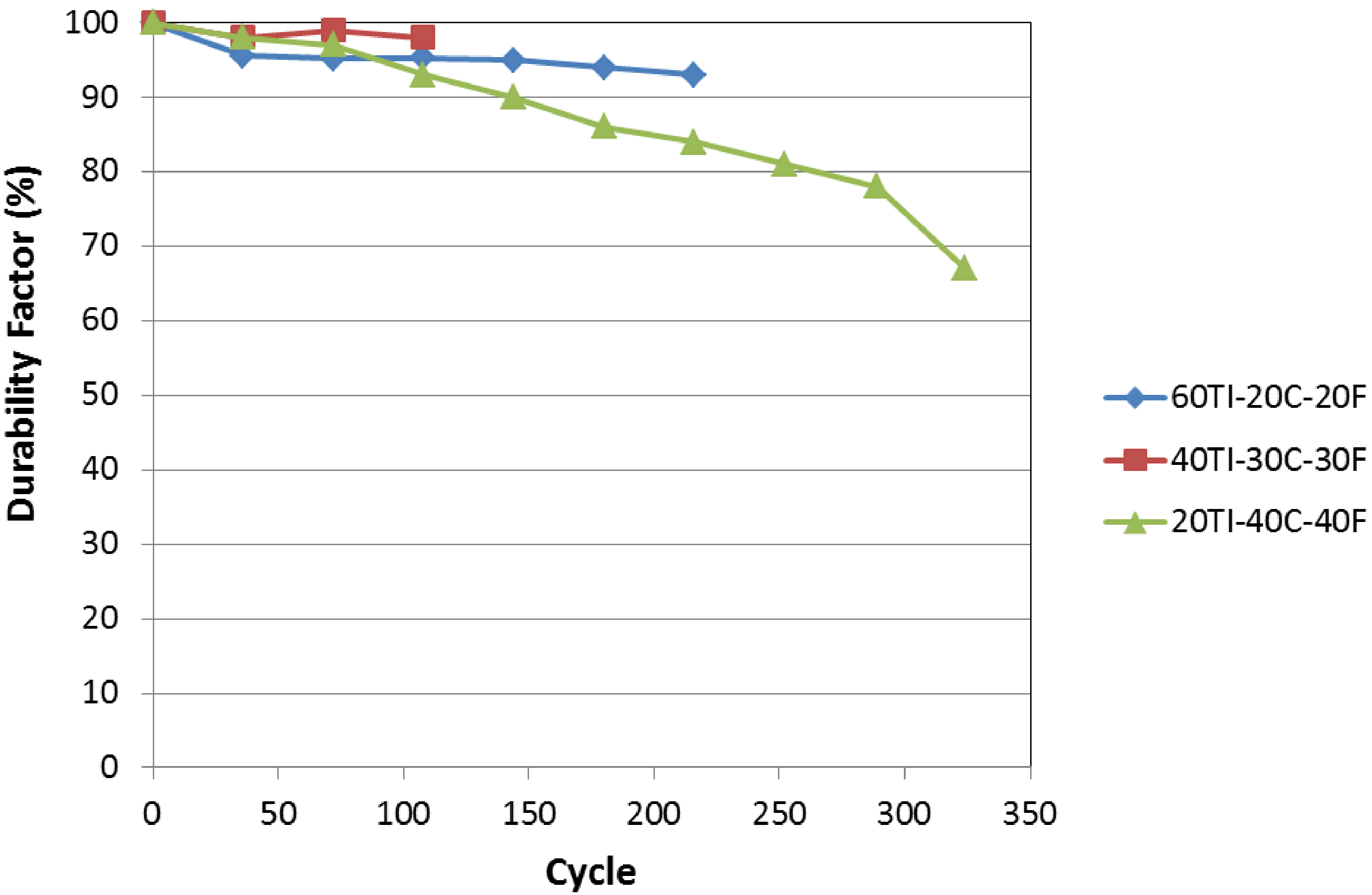
Durability Factor (%)
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
Cycle
50TI-30G120S-20C
40TI-30G120S-30C
30TI-30G120S-40C
30TI-50G120S-20C
20TI-50G120S-30C
10TI-50G120S-40C

Results



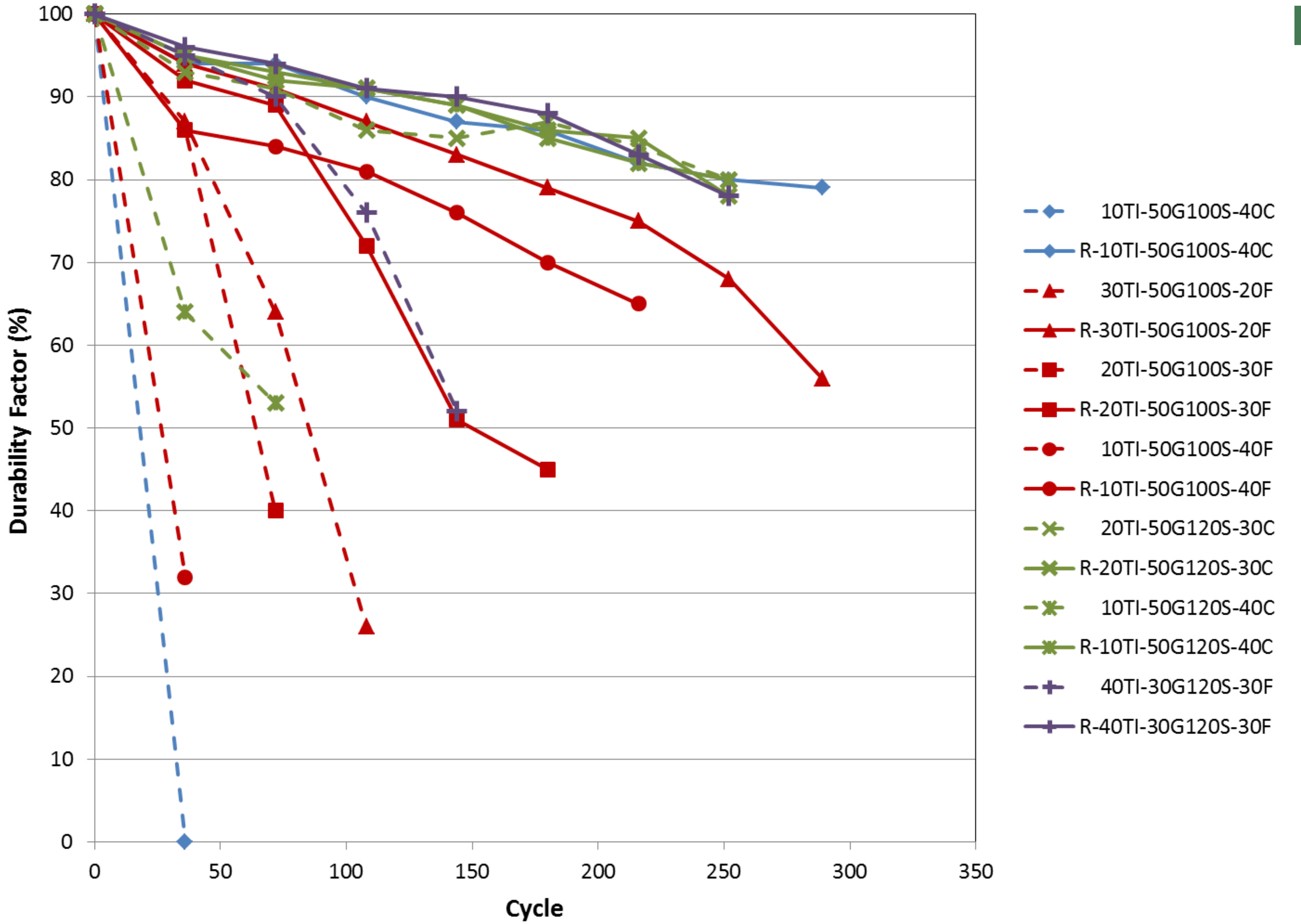
Durability Factor (%)
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
Cycle
50TI-30G120S-20F
40TI-30G120S-30F
30TI-30G120S-40F
30TI-50G120S-20F
20TI-50G120S-30F
10TI-50G120S-40F

Results



Durability Factor (%)
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
Cycle
60TI-20C-20F
40TI-30C-30F
20TI-40C-40F

Results



Durability Factor (%)
Cycle
100
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
10TI-50G100S-40C
R-10TI-50G100S-40C
30TI-50G100S-20F
R-30TI-50G100S-20F
20TI-50G100S-30F
R-20TI-50G100S-30F
10TI-50G100S-40F
R-10TI-50G100S-40F
20TI-50G120S-30C
R-20TI-50G120S-30C
10TI-50G120S-40C
R-10TI-50G120S-40C
40TI-30G120S-30F
R-40TI-30G120S-30F

Results – Cost-Benefit Analysis

Mixture Design	Cementitious Materials Cost ($/mile)	Potential Savings per Mile ($)	Potential Savings per Mile (%)
80TI-20C	$90,566	N/A	N/A
40TI-30G100S-30C	$72,453	$18,113	20.0
30TI-35C-35F	$65,409	$25,157	27.8

Mixture Design	Cementitious Materials Cost	Potential Savings ($)	Potential Savings (%)
80TI-20C	$17,298,106	N/A	N/A
40TI-30G100S-30C	$13,838,523	$3,459,583	20.0
30TI-35C-35F	$12,493,119	$4,807,515	27.8

Cementitious Material	Cost per Ton ($)
Portland Cement	$100.00
Fly Ash	$50.00
Slag	$90.00

Results – CO_2 Load Analysis

Cementitious Material	CO_2 Load (Tons)
Portland Cement	0.92
Fly Ash	0.00
100 Grade Slag	0.15
120 Grade Slag	0.20

Mixture Design	CO_2 Load for the 2007-2008 Bid Years (Tons)	Potential CO_2 Savings (Tons)	Potential CO_2 Savings (%)
80TI-20C	141531	N/A	N/A
40TI-30G100S-30C	79456	62075	43.9
40TI-30G120S-30F	83321	58210	41.8
30TI-35C-35F	53098	98433	62.5

Conclusions

- Compressive strengths equal or greater than control, especially at later ages
- Compressive strength ratios indicate a greater resistance to early age cracking
- Flexural strengths are adequate for paving applications
  - May be able to reduce thicknesses

Conclusions

- Shrinkage results indicate that ternary mixtures perform equal to or better than the control mixtures
- RCP results show that the ternary mixtures will easily meet the new permeability specifications
- The ternary mixtures are freeze-thaw durable
  - Entrained air
  - Adequate strength

Conclusions

- Cost benefit ratio up to 21
- Save approximately 58,000 – 60,000 tons of CO_2 annually
- 70% SCM replacement level
- **Care should be exercised when interpreting and implementing these results**

Recommendations

- Implement up to 70% replacement of portland cement for ternary mixtures
  - When using slag-fly ash mixtures, do not use more fly ash than slag
  - When using class C fly ash-class F fly ash mixtures, add them at the same rate
  - Temperature limitations

901 ***Proposed*** Changes - Ternary

- Substitutions - Binary
  - The maximum substitution rate for Binary mixtures is 30 percent fly ash on a pound (kilogram) for pound (kilogram) basis. Use a maximum substitution rate of 50 percent slag on a pound (kilogram) for pound (kilogram) basis.

901 ***Proposed*** Changes - Ternary

- Substitutions – Ternary w/ Type I, II, or III
  - The maximum substitution rate for ternary mixtures containing Type I, II, or III portland cement is 70 percent by weight (mass) of cement. Ternary combinations of class C and F fly ash are allowable. When using fly ash ternary mixtures, replace portland cement with class C and class F fly ash at the same rate. Do not use more fly ash than slag when using combinations of slag and fly ash.

901 ***Proposed*** Changes - Ternary

- Substitutions – Ternary w/ Type IP or IS
  - When using only Type IP or IS portland cement in concrete mixes, the maximum substitution rate for ternary mixtures is 40 percent by weight (mass) of cement. When using fly ash ternary mixtures, replace portland cement with class C and class F fly ash at the same rate. Do not use more fly ash than slag when using combinations of slag and fly ash.

Major 901 *Proposed* Changes

- Cold Weather Limitations
  - For the location of placement; discontinue mixing and concreting operations when a descending air temperature in the shade and away from artificial heat reaches 35°F (2°C) (50°F (10°C) for ternary mixes) or NOAA forecast the temperature to be less than 32°F (0°C) within the 24 hour period following placement; 36 hours for binary mixes and 48 hours for ternary mixes. Do not resume mixing and concreting operations until an ascending air temperature in the shade and away from artificial heat reaches 32°F (0°C) provided the high temperature forecasted by NOAA is above 35°F (2°C) and remains above 32°F (0°C) for a minimum of 24 hours; 36 hours for binary mixes and 48 hours for ternary mixes

Major 901 ***Proposed*** Changes

Table 901-3
Master Proportion Table for Portland Cement Concrete

	Average Compressive Strength, psi (MPa) at 28 days	Grade of Coarse Aggregate	Min. Cement, lb/yd^3 (kg/m^3) of Concrete [9,14]	Maximum Water/Cement ratio, lb/lb (kg/kg) [1,9]	Air Content (Percent by volume) [4]	Slump Range [10], inches (mm)		
						Non-Vibrated	Vibrated	Slip Form Paving [2]
Structural Class [11]								
AA(M)	4400 (30.4)	A, P	560 (332)	0.44	7 max[15]	2-5 (50-125)	2-4 (50-100)	N.A.
AA	4200 (29.0)	A, P	560 (332)	0.44	7 max[15]	2-5 (50-125)	2-4 (50-100)	N.A.
A(M)	4400 (30.4)	A, P	510 (302)	0.53	7 max	2-5 (50-125)	2-4 (50-100)	N.A.
A	3800 (26.2)	A, F [8], P	510 (302)	0.53	7 max	2-5 (50-125)	2-4 (50-100)	1-2.5 (25-65)
D	3300 (22.8)	A, B, D, P	420 (249)	0.58	7 max	2-5 (50-125)	1-3 (25-75)	N.A.
F	3400 (23.5)[5]	A,P	460 (273)	0.44	7 max[15]	2-5 (50-125)	2-4 (50-100)	N.A.
P(X)	7500 (51.7) [5]	A, F [8], P	700 (415)	0.40	7 max	N.A.	2-10 (50-250)	N.A.
P(M)	6000 (41.4)[5]	A, F [8], P	600 (356)	0.44	7 max	N.A.	2-6 (50-150)[7]	N.A.
P	5000 (34.5)[5]	A, F [8], P	560 (332)	0.44	7 max	N.A.	2-6 (50-150)[7]	N.A.
S	3800 (26.2)	A,P	650 (385)	0.53	7 max	6-8 (150-200)	N.A.	N.A.
Minor Structure Class [11]								
M	3000 (20.7)	A, B, P	470 (279)	0.56	7 max	2-5 (50-125)	2-4 (50-100)	1-2.5 (25-65)
R	1800 (12.4)	A, B, D, P	370 (219)	0.70	7 max	2-5 (50-125)	2-4 (50-100)	N.A.
Y	3000 (20.7)	Y	560 (332)	-[3]	6-9	N.A.	1-3 (25-75)	N.A.
Pavement Type [11]								
B	4000 (27.6)[6]	N/A[13]	475 (282)	0.53	7 max[16]	N.A.	2-4 (50-100)	1-2.5 (25-65)
D	4000 (27.6)[6]	N/A[13]	450 (267)	0.53	7 max[16]	N.A.	2-4 (50-100)	1-2.5 (25-65)
E	4000 (27.6)[6]	A, F[12], P	600 (356)	0.40	7 max	N.A.	2-4 (50-100)	1-2.5 (25-65)

N.A. – Not Applicable

[1] Except for Class AA, AA(M), or F concrete, the maximum volume of water; gal. (L), shall be reduced 5 percent when a water-reducing admixture is used, and 10 percent when an air-entraining admixture, or air-entraining and water-reducing admixtures, is used. When the coarse aggregate portion of the mix is 100 percent crushed aggregate, the water may be increased by 5 percent provided the maximum water listed in Table 901-3 is not exceeded.
[2] Also slump range for other concrete placed by extrusion methods.
[3] Refer to Subsection 901.08(c).
[4] Maximum allowed air content when air-entrainment is allowed or specified. See Subsection 901.08(b).
[5] Values shown represent the minimum compressive strengths allowed.
[6] Average compressive strengths for Pavement Type concrete shall be 3600 psi (25.0 MPa) when air-entrainment is used.
[7] No more than a 2 inch (50 mm) slump differential for any design pour.
[8] Grade F coarse aggregate shall be used only when specified or permitted. The minimum cement content shall be increased when this aggregate is used.
[9] For mixes including partial replacement of cement with fly ash or ground granulated blast furnace slag, the minimum cement and maximum water contents shown apply to the total cement and fly ash or ground granulated blast furnace slag content of the mix. Additional cement may be required to achieve minimum compressive strength.
[10] When a slump range is specified in other sections, that range shall govern.
[11] See Subsection 901.08(a) for allowable types of cement.
[12] For use in partial depth patching.
[13] Aggregate grading shall comply with the requirements of Subsection 1003.02(b).
[14] The minimum cement factors may be waived in writing by the District Laboratory Engineer in accordance with Subsection 901.06(a).
[15] Test first loads for air content. Subsequent loads shall maintain a minimum 2% air content to avoid rejection.
[16] If slip formed, test first loads for air content. Subsequent loads shall maintain a minimum 2% air content to avoid rejection.

Major 901 *Proposed* Changes

	Average Compressive Strength, psi (MPa) at 28 days	Grade of Coarse Aggregate	Surface Resistivity (Permeability) (kΩ-cm)	Maximum Water/Cementitious ratio, lb/lb (kg/kg)	Air Content (Percent by volume) [2]	Slump Range [6], inches (mm)		
						Non-Vibrated9	Vibrated	Slip Form Paving [1]
Structural Class [7]								
A	4,000 (27.6)	A,B,D, F[5], P, [8]	27	0.44	2 - 7	2-5 (50-125)	2-4 (50-100)9	1-2.5 (25-65)
P1	6,000 (41.4)[3]	A,B,D, F[5], P, [8]	27	0.44	2 - 7	N/A	2-6 (50-150)[4]	N/A
P2	7,500 (51.7)[3]	A,B,D, F[5], P, [8]	27	0.40	2 - 7	N/A	2-6 (50-150)[4]	N/A
P3	8,500 (58.6) [3]	A,B,D, F[5], P, [8]	27	0.40	2 - 7	N/A	2-6 (50-150)[4]	N/A
P4	10,000 (68.9)[3]	A,B,D, F[5], P, [8]	27	0.40	2 - 7	N/A	2-6 (50-150)[4]	N/A
S	4,000 (27.6)	N/A[13]	27	0.53	2 - 7	6-8 (150-200)	N/A	N/A
MASS	4,000 (27.6)	N/A[13]	27	0.53	2 - 7	N/A	2-4 (50-100)9	N/A
Minor Structure Class [7]								
M	3,000 (20.7)	A,B,D, F [5], P, [8]		0.56	2 - 7	2-5 (50-125)	2-4 (50-100)9	1-2.5 (25-65)
R	1,800 (12.4)	A, B, D, P		0.70	2 - 7	2-5 (50-125)	2-4 (50-100)9	N/A
Pavement Type [7]								
B	4,000 (27.6)[6]	N/A[8]		0.53	2 – 7	N.A.	2-4 (50-100)	1-2.5 (25-65)
D	4,000 (27.6)[6]	N/A[8]		0.53	2 – 7	N.A.	2-4 (50-100)	1-2.5 (25-65)
E	4,000 (27.6)[6]	A, F[12], P, [8]		0.40	2 - 7	N.A.	2-4 (50-100)	1-2.5 (25-65)

N/A – Not Applicable

[1] Also slump range for other concrete placed by extrusion methods.

[2] See Subsection 901.08(b).

[3] Values shown represent the minimum compressive strengths allowed for all test cylinders.

[4] No more than 2 inch (50 mm) slump differential for any design placement. Allow 9-inch maximum slump if water reducers are used.

[5] Grade F coarse aggregate shall be used only when specified or permitted.

[6] Additional allowance in slump range to be approved by the Chief Construction Engineer.

[7] See Subsection 901.08(a) for allowable types of cement.

[8] Aggregate grading shall comply with the requirements of Subsection 1003.02(b).

9 Allow a 8-inch maximum slump if water reducers are used.

Acknowledgements

- Randy Young
- Matt Tircuit
- Shane Laws
- Jacob Newgard
- Scott Reech
- Kelly Goude
- Joel Taylor
- Carly Spaulding
- Mike Bailey

Acknowledgements

- Holcim
- LaFarge
- Buzzi Unicem
- Headwaters
- FHWA, LADOTD, and LTRC for funding
- Grade 100 slag
- Type I portland cement
- Grade 120 slag
- Class C & F fly ash

Questions