Nov. 9th, 2023

MASTERING COLD WEATHER CONCRETE

Does Concrete Really Know
Where it is?

iowa
better
concrete
conference

IOWA STATE UNIVERSITY

ABOUT THE PRESENTER

- James R. Baty II, Executive Director
- jbaty@cfaconcretepros.org

- Executive Director of the Concrete Foundations Association (CFA) and serves as Manager for Regulatory and Technical Affairs for the Tilt-Up Concrete Association (TCA).
- Over 30 years of involvement in the concrete industry as an educator, examiner, trainer, organizer and advocate. His work has focused on the practical and technical aspects of residential foundations as well as tilt-up or site cast precast construction with emphasis on architectural applications, structural and thermal behavior and construction activities.
- Bachelor of Architecture (1992) from Iowa State University and is a Fellow for both the American Concrete Institute and the Tilt-Up Concrete Association.
- Managing two concrete associations since 2001 and involved in numerous industry efforts to improve concrete safety, performance and regulations. Currently serves as chair for four ACI committees CSAO, C-650, 380 and 332-G; is secretary for ACI 551 and a voting member of 319, 306, 332, and C-650.

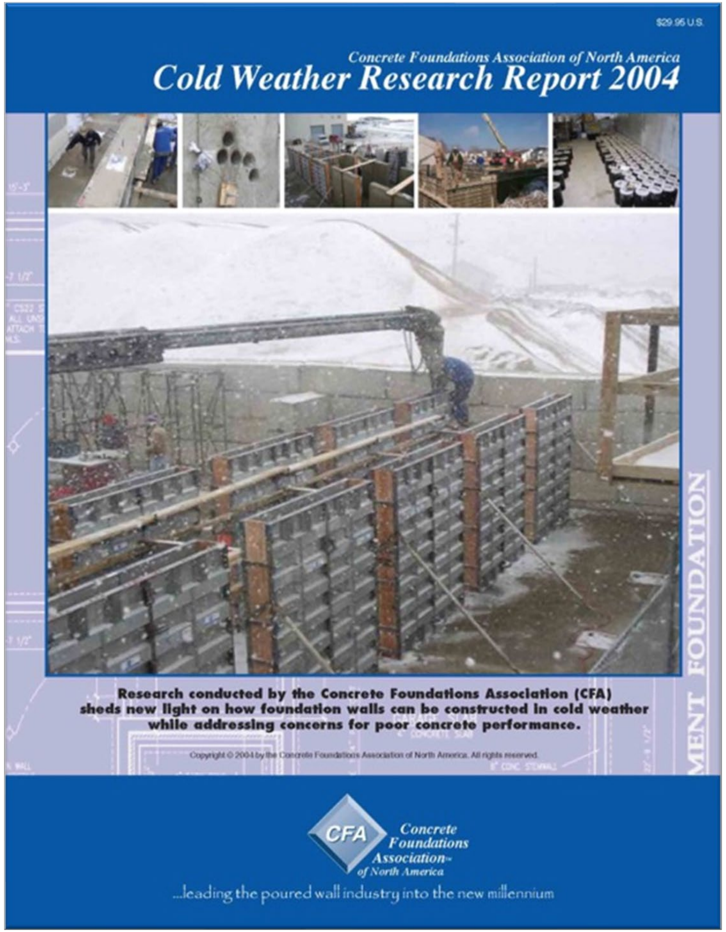
CONCRETE FOUNDATIONS ASSOCIATION

TILT-UP CONCRETE ASSOCIATION

TODAY'S LEARNING OBJECTIVES

Using testing results from November 2002 to July 2003:

- Identify the key factors for concrete strength development and how they are impacted by declining temperatures.
- Understand the relationships of in-place strength to test samples.
- Determine appropriate decision-making for cold weather concrete plans based on severity of climate expectations.



CFA's Cold Weather Research Report

Lab and Field Research

Discussion of Maturity

Description of possible mix designs

Recommended best practices

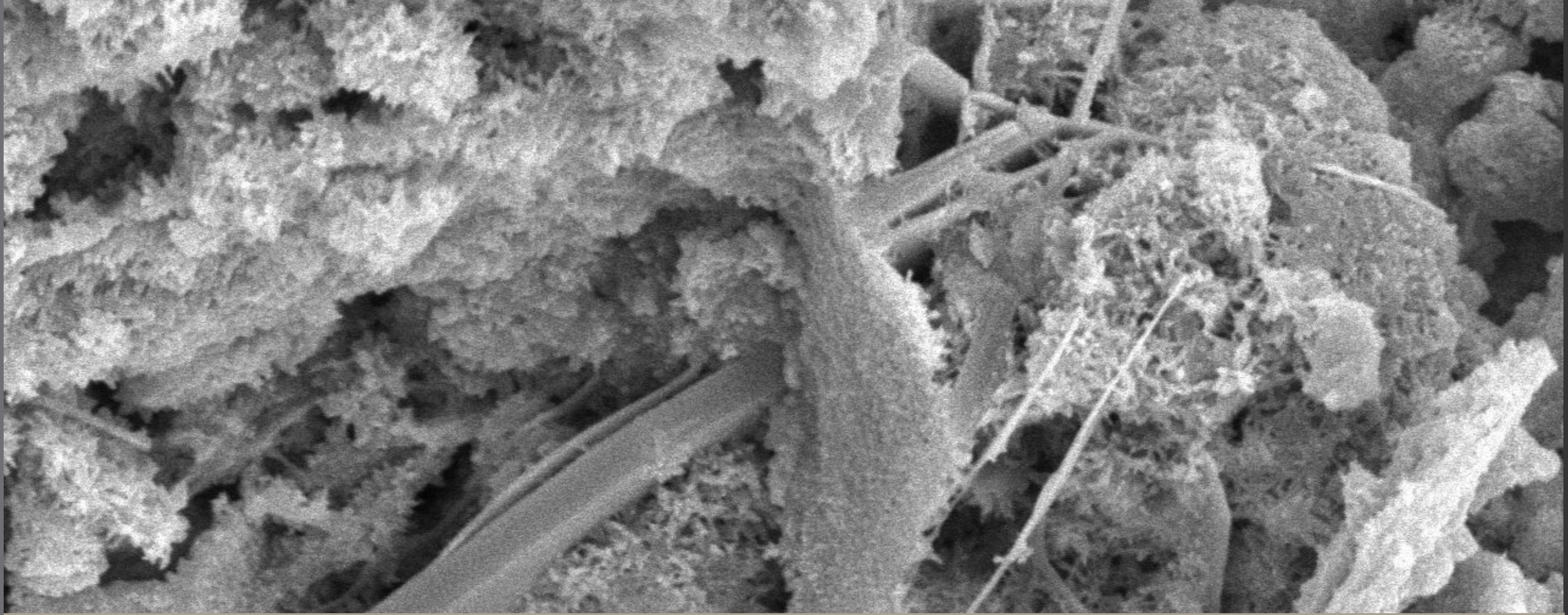
Referenced by ACI 332 Code and ACI 306

THE BIG THREE TAKE-AWAYS

Air Temperature is an indicator not a predictor

Surface Temperatures are negligible (< #8 bar)

Curing is EVERYTHING Consider Maturity



Why Concrete Gets Hard?

Chemical reaction called *hydration* is the process, heat is the by-product.

Cementitious Materials

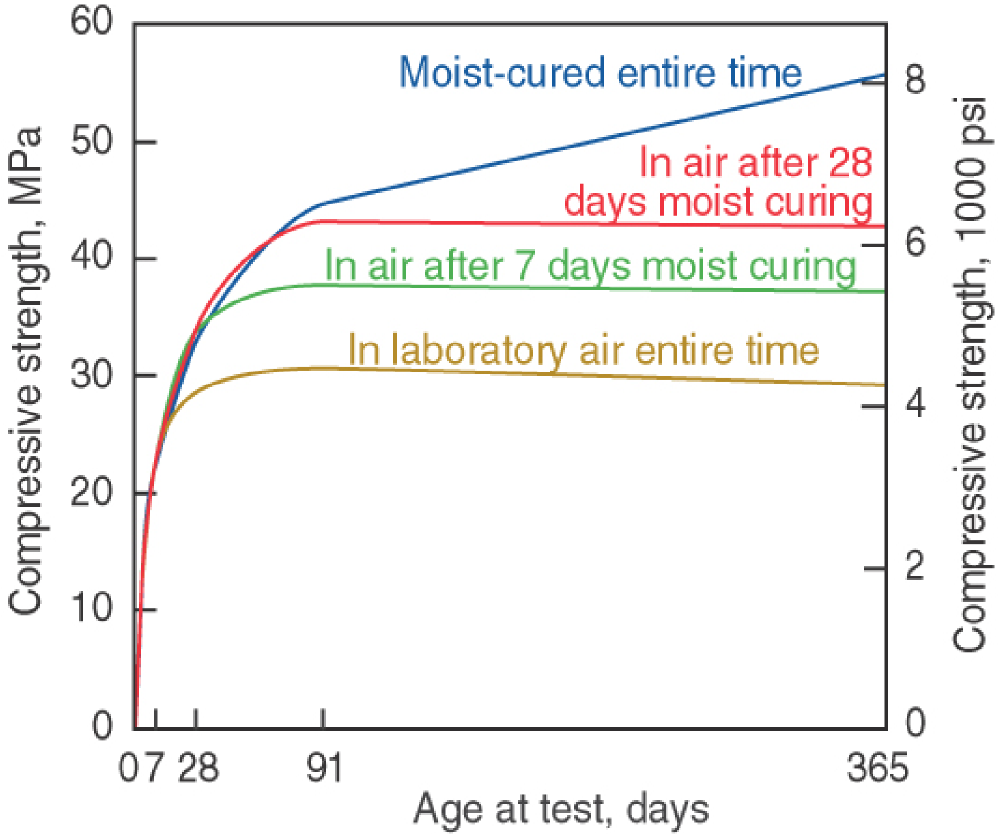
Portland Cement

- Calcium (Limestone)
- Silica
- Alumina
- Iron
- Other Additives

Supplementary-Cementitious Materials

- Fly Ash & Other Pozzolans
- Granulated Blast-Furnace Slag
- Silica Fume
- Hydrated Lime

Concrete Needs…



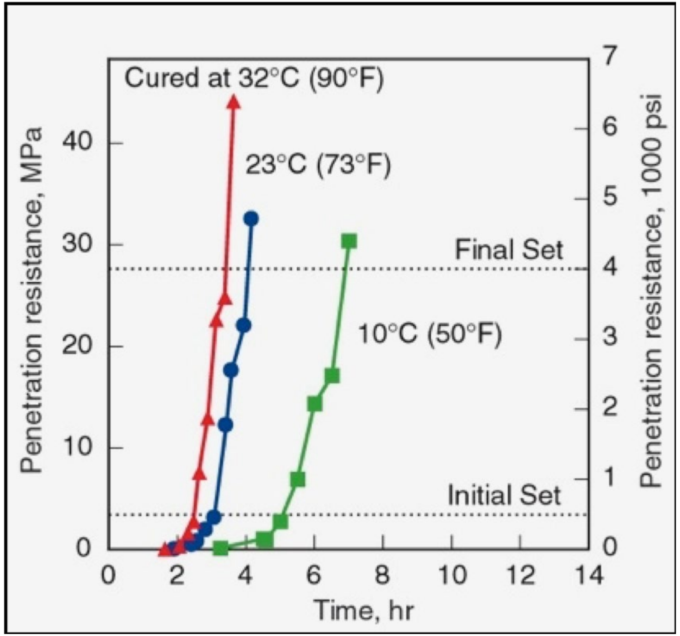
Concrete Properties

Effect of Age & Curing on Strength @ 70º F (

Concrete Curing

Temperature

- Higher Temp = Faster Curing
- Protect Fresh Concrete Below 40 Degrees F until 500 psi



Admixtures: Improving Concrete

- Retarder - slows cure (good in hot weather)
- Air entrainment - durability & workability
- Water-reducers (MRWR) - reduce *w/cm* & increase slump
- Superplasticizers (HRWR) - creates increased flowability
- Accelerators: early-age strength gain
- Coloring – aesthetics
- Others - corrosion inhibitors, shrinkage reducers

COLD WEATHER AND HOW IT AFFECTS CONCRETE DURABILITY

COLD WEATHER

- Human factors
- Freezing
- Very slow setting and drastically slowed rate of strength gain
- Low humidity=high rate of moisture loss

Durable Concrete is the goal!


FROZEN WALL DAMAGE
Winter 2014-15 – Minneapolis, MN

COLD WEATHER AND HOW IT AFFECTS CONCRETE DURABILITY

What are the effects of extreme weather conditions on concrete

- Fresh properties
  (slump, air, water requirements)
- Curing
- In-place strengths
- Cylinder strengths

Potential problems created in cold conditions

- **Concrete issues**
- **Human factors**

Mitigation Strategies to be considered

- **Planning and knowledge are powerful tools**

ACI 306R-16: GUIDE TO COLD WEATHER

- Concrete does not freeze when the ambient air temperature is 32F.
- The old belief that "hydration ceases at 40F" is totally wrong and extremely conservative.
- Concrete actually cures very well at low internal temperatures, albeit slowly, and….

COLD WEATHER COMMITTEE VIEWPOINT: 306R-16

- Concrete can be placed at ANY ambient air temperature, provided:
  - Delivery/placement temperature of the CONCRETE is adequate to prevent the concrete from falling below the "*liquidus*" temperature before protection measures are applied.

COLD WEATHER COMMITTEE VIEWPOINT: 306R-16

"Take advantage of the opportunity provided by cold weather to place low-temperature concrete. Concrete placed during cold weather, protected against freezing, and properly cured for a sufficient length of time, has the potential to develop ***higher ultimate strength and greater durability*** *than concrete placed at higher temperatures. It is susceptible to less thermal cracking than similar concrete placed at higher temperatures."*

COLD WEATHER COMMITTEE VIEWPOINT: 306R-16

- Concrete can be placed at ANY ambient air temperature, provided:
  - Protection measures are taken, such as:
    - Delivery temperature sufficient
    - Insulation
      (blankets, forms, even just poly sheeting)
    - External heat applied
    - Enclosures constructed

306R-16
TABLE 5.1

.1—Recommended concrete temperatures

Line	Air temperature	Section size, minimum dimension			
		< 12 in. (300 mm)	12 to 36 in. (300 to 900 mm)	36 to 72 in. (900 to 1800 mm)	> 72 in. (1800 mm)
		Minimum concrete temperature as placed and maintained			
1	—	55°F (13°C)	50°F (10°C)	45°F (7°C)	40°F (5°C)
		Minimum concrete temperature as mixed for indicated air temperature*			
2	Above 30°F (–1°C)	60°F (16°C)	55°F (13°C)	50°F (10°C)	45°F (7°C)
3	0 to 30°F (–18 to –1°C)	65°F (18°C)	60°F (16°C)	55°F (13°C)	50°F (10°C)
4	Below 0°F (–18°C)	70°F (21°C)	65°F (18°C)	60°F (16°C)	55°F (13°C)
5	—	**Maximum allowable gradual temperature drop in first 24 hours after end of protection**			
		50°F (28°C)	40° (22°C)	30°F (17°C)	20°F (11°C)

*For colder weather, a greater margin in temperature is provided between concrete as mixed and required minimum temperature of fresh concrete in place.

Note 1: For Line 1, maximum placement temperature is minimum temperature in the table plus 20°F (11°C).

Note 2: For Lines 2-4, maximum temperature is minimum temperature in the table plus 15°F (9°C).

306R-16

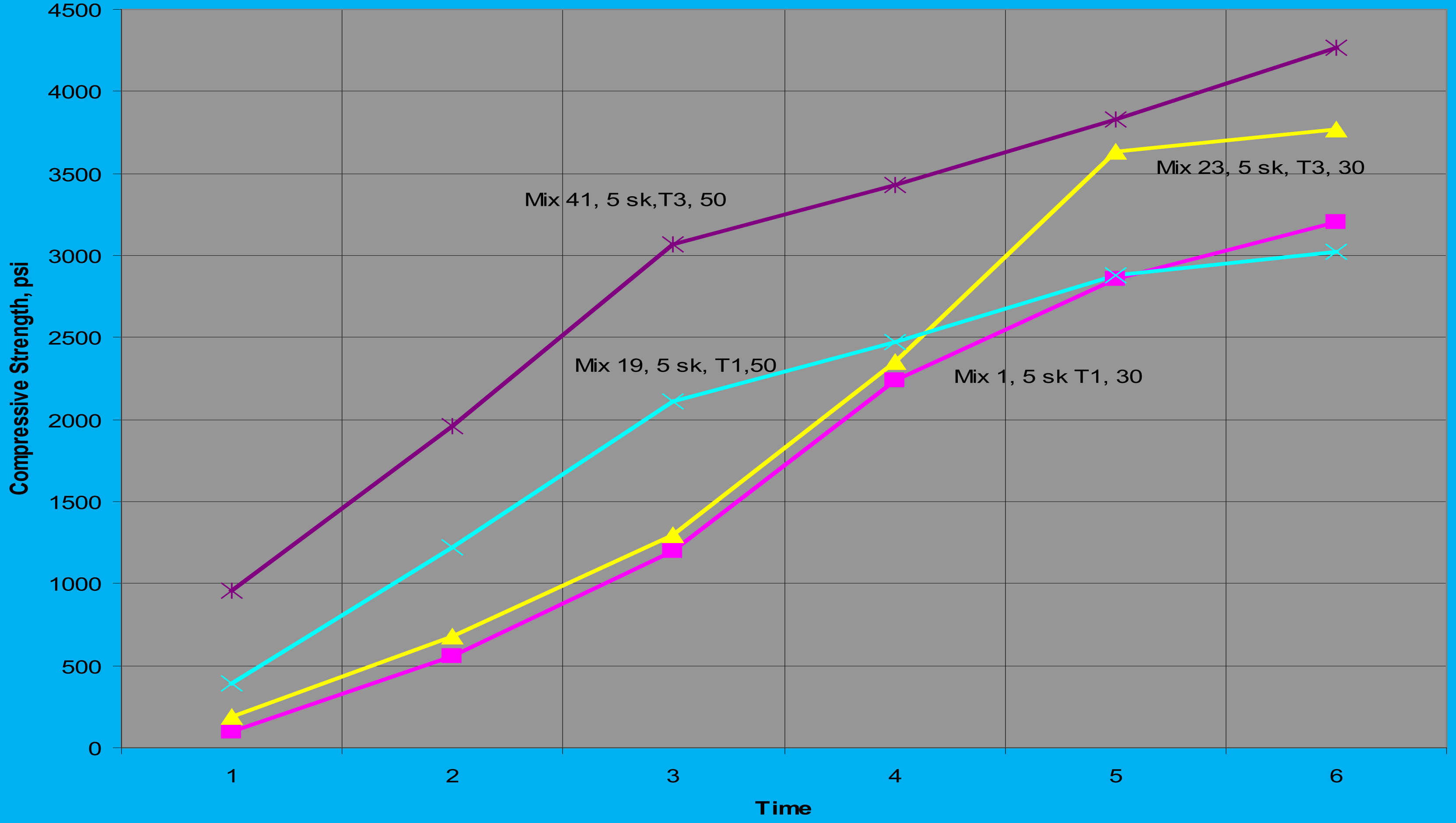
Line	Service condition	Protection period at minimum temperature indicated in Line 1 of Table 5.1, days	
		Normal-set concrete	Accelerated-set concrete
1	No load, not exposed	2	1
2	No load, exposed	3	2
3	Partial load, exposed	6	4
4	Full load	Refer to Chapter 8	

PHASE I: THE LABORATORY

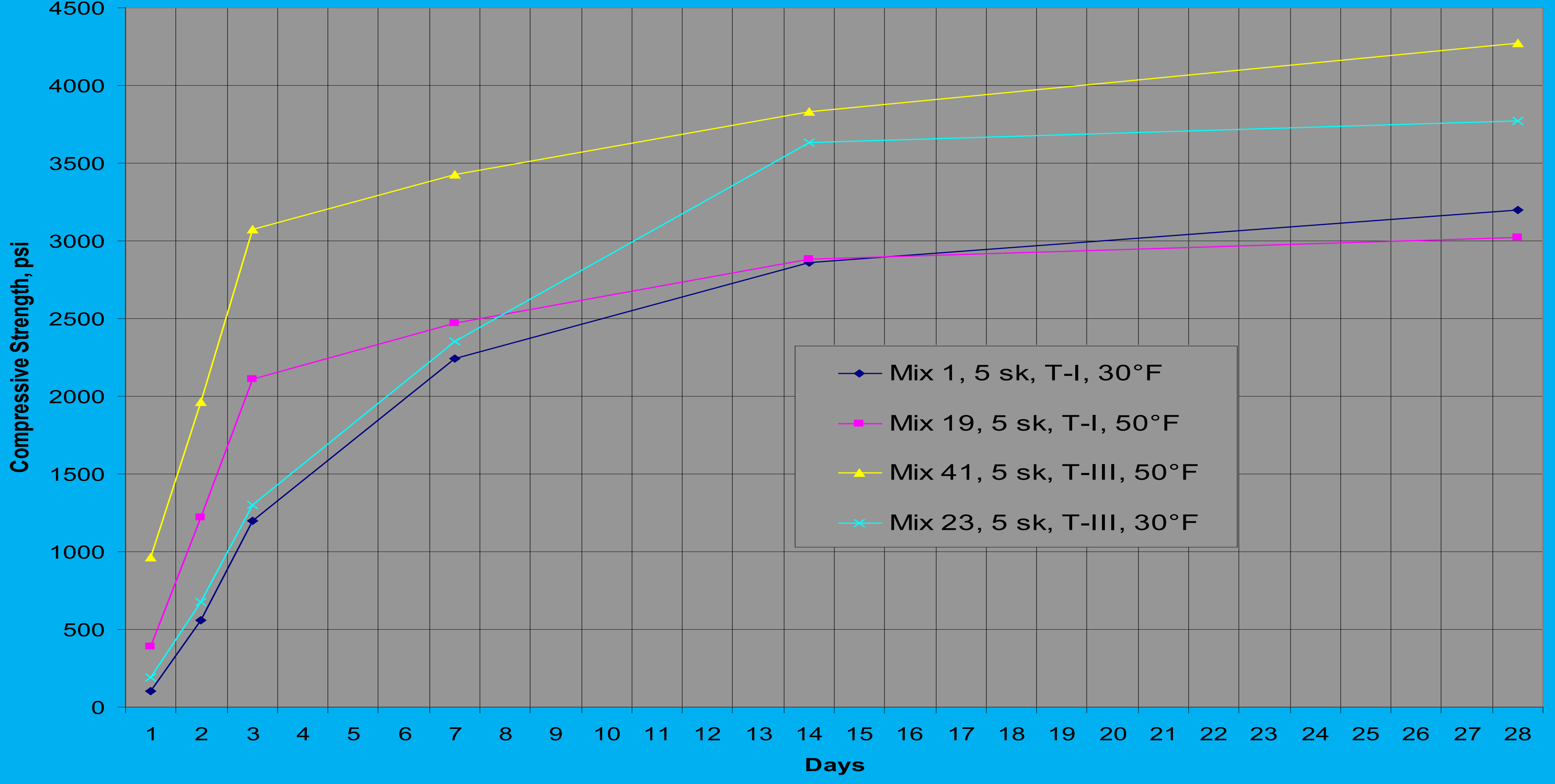
- **Ambient and internal concrete temperatures were tracked.**
- **Compressive strengths were made at close ages (1,2,3,7, 14 and 28 days)**
- **Maturity curves for each mix were created using the Con-Cure maturity system.**

Mix ID	Init Set	Final Set	1D Age,hrs	1D AVGCS psi	2D Age,hrs	2D AVG CS psi	3D Age,hrs	3D CS psi	7D Age,hrs	7D CS psi	14D Age,hrs	14D CS psi	28D Age,hrs
1	10:55	16:07	24.07	**100**	52.40	**560**	76.90	**1200**	172.90	**2240**	340.40	**2860**	678.40
2	9:05	13:49	24.05	**190**	51.47	**770**	76.13	**1300**	171.97	**2240**	339.47	**2950**	677.55
3	6:52	10:28	24.05	**260**	51.13	**780**	75.80	**1200**	171.63	**2040**	339.13	**2760**	677.13
4	5:13	8:55	24.00	**390**	50.27	**1170**	74.93	**1840**	170.68	**2900**	338.18	**3600**	676.27
5	8:34	12:55	24.08	**410**	52.83	**1350**	77.83	**2060**	173.33	**2990**	341.17	**3650**	677.83
6	11:17	17:47	24.12	**130**	52.53	**690**	76.53	**1330**	172.45	**2430**	339.95	**3160**	677.98
7	7:40	12:20	24.07	**220**	50.15	**960**	74.65	**1550**	170.32	**2570**	337.82	**3380**	675.90
8	5:19	8:57	24.08	**340**	49.17	**950**	73.67	**1420**	169.25	**2490**	336.75	**3130**	674.88
9	5:36	9:28	24.10	**370**	48.77	**1370**	73.27	**2200**	168.77	**3210**	336.27	**3970**	674.43
10	8:18	12:17	24.08	**450**	52.50	**1590**	77.50	**2520**	173.00	**3540**	340.75	**3960**	677.42
11	9:22	13:09	24.05	**320**	52.13	**1230**	77.13	**1800**	172.55	**2750**	340.30	**3620**	676.97
12	7:05	10:47	24.02	**510**	51.43	**1400**	76.43	**2150**	171.77	**3080**	339.52	**4010**	676.18
13	4:59	8:06	24.03	**680**	51.12	**1410**	76.12	**1940**	171.37	**2670**	339.12	**3750**	675.78
14	4:19	6:57	24.00	**820**	50.83	**2260**	75.83	**2890**	171.00	**3910**	338.75	**4720**	675.42
15	7:25	11:15	24.08	**460**	50.67	**1910**	75.67	**2990**	170.75	**3940**	338.50	**4740**	675.17
16	8:59	13:00	24.07	**290**	51.90	**1170**	77.57	**1830**	172.57	**2740**	340.32	**3570**	676.98
17	6:46	10:09	23.97	**510**	50.38	**1660**	75.38	**2460**	170.30	**3260**	338.05	**4150**	674.72
18	5:17	8:26	23.98	**720**	50.07	**1430**	75.07	**2320**	169.90	**2990**	337.73	**3620**	674.32
23	12:44	19:46	24.42	**190**	49.67	**680**	72.67	**1300**	174.25	**2350**	341.17	**3630**	677.42
24	7:36	11:56	24.05	**430**	48.72	**1190**	71.63	**1750**	173.38	**2680**	340.13	**3420**	676.30
25	4:53	7:55	24.25	**630**	49.00	**1400**	71.33	**1840**	173.00	**2710**	339.75	**3470**	675.92
26	3:51	6:40	23.75	**340**	48.42	**780**	70.67	**1290**	172.42	**3020**	339.08	**3920**	675.25
27	7:17	11:07	23.90	**310**	47.98	**1080**	70.23	**1840**	171.98	**3280**	338.57	**4180**	674.73
28	12:02	19:48	24.22	**200**	49.13	**1000**	72.05	**1790**	173.80	**3030**	340.55	**4210**	677.13
29	6:17	10:02	23.80	**400**	47.53	**1560**	69.87	**2370**	171.53	**3800**	338.12	**4560**	674.37
30	3:48	5:42	24.18	**790**	47.18	**1640**	69.52	**2330**	171.27	**3360**	337.77	**4130**	674.02
31	3:17	5:11	24.13	**400**	46.80	**1060**	69.13	**1810**	170.80	**3900**	337.30	**4610**	697.88
32	6:57	11:03	24.10	**420**	46.35	**1530**	68.68	**2360**	170.35	**3770**	336.85	**4740**	697.43
33	10:37	16:46	24.07	**130**	51.57	**770**	76.07	**1660**	172.90	**3620**	337.32	**4450**	676.07
34	7:01	10:22	24.03	**680**	51.03	**1630**	75.53	**2410**	172.28	**3960**	336.70	**4840**	675.37
35	3:44	5:51	23.93	**1030**	50.27	**2080**	74.77	**2700**	171.43	**4050**	335.85	**4610**	674.43
36	3:29	5:28	23.97	**740**	49.97	**1400**	74.47	**2380**	171.05	**3880**	335.47	**4770**	673.97
37	7:13	11:18	24.03	**930**	49.62	**2430**	74.12	**3350**	170.62	**4820**	335.03	**5600**	673.45
38	9:54	16:26	23.95	**450**	49.28	**1770**	73.78	**2560**	170.20	**4060**	334.62	**4750**	672.95
39	5:41	8:56	24.03	**750**	49.03	**2280**	73.53	**3170**	169.87	**4480**	334.28	**5180**	672.53
40	3:34	5:52	24.02	**1230**	48.68	**2240**	73.18	**3170**	169.43	**4430**	333.85	**5160**	672.02
19	7:23	10:34	24.13	**390**	52.63	**1220**	77.13	**2110**	173.63	**2470**	338.63	**2880**	678.38
20	6:28	9:34	23.92	**660**	52.33	**1860**	76.83	**2810**	173.25	**3270**	338.25	**3860**	678.00
21	6:55	10:02	24.00	**730**	52.08	**2120**	76.58	**2990**	172.92	**3460**	337.92	**3620**	677.67
22	6:10	8:45	24.07	**870**	51.82	**2410**	76.32	**3560**	172.57	**3840**	337.65	**4520**	677.32
41	6:14	9:02	24.00	**960**	51.50	**1960**	76.00	**3070**	172.17	**3430**	337.25	**3830**	676.92
42	5:59	8:38	24.00	**1130**	51.17	**2640**	75.67	**3670**	171.75	**4160**	336.92	**4420**	676.50
43	5:55	8:15	24.03	**1290**	50.87	**3030**	75.37	**3980**	171.37	**4480**	336.53	**4860**	676.12
44	6:02	8:19	24.07	**1300**	50.57	**2990**	75.07	**4350**	170.98	**4830**	336.23	**5390**	675.73

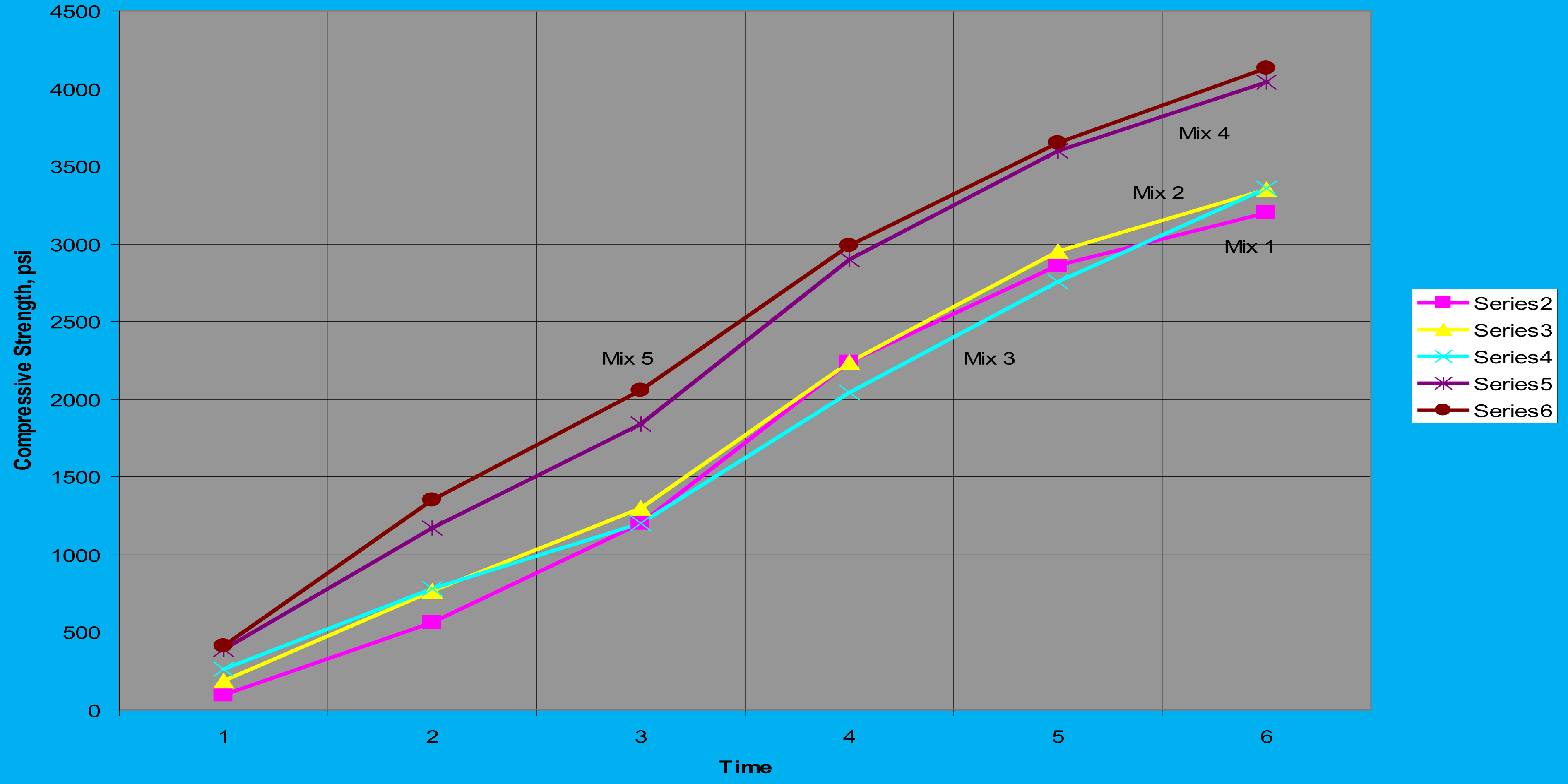
Compressive Strength of 3,000 psi Plain Mixes

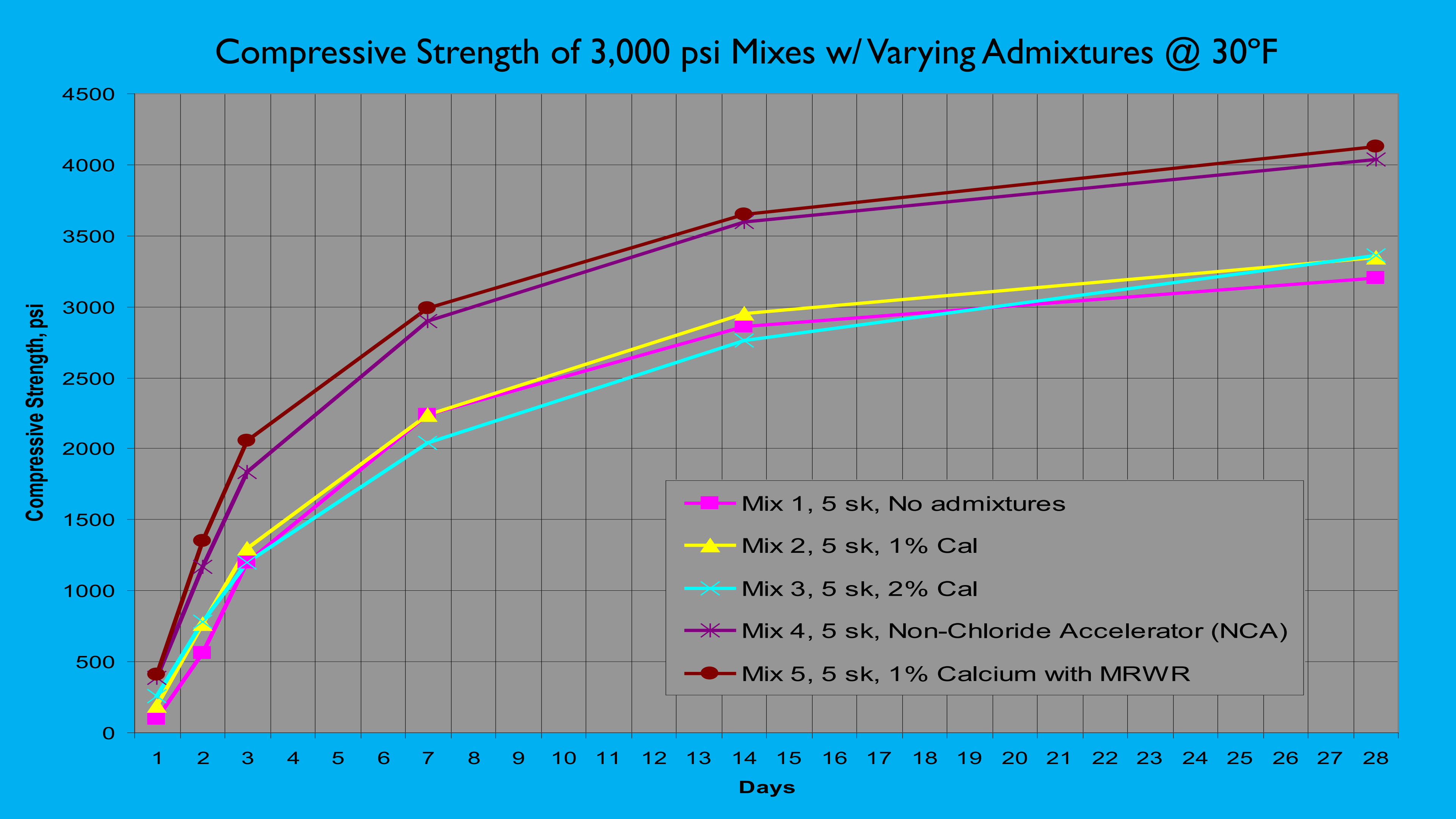


Compressive Strength of 3,000 psi Plain Mixes



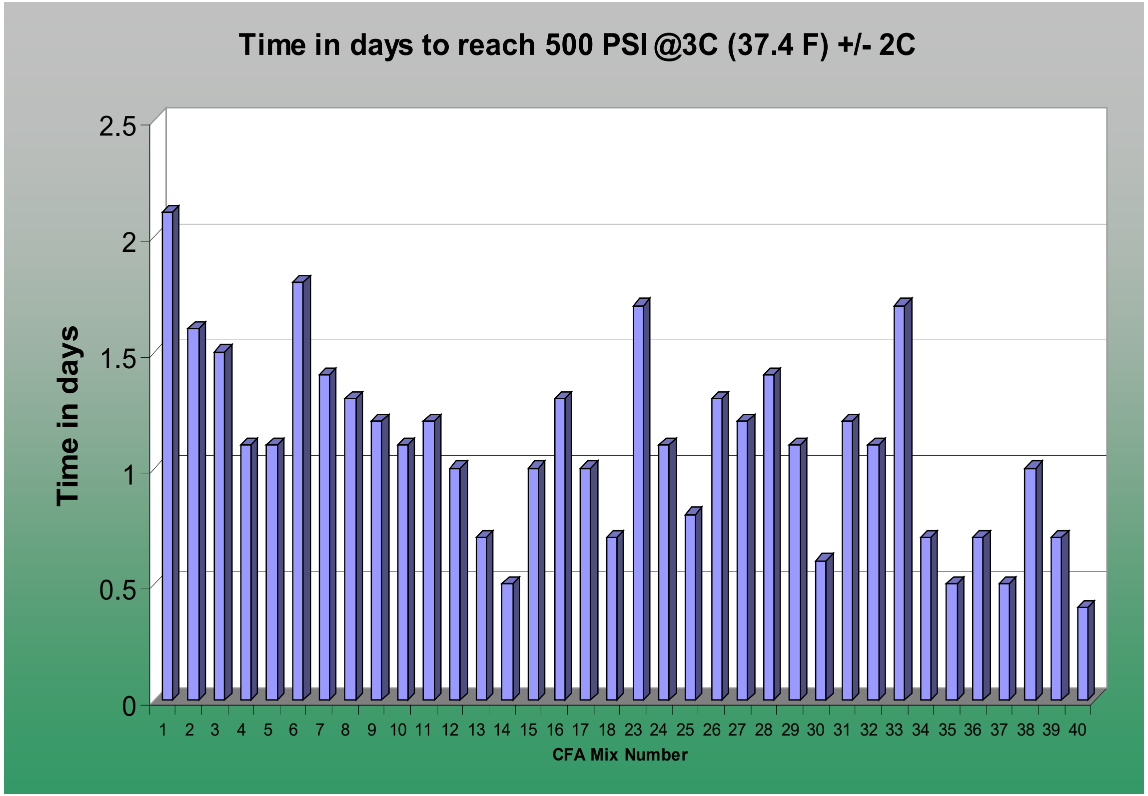
Compressive Strength of 3,000 psi Mixes w/ Varying Admixtures



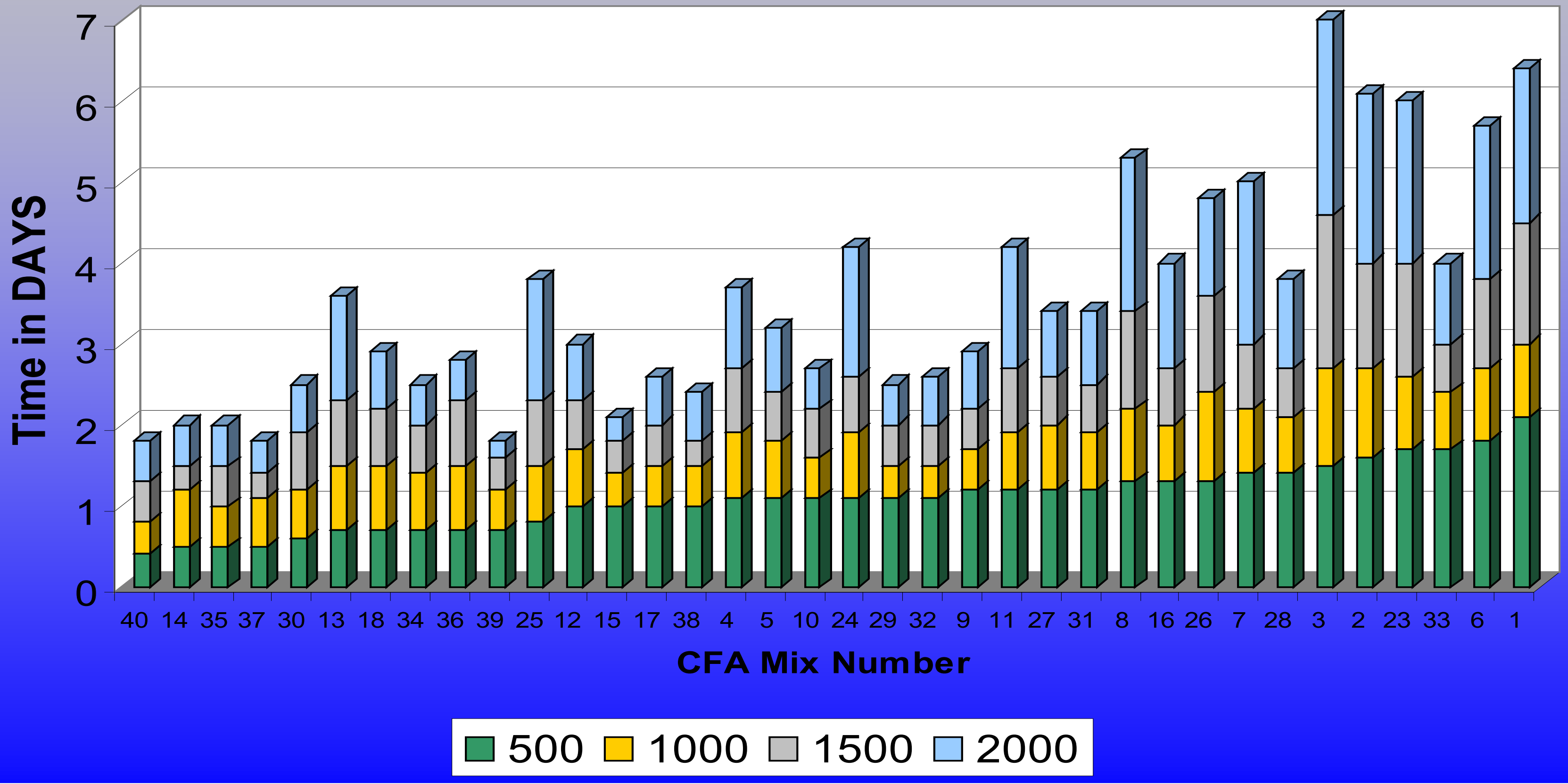


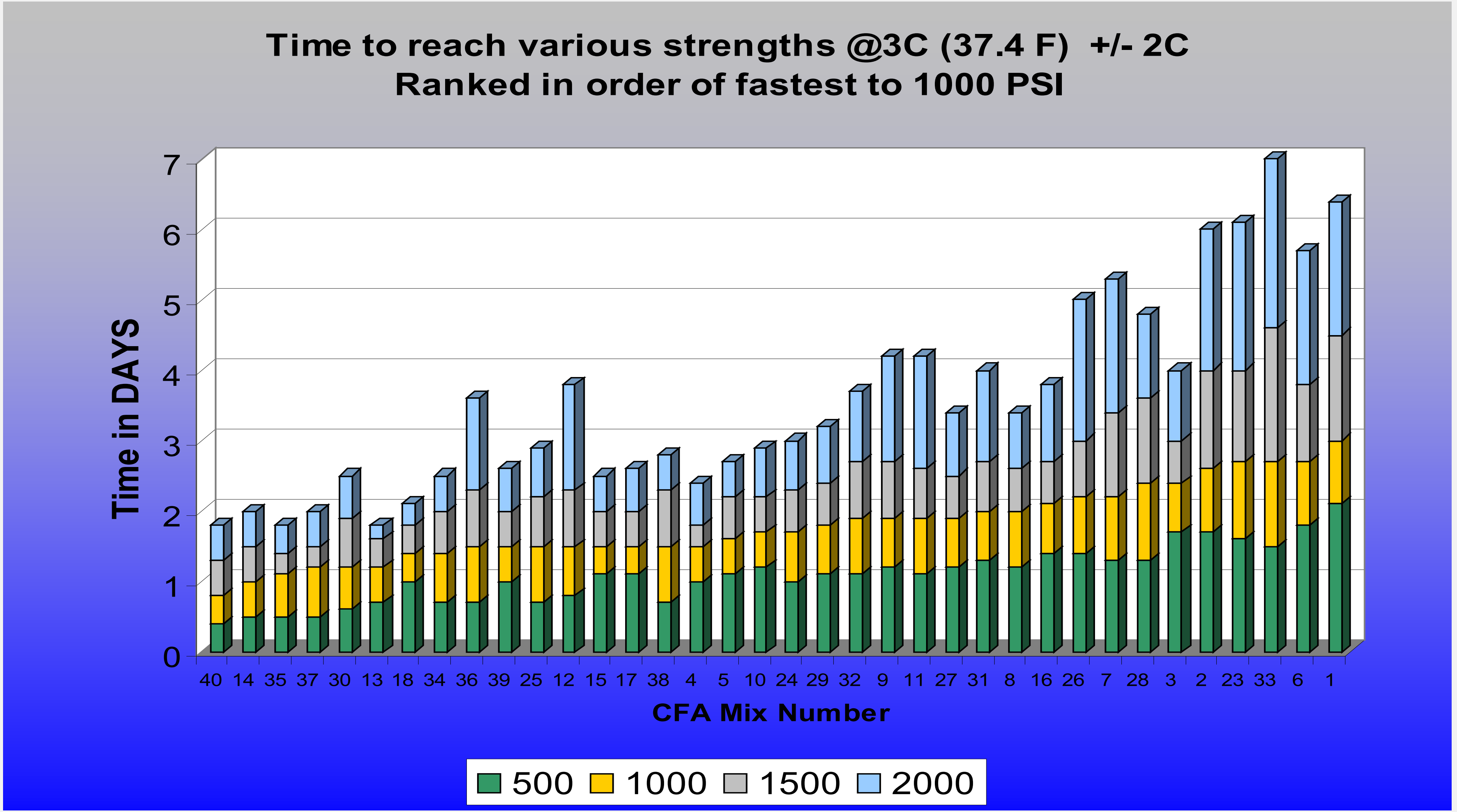
Compressive Strength of 3,000 psi Mixes w/ Varying Admixtures @ 30°F
Compressive Strength, psi
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
Days
Mix 1, 5 sk, No admixtures
Mix 2, 5 sk, 1% Cal
Mix 3, 5 sk, 2% Cal
Mix 4, 5 sk, Non-Chloride Accelerator (NCA)
Mix 5, 5 sk, 1% Calcium with MRWR

TIME (IN DAY) TO REACH 500 PSI. *TEMP. HELD AT 3 C (37.4 F)*



Time to reach various strengths @3C (37.4 F) +/- 2C
Ranked in order of fastest to 500 PSI




Time to reach various strengths @3C (37.4 F) +/- 2C
Ranked in order of fastest to 1000 PSI
Time in DAYS
0
1
2
3
4
5
6
7
40 14 35 37 30 13 18 34 36 39 25 12 15 17 38 4 5 10 24 29 32 9 11 27 31 8 16 26 7 28 3 2 23 33 6 1
CFA Mix Number
500
1000
1500
2000

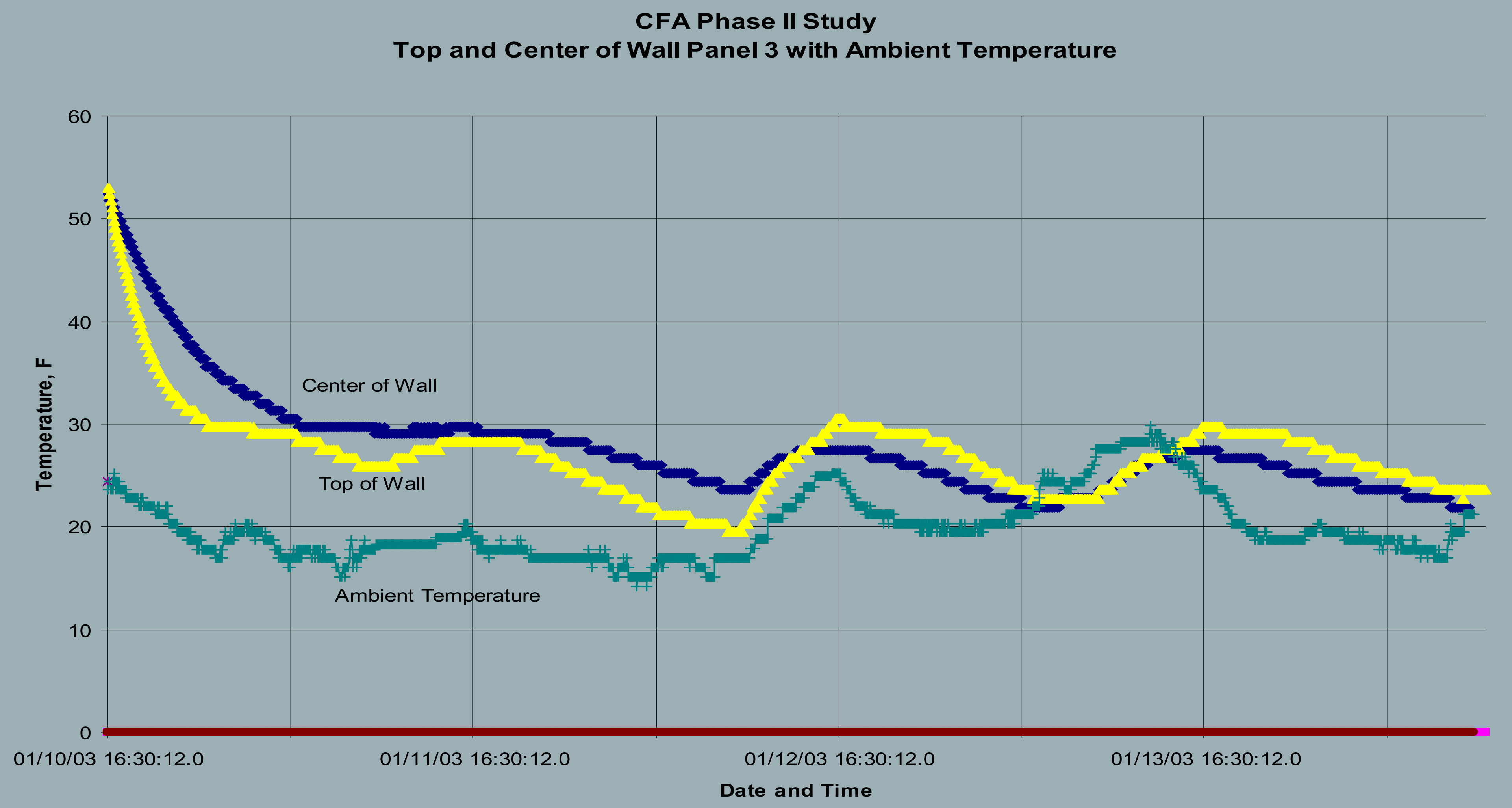
PHASE II: IN THE FIELD

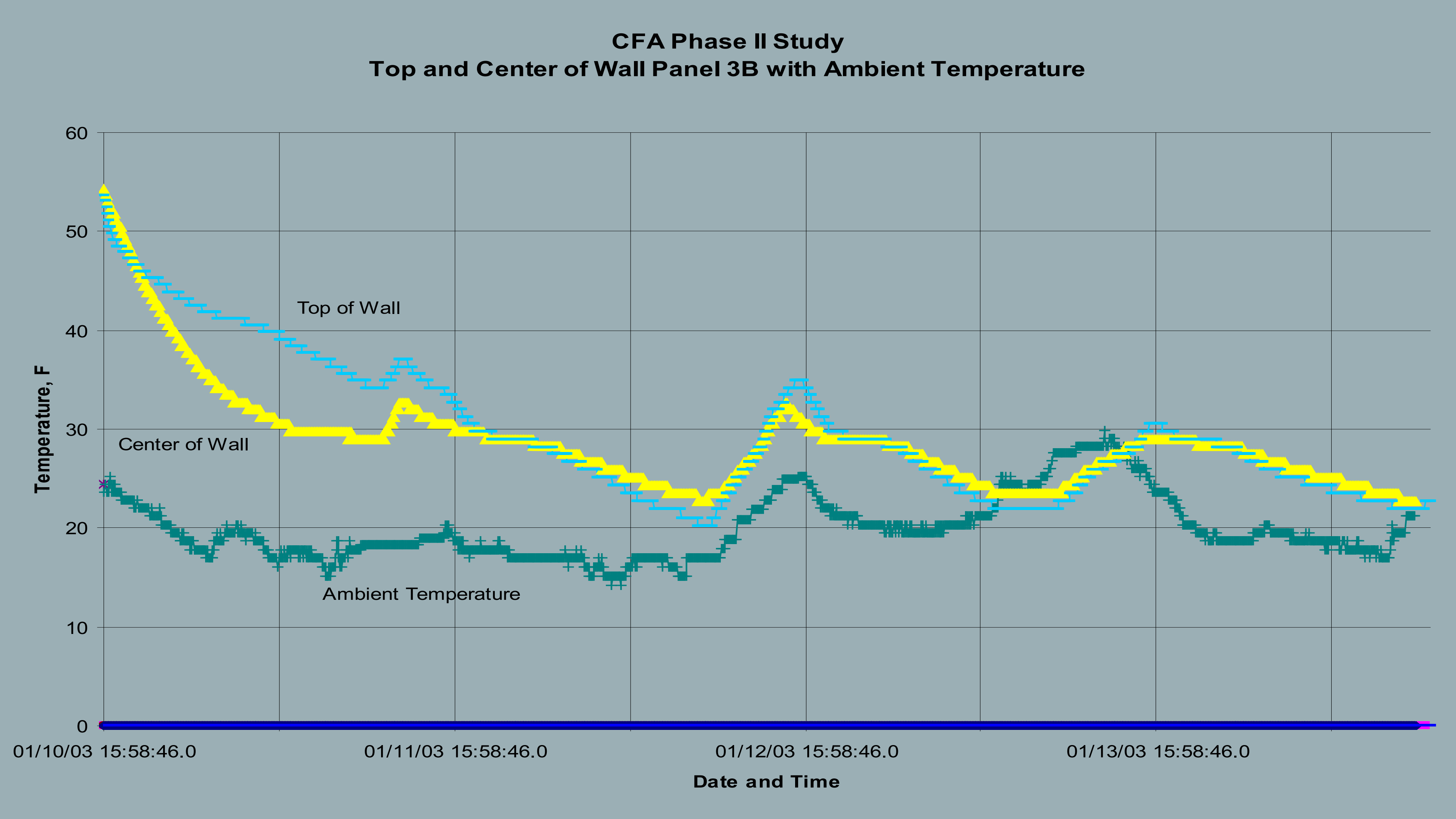
- Full-scale wall segments tested in winter field conditions.
- Mixes from phase I identified as providing acceptable performance characteristics.
- Core samples and field cylinders were used to compare. Maturity was also tracked.
- Wall segments were both covered and uncovered.

JAN-03 FOR CLEVELAND, OH (804')											LAT=41.4N LON= 81.8W
TEMPERATURE DATA											
	ACTUAL			NORMAL				PRECIPITATION			
	HI	LO	AVG	HI	LO	AVG	DEPT	AMNT	SNOW	SNCVR	HDD
1	34	31	33	34	21	28	5	0.14	trace	0	32
2	31	27	29	33	20	27	3	0.15	1.5	0	36
3	30	25	28	33	20	27	1	0.05	0.6	1	37
4	28	25	27	33	20	27	0	0.05	0.6	2	38
5	31	23	27	33	20	27	1	0.01	0.1	2	38
6	30	20	25	33	20	27	-2	0.41	5	3	40
7	35	10	23	33	19	26	-4	0	0	5	42
8	45	32	39	33	19	26	13	0	0	3	26
9	44	33	39	33	19	26	13	trace	trace	0	26
10	33	20	27	33	19	26	1	0.13	2	0	38
11	20	17	19	33	19	26	-8	0.01	0.2	1	46
12	27	16	22	33	19	26	-5	trace	trace	1	43
13	27	19	23	32	19	26	-3	0.01	0.1	0	42
14	22	18	20	32	19	26	-6	0.02	0.3	0	45
15	20	10	15	32	19	26	-11	0.08	1.6	1	50
16	20	12	16	32	18	25	-9	0.04	0.9	2	49
17	22	6	14	32	18	25	-11	0.06	1.8	2	51
18	22	4	13	32	18	25	-12	trace	0.4	2	52
19	24	14	19	32	18	25	-6	0.05	1	2	46
20	26	15	21	32	18	25	-5	0.06	1.1	3	44
21	19	6	13	32	18	25	-13	trace	trace	2	52
22	14	5	10	32	18	25	-16	0.02	0.6	2	55
23	18	4	11	32	18	25	-14	0.06	2.1	2	54
24	20	14	17	32	18	25	-8	0.02	0.5	3	48
25	25	15	20	32	18	25	-5	trace	trace	3	45
26	27	10	19	33	18	26	-7	0.3	6.6	3	46
27	15	-4	6	33	18	26	-20	trace	trace	7	59
28	29	14	22	33	18	26	-4	0.12	1.3	6	43
29	29	19	24	33	19	26	-2	0.19	2	9	41
30	30	5	18	33	19	26	-9	trace	trace	8	47
31	39	12	26	33	19	26	-1	0	0	8	39
TOTALS FOR CLE											
HIGHEST TEMPERATURE			45		TOTAL PRECIP			1.98			
LOWEST TEMPERATURE			-4		TOTAL SNOWFALL			30.3			
AVERAGE TEMPERATURE			21.2		NORMAL PRECIP			2.48			
DEPARTURE FROM NORM			-4.5		% OF NORMAL PRECIP			80			

RESEARCH: A REAL WORLD EXAMPLE

- Placed Concrete, stripped and cored on Sunday, Jan. 10th.
- 21 straight days of sub-freezing weather


CFA Phase II Study
Top and Center of Wall Panel 3 with Ambient Temperature
Temperature, F
60
50
40
30
20
10
0
Center of Wall
Top of Wall
Ambient Temperature
01/10/03 16:30:12.0
01/11/03 16:30:12.0
01/12/03 16:30:12.0
01/13/03 16:30:12.0
Date and Time


CFA Phase II Study
Top and Center of Wall Panel 3B with Ambient Temperature
Top of Wall
Center of Wall
Ambient Temperature
Temperature, F
60
50
40
30
20
10
0
01/10/03 15:58:46.0
01/11/03 15:58:46.0
01/12/03 15:58:46.0
01/13/03 15:58:46.0
Date and Time


HILTI
DD-160 E


34
29
24
13
8
3
34
29
24
13
8
3
34B
29 B
24 B
13 B
8B
3B
34 B
29 B
24 B
13 B
8B
3 B

COMPARING THE PHASES

COMPRESSIVE STRENGTH DATA

A. 6 x 12 Cylinders (Avg. of 2 samples)

CFA Mix ID	Day 1 (-27 hrs.)	Day 2 (-46 hrs.)	Day 3 (-72 hrs.)	Day 7 (-168 hrs.)
3	400	1150	1730	3320
8	580	1480	2070	3540
13	650	1760	2310	3690
24	1080	2330	2800	3890
29	1670	3080	3610	4580
34	2130	3420	4150	5345

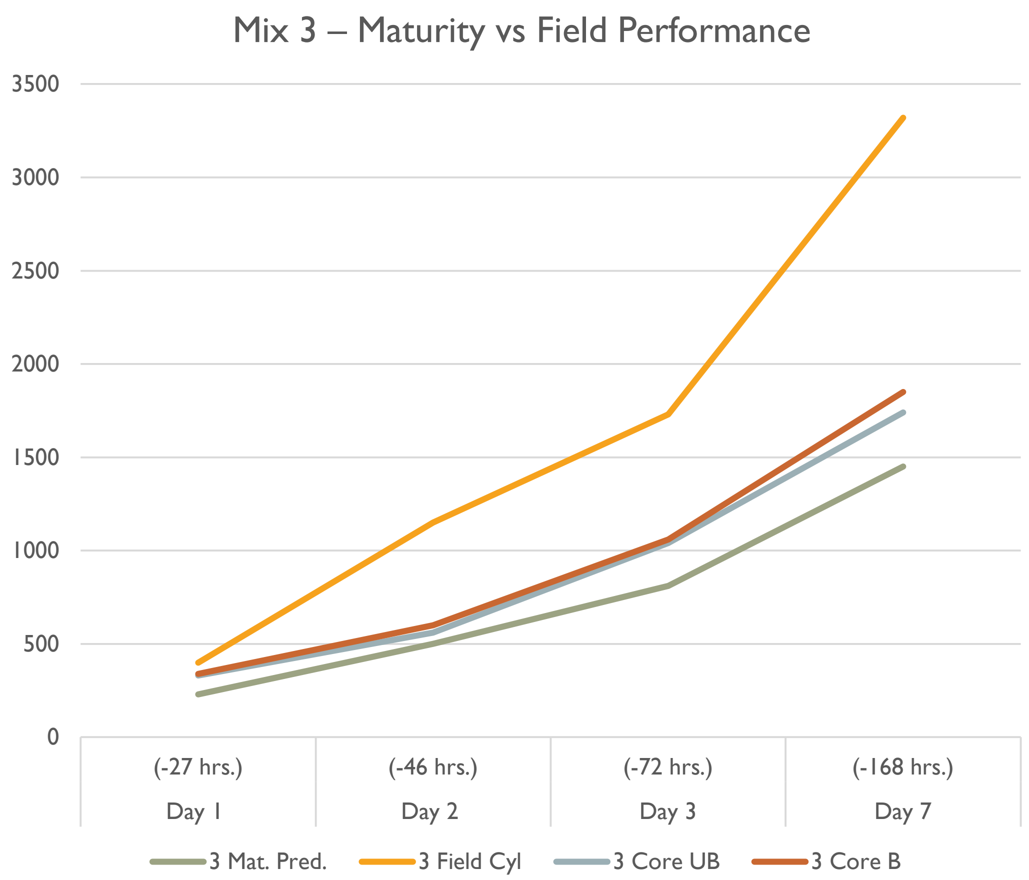
B. 4" Cores from Uncovered Panel (Avg. of 2 samples)

CFA Mix ID	Day 1 (-27 hrs.)	Day 2 (-46 hrs.)	Day 3 (-72 hrs.)	Day 7 (-168 hrs.)
3	330	560	1040	1740
8	410	600	1020	1650
13	510	700	1160	1840
24	500	840	1350	1750
29	990	1320	1840	2220
34	1400	1870	2500	3030

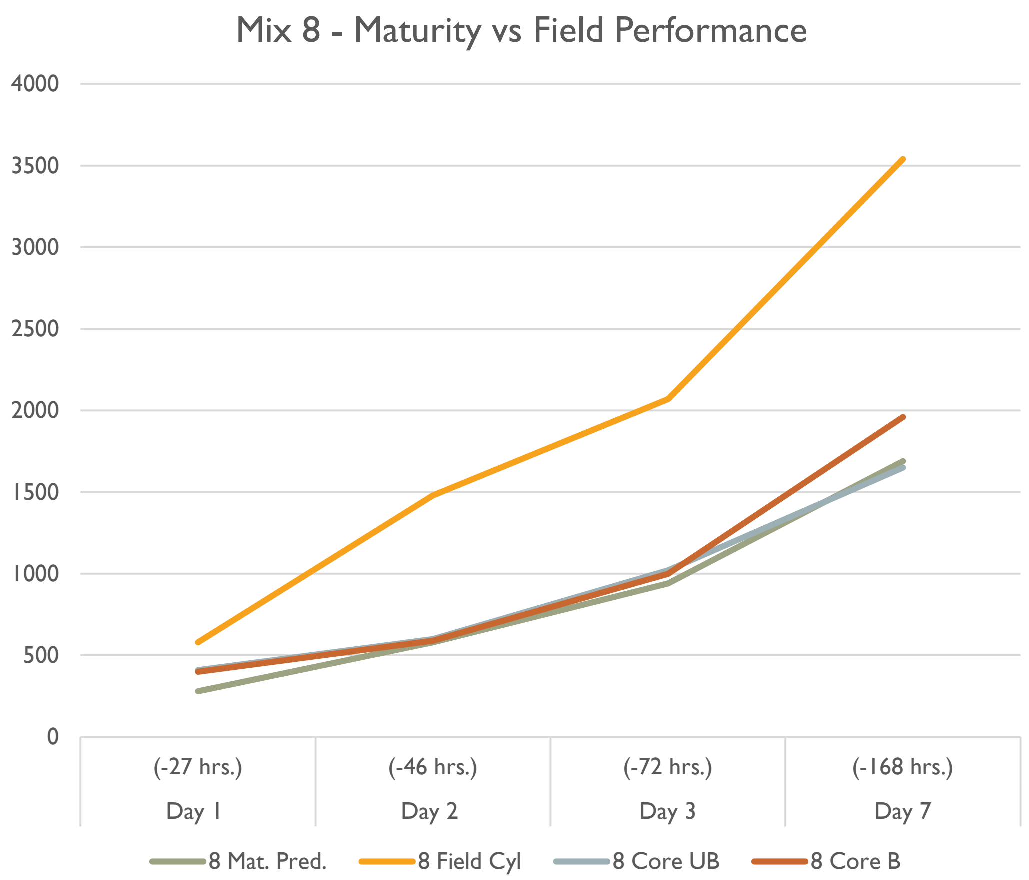
C. 4" Cores from Covered Panel (Mixes marked with B) (Avg. of 2 samples)

CFA Mix ID	Day 1 (-27 hrs.)	Day 2 (-46 hrs.)	Day 3 (-72 hrs.)	Day 7 (-168 hrs.)
3	340	600	1060	1850/1730*
8	400	590	1000	1960/1670*
13	520	740	1280	2020/1990*
24	510	870	1470	2090/1980*
29	990	1370	2110	2820/2600*
34	1550	1970	2620	3290/3430*

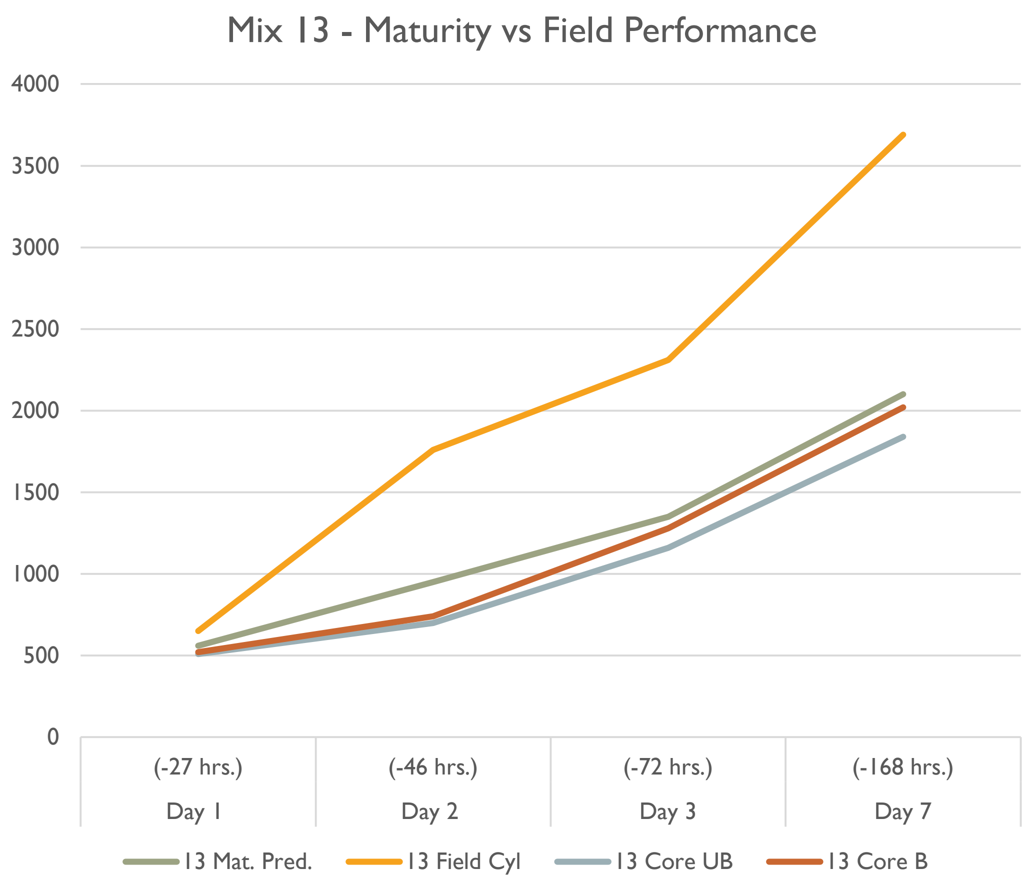
FIELD MIX PERFORMANCE MEASUREMENTS



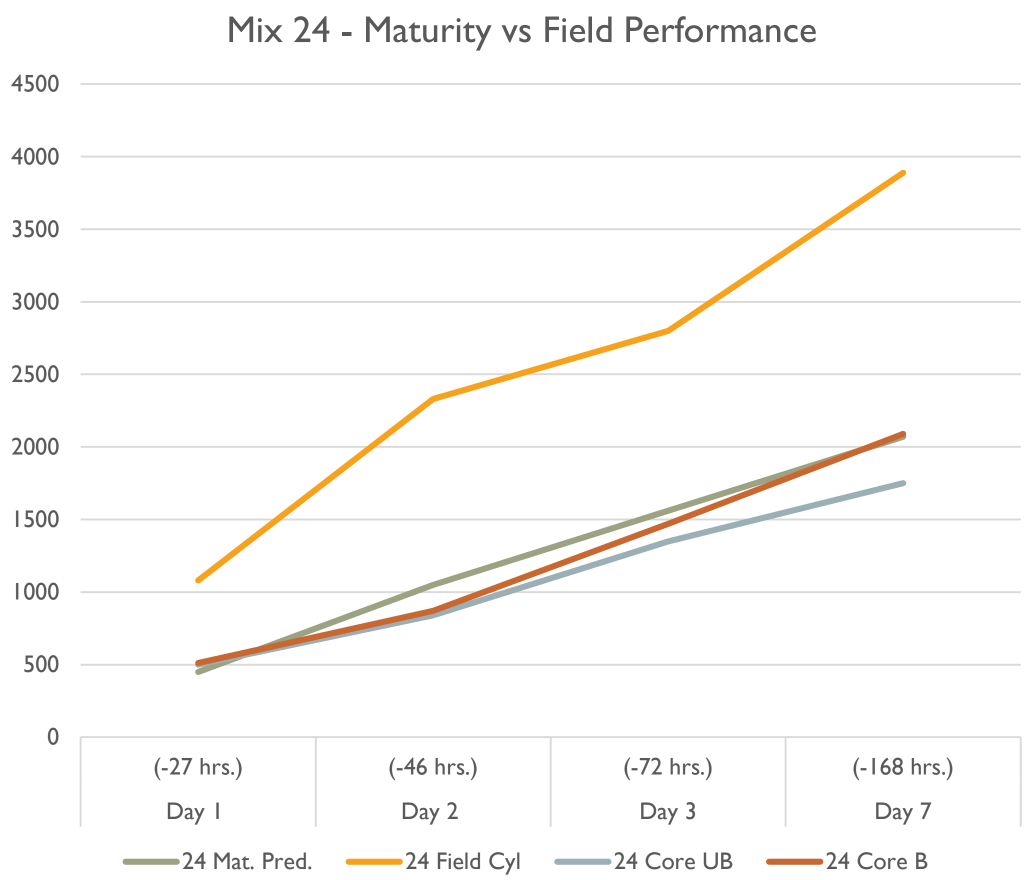
FIELD MIX PERFORMANCE MEASUREMENTS



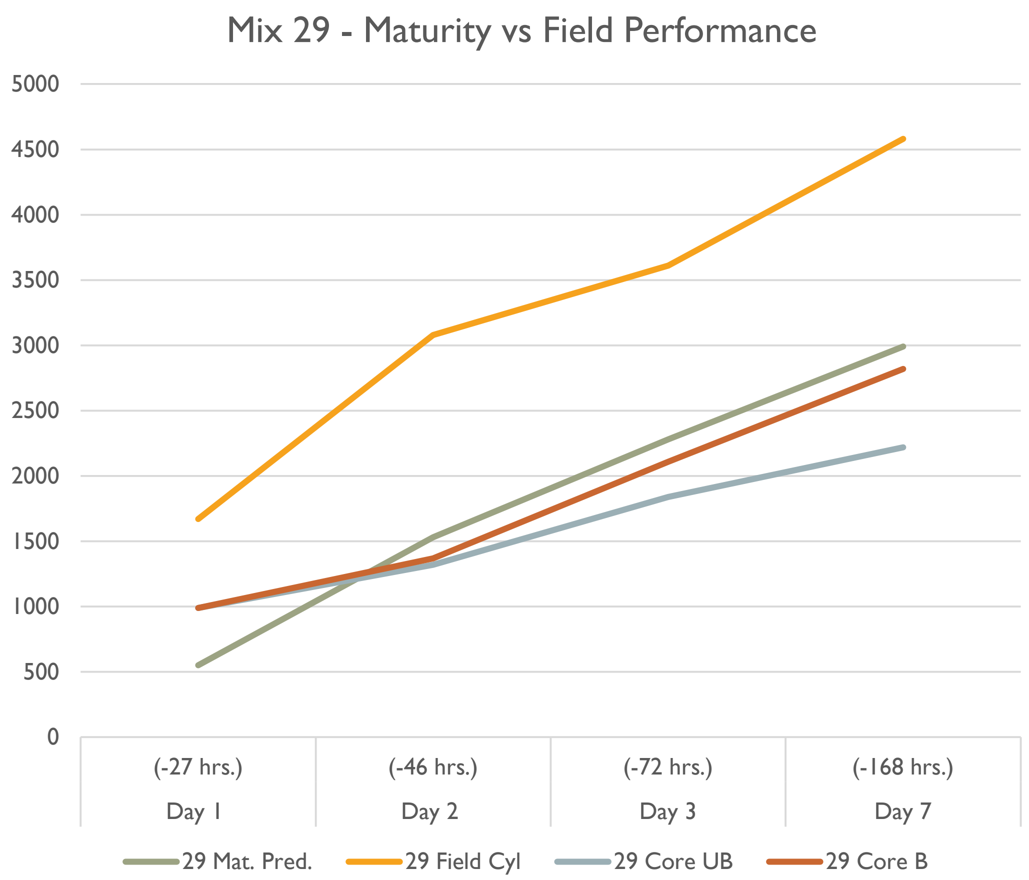
FIELD MIX PERFORMANCE MEASUREMENTS



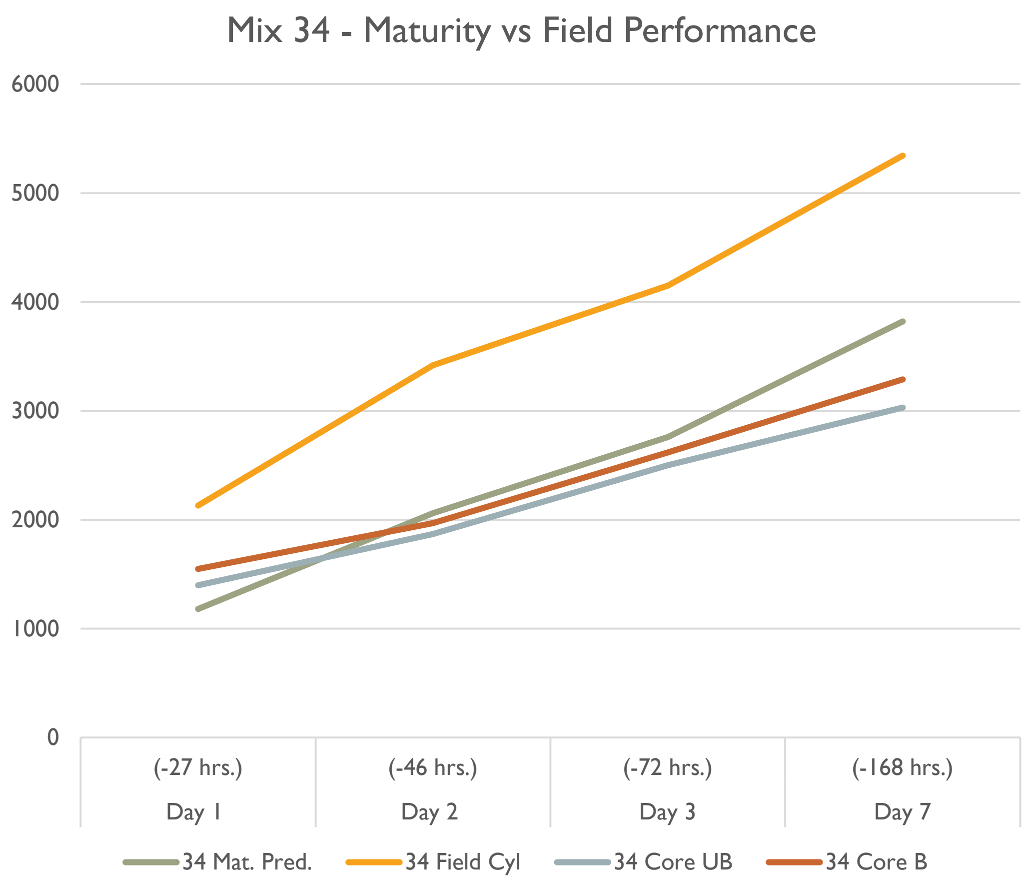
FIELD MIX PERFORMANCE MEASUREMENTS



FIELD MIX PERFORMANCE MEASUREMENTS



FIELD MIX PERFORMANCE MEASUREMENTS



CONCLUSIONS FOR COLD WEATHER PLACEMENTS

- Concrete temperature not ambient temperature.
- Hydration does not stop at 40°F…strength gain continues well below freezing.
- Maturity prediction can be used to accurately track in-place strengths.
- 500 psi early strength before freezing is reasonable and can be readily achieved.
- Current restrictive codes should be relaxed through new techniques and professional practice.
- Codes should accommodate better quality control and maturity testing.

CONCLUSIONS FOR CONTRACTORS

- No single mix answer.
- Selection of a few mix designs supported by maturity testing to confirm local performance.
- Pour earlier in the day – solar gain on concrete mass
- Type III cements over Type I for performance
- Economical strength gain from use of calcium chloride.
- Slower strength gain in cold weather – use caution when removing support.

KEY INFORMATION FOR SUPPLIERS (AND CONTRACTORS)

- Work together to understand unique mix behavior.
- Anticipate delivery impact to temperatures, the temperature of concrete when it is placed is of great importance.
- **Watch delivery temperatures with accelerating admixtures!!!**
- Water/cementitious material ratio *(w/cm)* is a huge factor, reduce as much water as possible.
- The earth can benefit sustained temperatures of concrete. Use the mass and temperature of Mother Earth.
- Promote the concept that codes and practices based solely on weather forecast are out of date and out of step with research.
- Communicate about material heating systems (if available) related to time of day.

KEY INFORMATION FOR INSPECTORS, CODE OFFICIALS AND DESIGNERS

- Recognize that ACI 306 is a best practices guide and broad options for all applications
- Do not ignore the empirical evidence and experience of contractors and suppliers.
- Rather than relying on a specification for material composition, request performance-based records (maturity) for predictive behavior to demonstrate strength.
- Communicate with industry organizations (ACI, CFA, NRMCA, etc.) where problems occur for comparison to direction.

INVEST IN KNOWLEDGE

RESEARCH LOCAL MIXES AND UNDERSTAND PERFORMANCE BEHAVIOR

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