RowanUniversity
CENTER FOR RESEARCH & EDUCATION IN
ADVANCED TRANSPORTATION ENGINEERING SYSTEMS

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Engineer Research and
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Optimizing Ternary Blended Binders

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Outline

- Overview
- Compressive strength
- Calorimetry
- Concrete mixtures
- Application with RCA

Use of SCM

Use of supplementary cementitious materials (SCM) improves properties of portland cement concrete

- Increased strength
- Increased workability
- Reduced heat of hydration
- Reduced permeability

Sustainability

- Reduced carbon footprint of concrete production
- Lower cost of materials

Typical PC replacements

One SCMs and portland cement

- Class F fly ash : 15% to 25%
- Class C fly ash : 15% to 40%
- GGBFS : 30% to 40% (but can be up to 70%).
- Silica fume : up to 5% to 10%

Ternary blended binder

Two SCMs and portland cement

- Tikalsky, P., et al., Development of Performance Properties of Ternary Mixtures: Phase I Report, National Concrete Pavement Technology Center, Ames, IA. 2007.
- Rupnow, T.D., Evaluation of Ternary Cementitious Combinations, Louisiana Transportation Research Center, Baton Rouge, LA, 2012
- Taylor, P., The Use of Ternary Mixtures in Concrete, National Concrete Pavement Technology Center, Ames, IA. 2014.


National Concrete Pavement Technology Center

The Use of
TERNARY
MIXTURES IN CONCRETE

FACT SHEET

New Concrete Mixtures Turn Waste into Quality Roads

February 2012

WHAT WAS THE PROBLEM?

WHAT WAS DONE?

WHY SHOULD YOU DO IT?

WHAT ARE POTENTIAL FISCAL IMPACTS?

Ternary blend mixtures studied

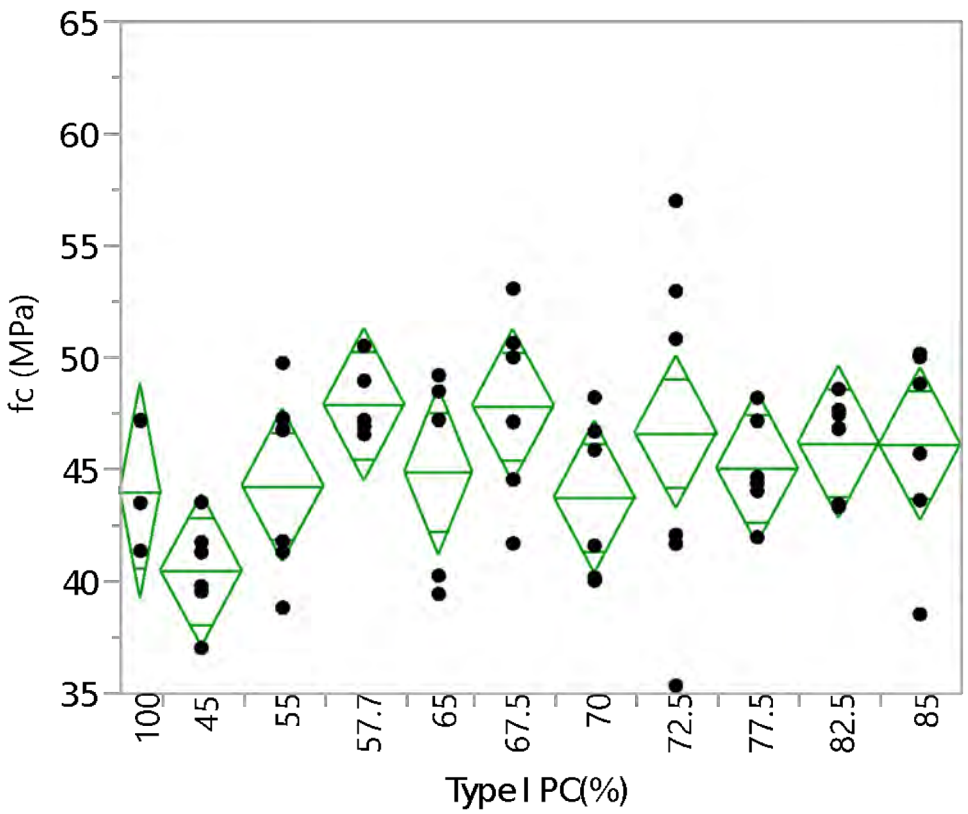
25 unique mixtures

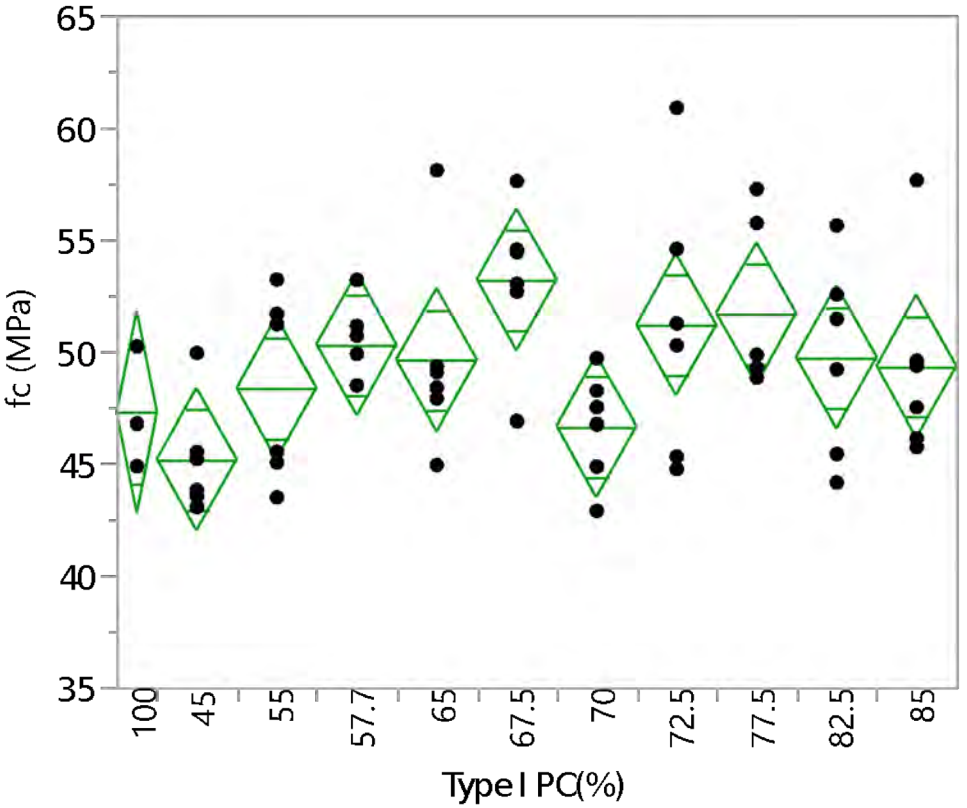
- Silica fume (0, 2.5, 5%)
- Class C fly ash (0, 12.5, 25%)
- Class F fly ash (0, 12.5, 25%)
- Blast furnace slag (0, 10, 20, 30%)
- Includes control (PCC only) and binary mixtures

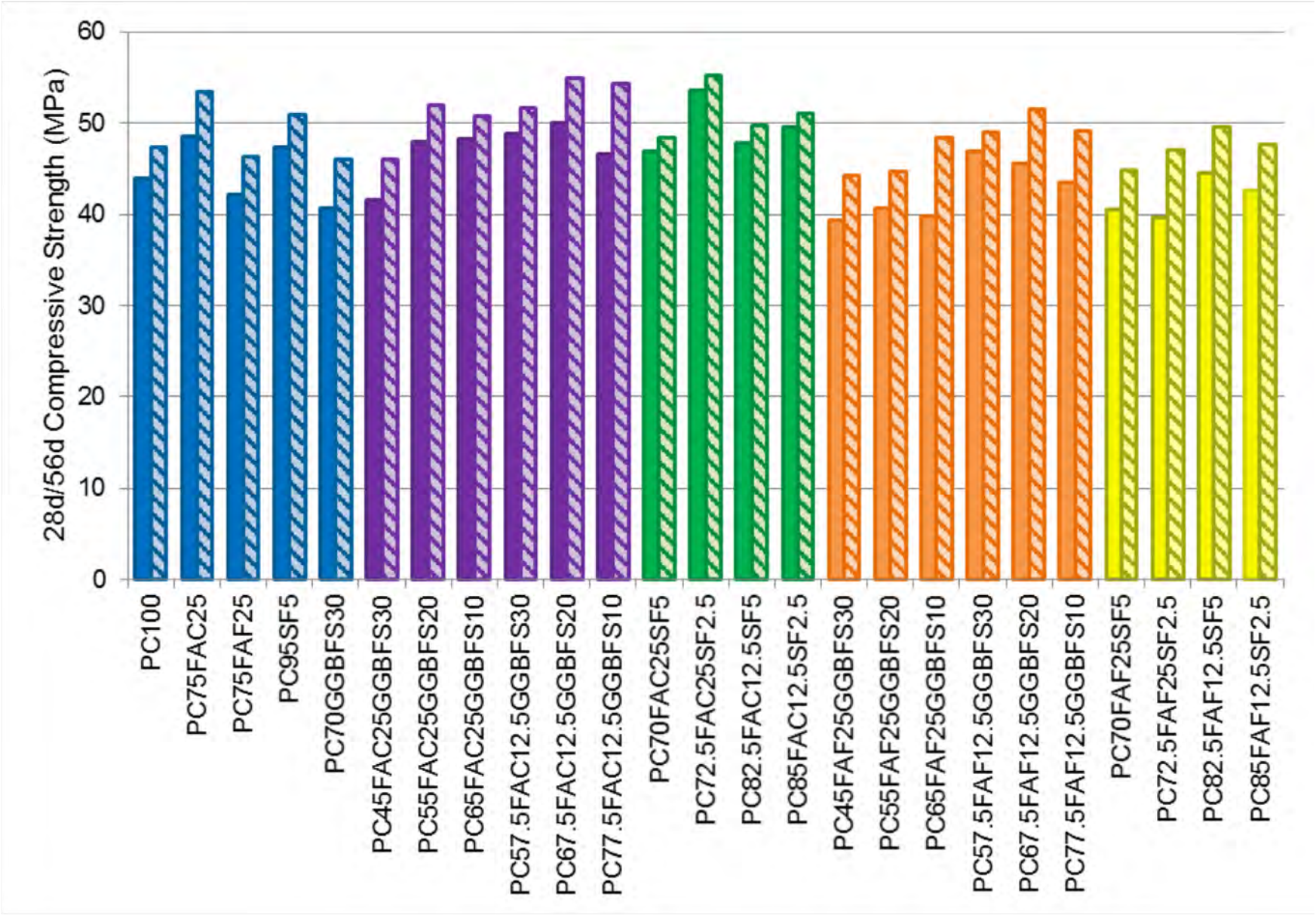
Cube Compressive Strength

- 2 inch mortar cubes
- Water to binder = 0.45
- Binder to aggregate = 0.5
- 28 & 56 day analysis
- Statistical analysis of SCM strength contribution

Cube Compressive Strength







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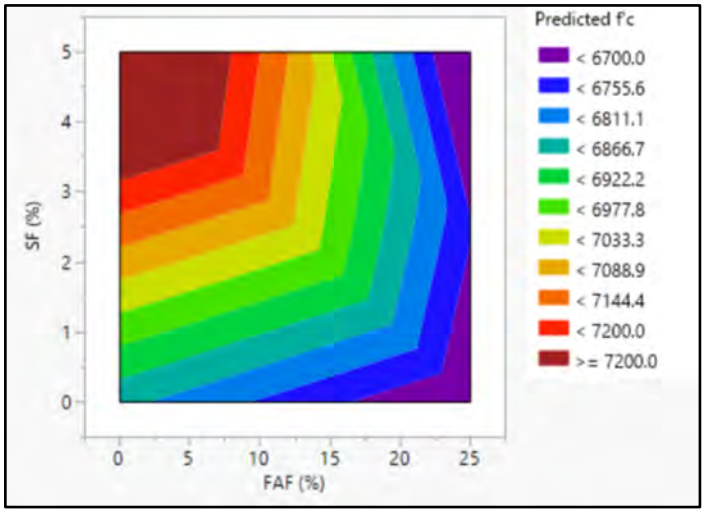
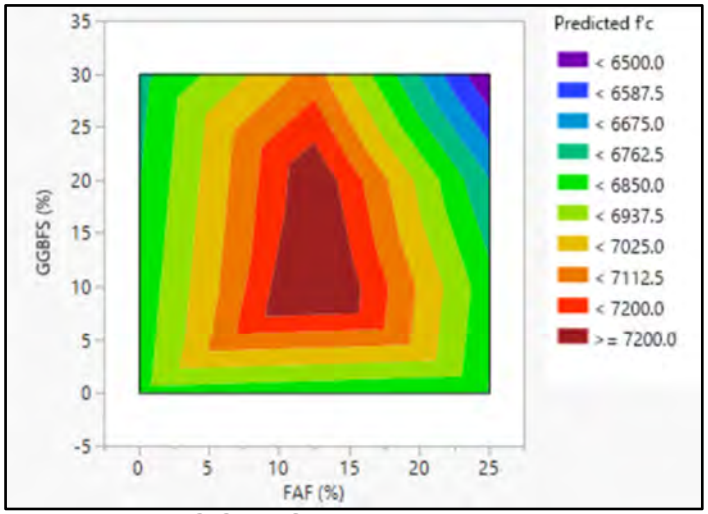
Mortar average compressive strength results for 28 day (solid bars) and 56 day (hatched bars) strength for mixtures tested.

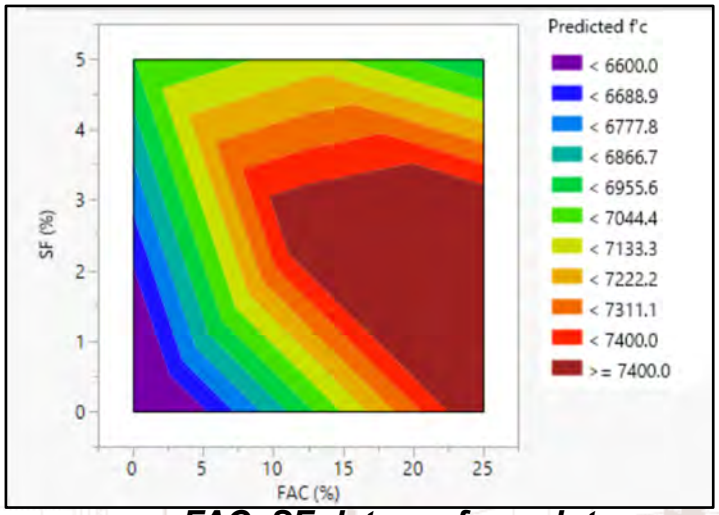
Compressive Testing – Modeling



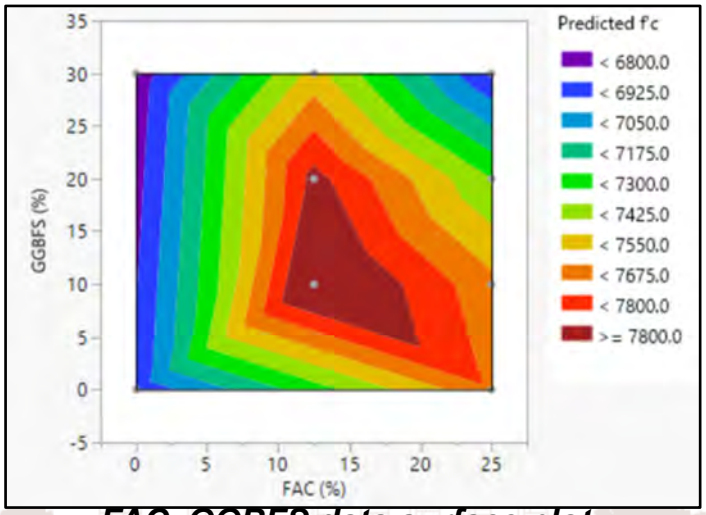
FAFxSF data surface plot.



FAFxGGBFS data contour plot.



FACxSF data surface plot.



FACxGGBFS data surface plot.

Compressive Testing – Statistical Analysis

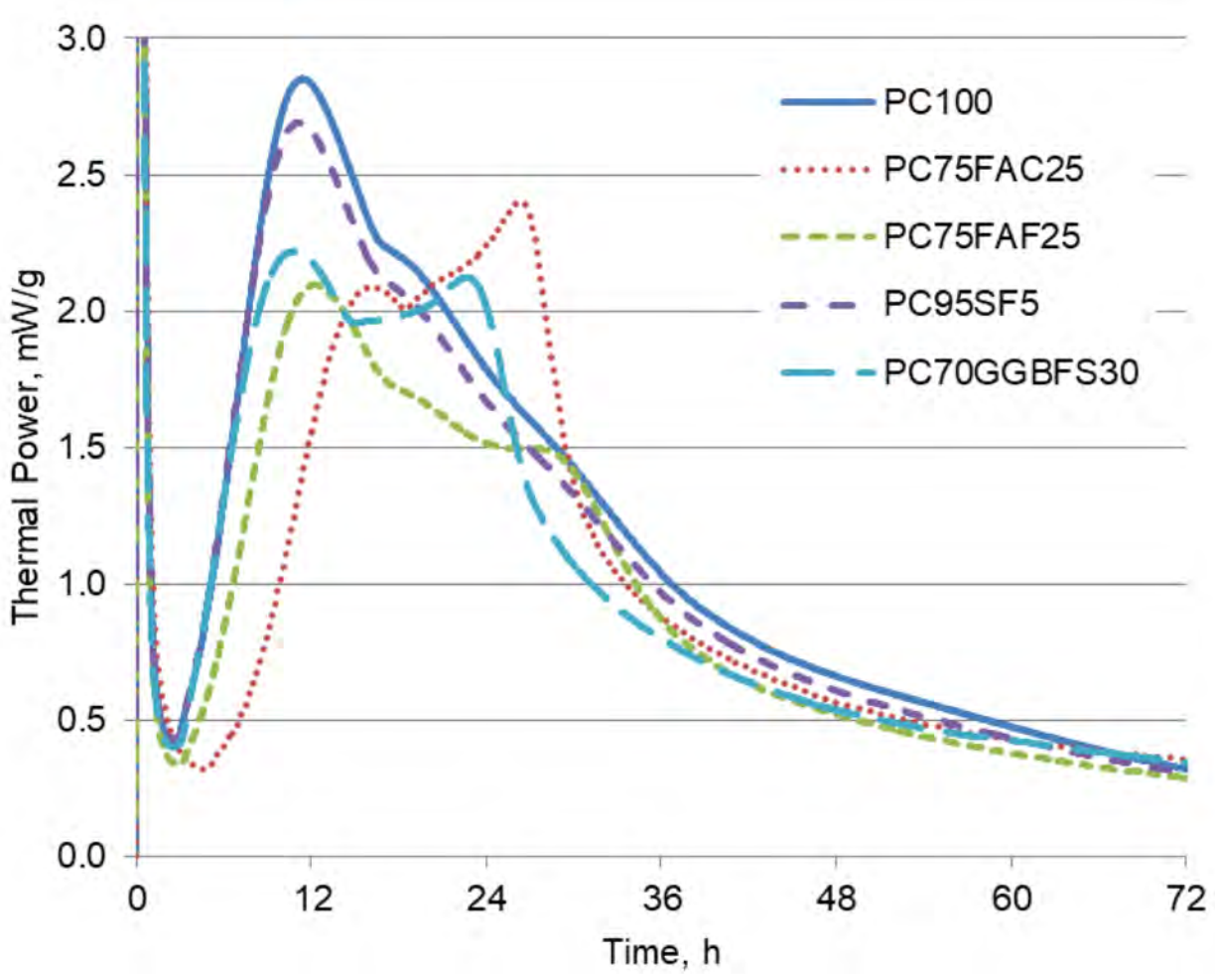
Combination	PC	FAC	FAF	GGBFS	SF	% PC Replaced	Rank By Replacement Rate	Predicted 56d Strength	Rank By f'c
	% of binder								
FAF&SF	95		0		5	5	4	7110	4
FAF&GGBFS	77.5		12.5	10		22.5	2	7520	3
FAC&SF	72.5	25			2.5	27.5	1	7923	2
FAC&GGBFS	77.5	12.5		10		22.5	2	8143	1

Calorimetry - ASTM C1702

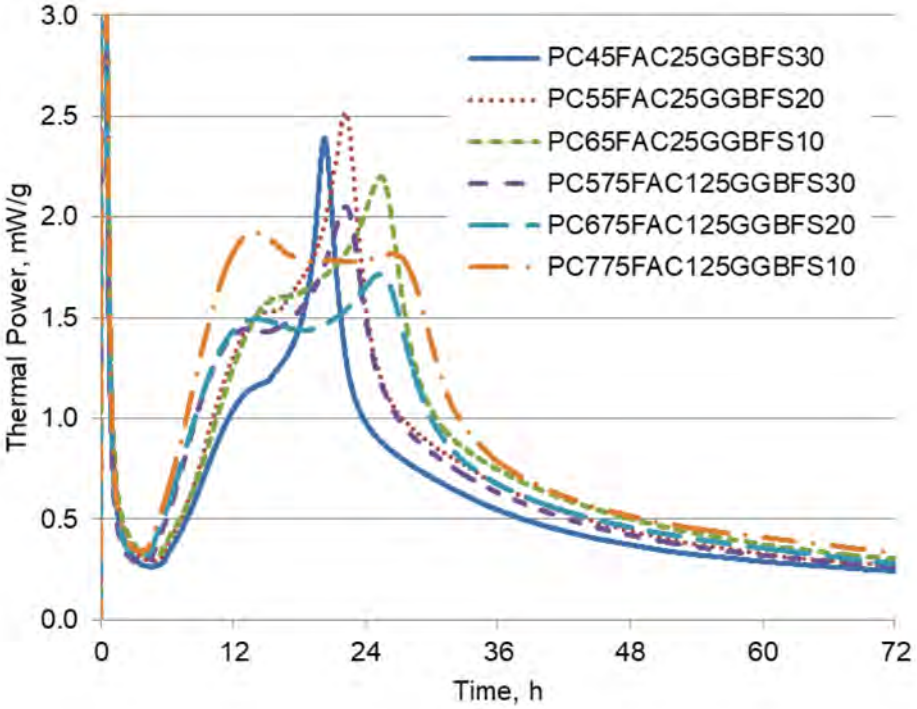
- 50grams of cementitious material
- water to binder = 0. 50
- 20˚C for 72 hours
- Cumulative heat of hydration (Joules) and power (Watts/gram cement) were recorded

I-Cal 2000 HPC

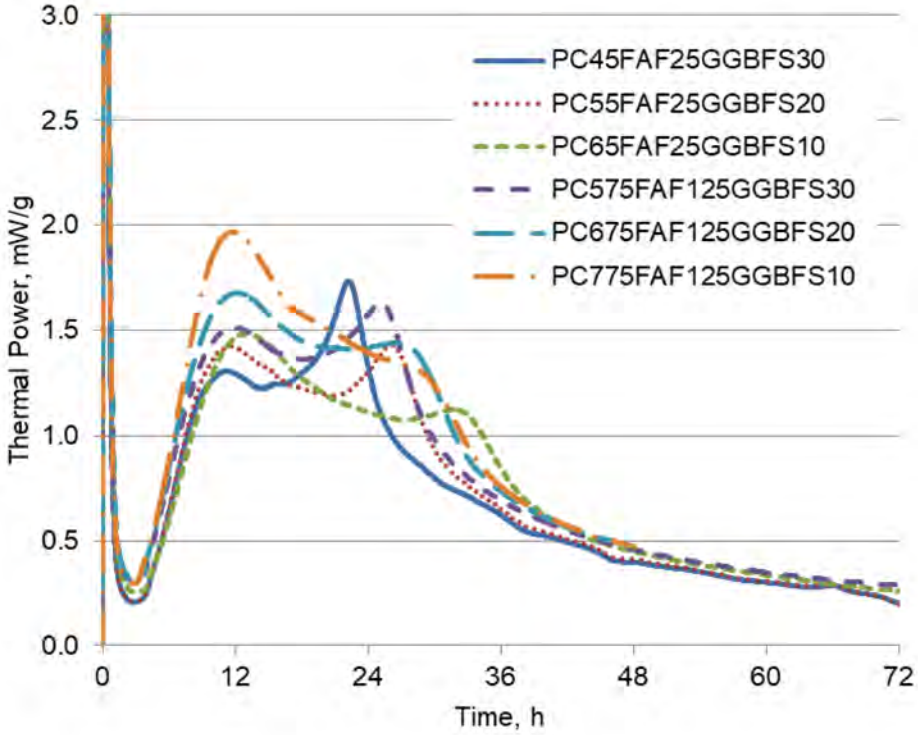
Type I cement and binary binders



PC + Fly Ash + GGBFS

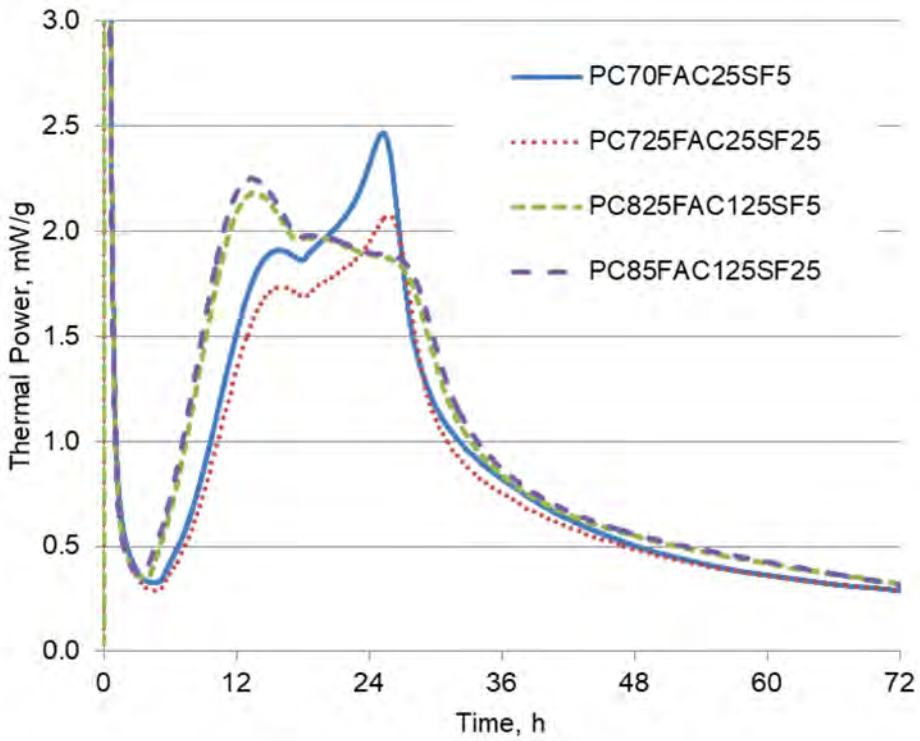


PC-FAC-GGBFS

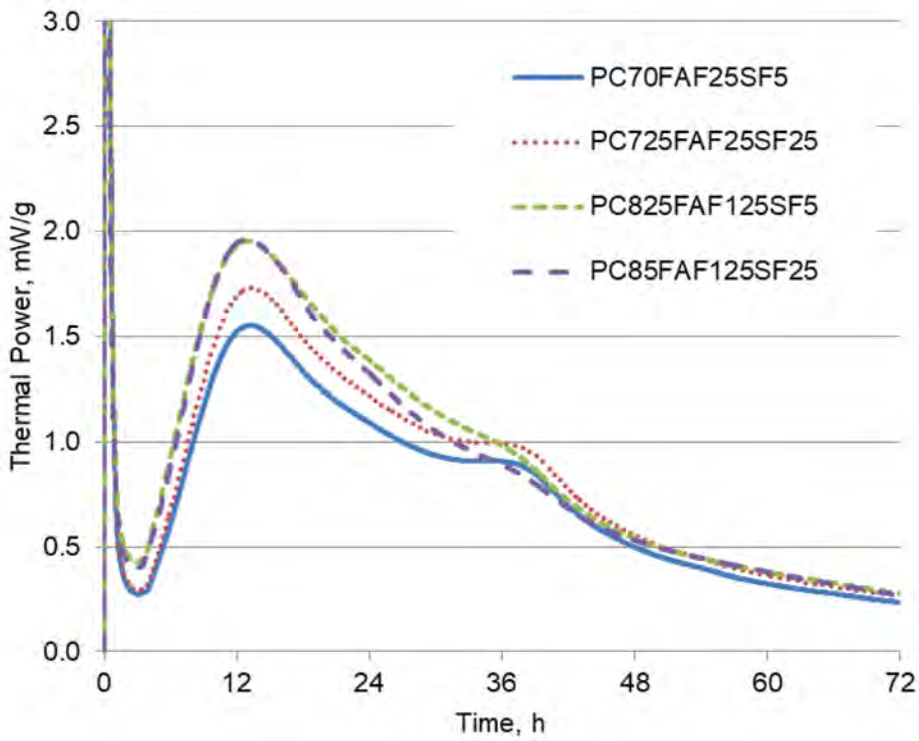


PC-FAF-GGBFS

PC + Fly Ash + Silica Fume

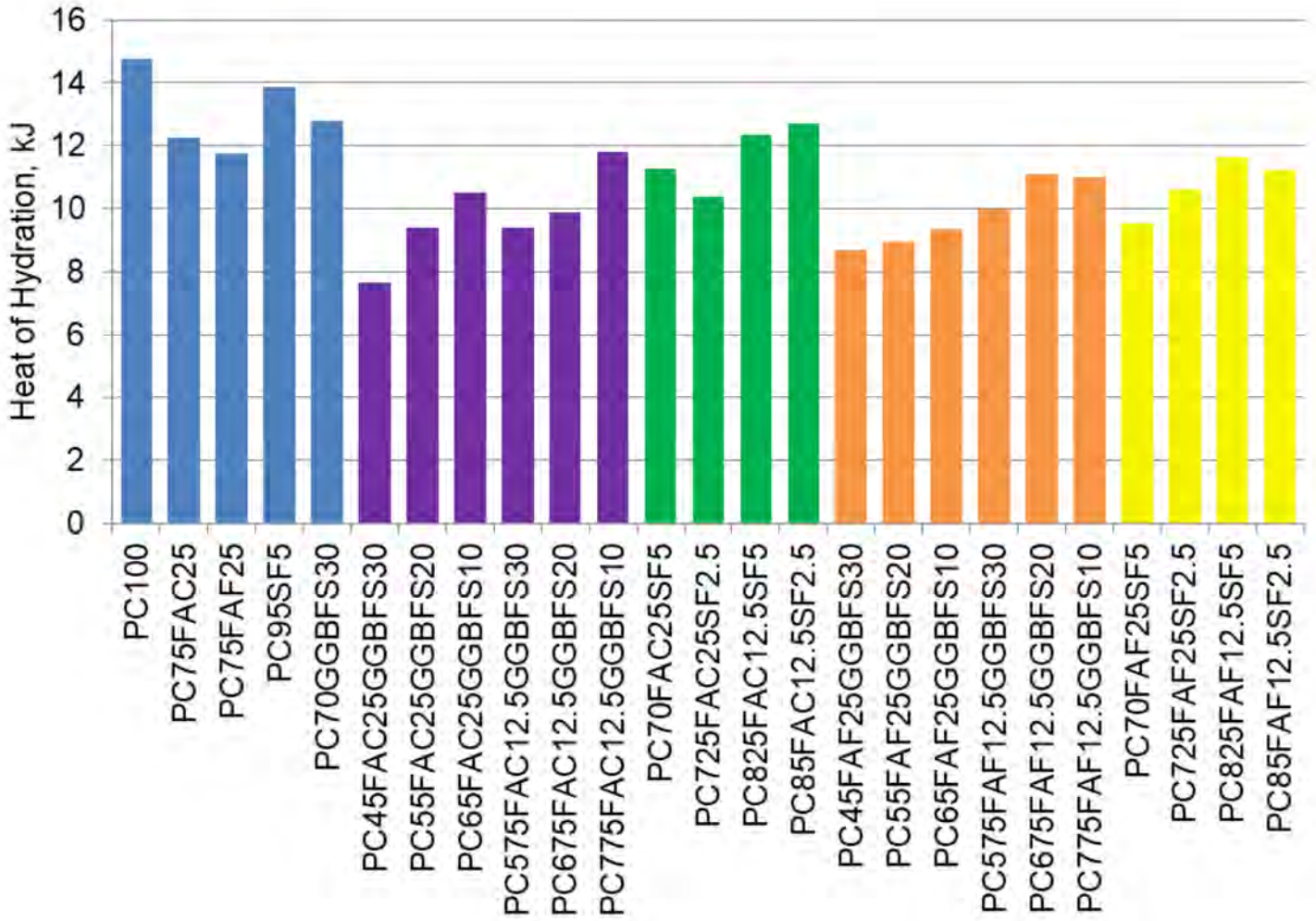


PC-FAC-SF



PC-FAF-SF

Heat of Hydration



Ternary Binder Concrete Mixtures

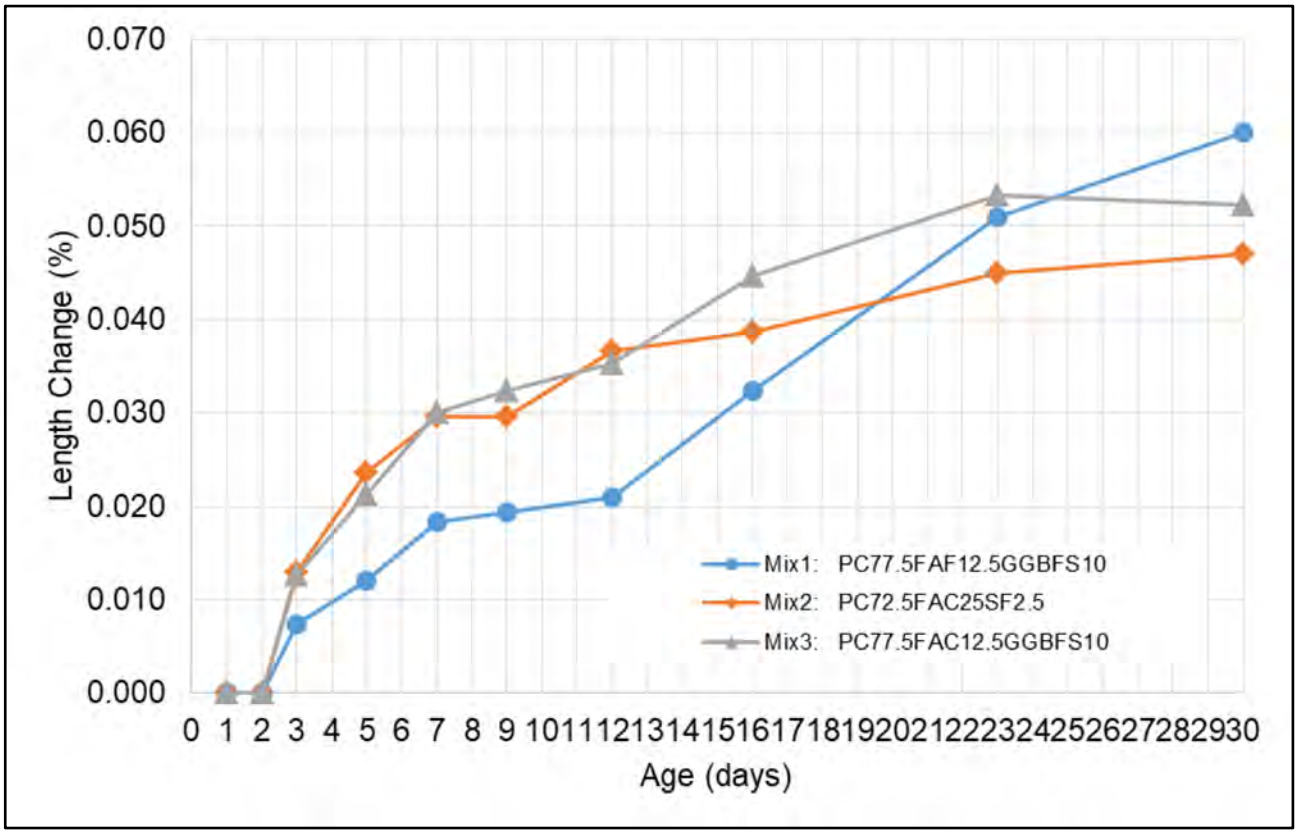
	PC77.5FAF12.5GGBFS10 Mix 1	PC72.5FAC25SF2.5 Mix 2	PC77.5FAC12.5GGBFS10 Mix 3
Cement, lb	344.7	415.8	405.3
Fly Ash, lb	74.9	148.5	90.1
Slag, lb	179.9		105.1
Silica Fume, lb		29.7	
Water, lb	269.8	267.3	270.2
Sand, lb	1459.2	1459.2	1459.2
Natural Agg, lb	1542.8	1542.8	1542.7
AEA, fl oz/cwt	1.8	2.2	2

Test three concrete mixtures with different ternary binders

Ternary Binder Results

	Mix 1	Mix 2	Mix 3
	PC77.5FAF12.5GGBFS10	PC72.5FAC25SF2.5	PC77.5FAC12.5GGBFS10
Fresh Properties			
Slump (in)	1.0	1.5	1.25
Air Content, %	5.50	5.50	5.00
Unit Wt. (pcf)	148.36	148.66	143.60
Mix temp (°F)	65	65	65
Hardened Properties			
Compressive strength, 3d (psi)	4189	3493	3231
7d	4309	4396	3892
14d	4953	4535	4438
28d	5037	5061	5426
56d	5528	5659	5686
Electrical Resistivity, 3d (kΩ/cm)	9.5	6.6	7.6
7d	14.1	11.4	10.8
14d	17.0	11.8	16.5
28d	23.2	17.8	21.9
56d	25.6	25.8	25.1

Ternary Binder Results



Alkali-silica reaction test results.

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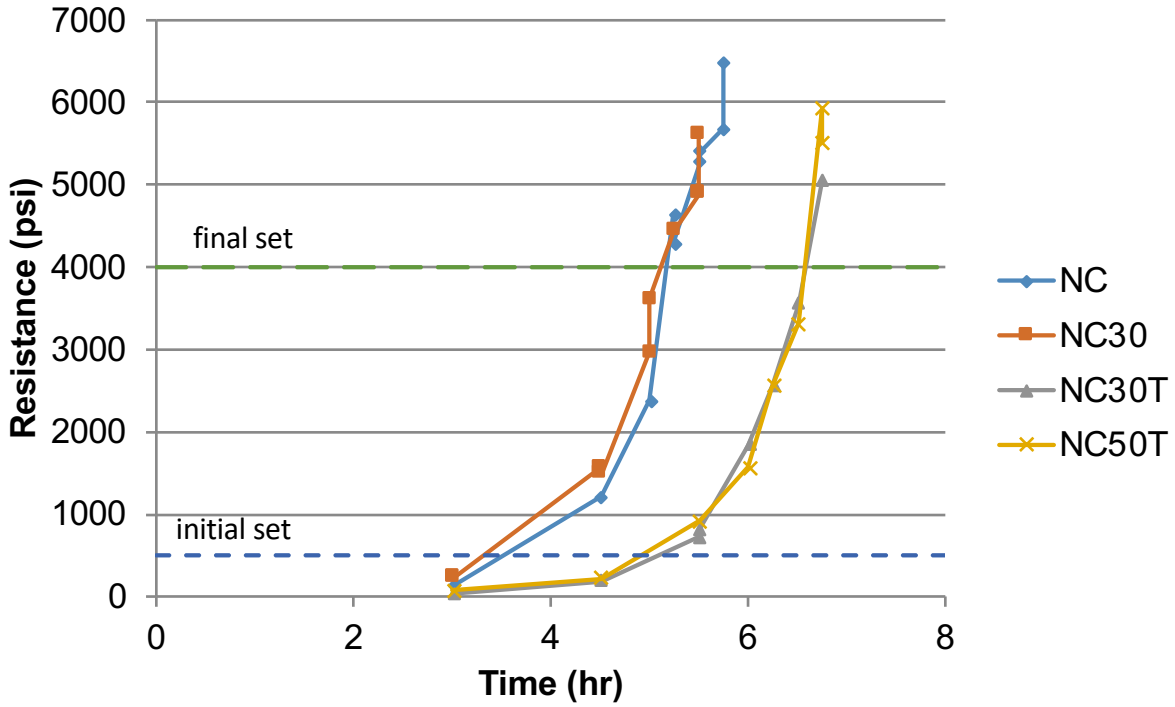
RCA Concrete Mixtures

	Mix 4 NC	Mix 5 NC30	Mix 6 NC30T	Mix 7 NC50T
Cement, lb	656.0	656.0	502.3	502.3
Fly Ash C, lb	-	-	81	81
Slag, lb	-	-	64.8	64.8
Water, lb	262.4	262.4	259.3	259.3
Sand, lb	1455.4	1455.4	1455.4	1455.4
Natural Agg, lb	1538.7	1077.1	1077.1	769.4
RCA, lb	-	415.0	415.0	691.6
AEA, fl oz/cwt	4.0	4.0	4.0	4.0
HRWR, fl oz/cwt	-	2.90	3.05	6.75

RCA Mixture Results

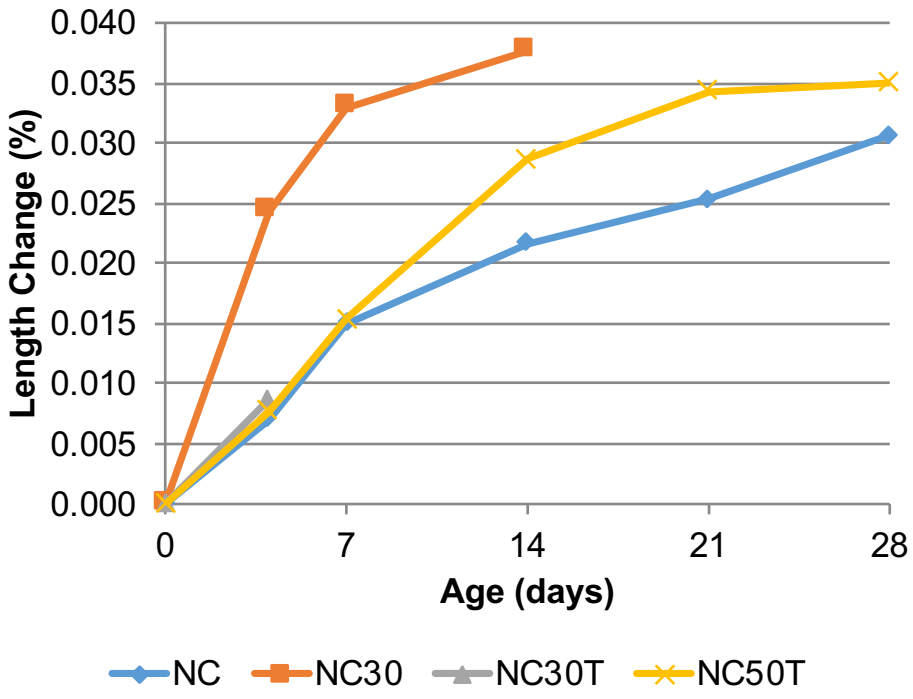
	Mix 4	Mix 5	Mix 6	Mix 7
	NC	NC30	NC30T	NC50T
Fresh Properties				
Slump (in)	1.25	1.0	1.0	0.75
Air Content, %	6.0	6.0	6.0	7.0
Unit Wt. (pcf)	145	146	146	142



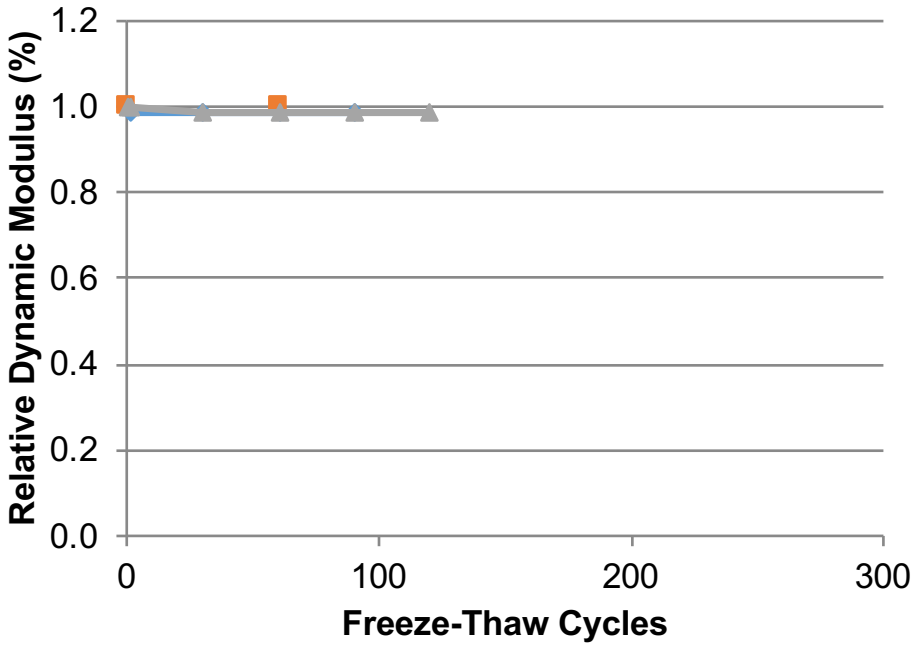
RCA Mixture Results

	Mix 4	Mix 5	Mix 6	Mix 7
	NC	NC30	NC30T	NC50T
Hardened Properties				
Compressive strength, 3d (psi)	3894	4984	4152	4714
7d (psi)	4700	5351	5069	5662
14d (psi)	5030	5942		6238
28d (psi)	5291			6571
Elastic Modulus, 3d (ksi)	7217	7416	7916	8415
7d (ksi)	7910	7798	8828	8983
14d (ksi)	7837	7929		8779
28d (psi)	8896			8145
Electrical Resistivity, 3d (kΩ/cm)	7.9	8.4	6.8	6.2
7d (kΩ/cm)	9.9	9.9	9.6	7.9
14d (kΩ/cm)	11.3	12.7		10.8
28d (kΩ/cm)	13.7			14.5
Modulus of Rupture, 28d (psi)	990			1013

RCA Mixture Results



Mix 4-7 drying shrinkage results.

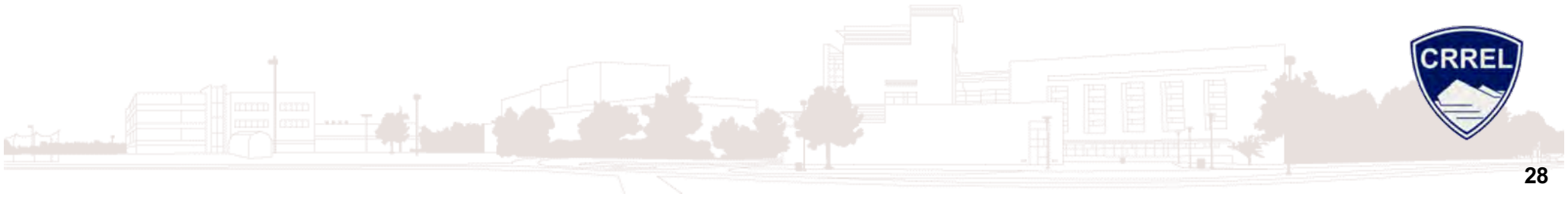


Mix 4-7 freeze thaw results.

Conclusions

- Blends with FAC/FAF & GGBFS stronger up to 55/57.5% replacement
- Blends with FAC & SF do not produce strengths higher than other ternary/binary options
- <55% PC may decrease mean strength in blends
- SCM tend to reduce peak heat and total HoH
- Optimal blend for low HoH = 25% FAC, 2.5% SF
- Optimal blend for max strength = 12.5% FAC, 10% GGBFS

THANK YOU!



Objectives

- Design concrete pavement mixtures with RCA using ternary blends of cementitious materials and low w/b;
- Measure fresh and hardened concrete properties;
- Assess the long-term performance of the RCA concrete

Task 2: Materials Identification & Mix Design

- Aggregates
  - grading, geometry, density, absorption
- Cementitious Materials
  - Type I Portland cement, Class C fly ash, ground granulated blast furnace slag, and silica fume.
- Chemical admixtures
  - air entraining admixture, water reducer, and hydration stabilizer

Task 3. Lab Testing of Fresh & Hardened Concrete

Mix No	Designation	Description of concrete mixture
Ternary binder mixtures		
1	TB1	NC with one type of ternary blended binder
2	TB2	NC with another type of ternary blended binder
3	TB3	NC with a third type of ternary blended binder
RCA pavement concrete mixtures		
4	NC	Normal concrete
5	NC30	NC with 30% replacement with RCA
6	NC30TB	NC30 with ternary blended binder
7	NC50TB	NC with 50% replacement with RCA, with ternary binder
8	HPC	High performance concrete
9	HPC30	HPC with 30% replacement with RCA
10	HPC30TB	HPC30 with ternary blended binder
11	HPC50TB	HPC with 50% replacement with RCA, with ternary binder

- Test three concrete mixtures with different ternary binders identified in Task 2

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Tests to be conducted

Property	Test Method	Mix 1-3	Mix 4-11
Fresh Concrete Properties			
Slump	ASTM C143 / AASHTO T 119	✓	✓
Air content	ASTM C231 / AASHTO T 152	✓	✓
Unit weight	ASTM C138 / AASHTO T 121		✓
Setting time	ASTM C403 / AASHTO T 197		✓
Air void system, AVA	AASHTO T 348	✓	✓
Hardened Concrete Properties			
Compressive strength (3,7,28,56d)	ASTM C39 / AASHTO T 22	✓	✓
Electrical resistivity	ASTM C1760 / AASHTO T95	✓	✓
Modulus of rupture (28, 90 days)	ASTM C78 / AASHTO T 97		✓
Elastic modulus (3,7,28,56 days)	ASTM C469		✓
Drying Shrinkage	ASTM C157 / AASHTO T 150		✓
Resistance to cyclic F-T	ASTM C666/ AASHTO T 161		✓
Alkali-Silica Reaction	ASTM C1293	✓	✓

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Ternary blend with RCA

Mix No	Designation	Description of concrete mixture
Ternary binder mixtures		
1	TB1	NC with one type of ternary blended binder
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3	TB3	NC with a third type of ternary blended binder
RCA pavement concrete mixtures		
4	NC	Normal concrete
5	NC30	NC with 30% replacement with RCA
6	NC30TB	NC30 with ternary blended binder
7	NC50TB	NC with 50% replacement with RCA, with ternary binder
8	HPC	High performance concrete
9	HPC30	HPC with 30% replacement with RCA
10	HPC30TB	HPC30 with ternary blended binder
11	HPC50TB	HPC with 50% replacement with RCA, with ternary binder

- Test NC and HPC with ternary blend and increasing recycled concrete aggregates

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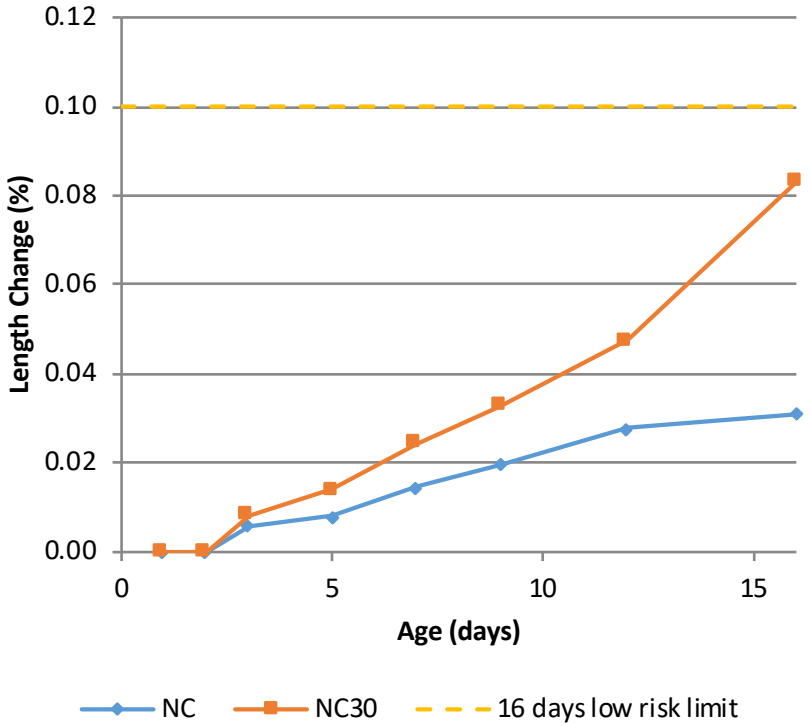
RCA Mixture Results



Mix 4-5 ASR results.

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