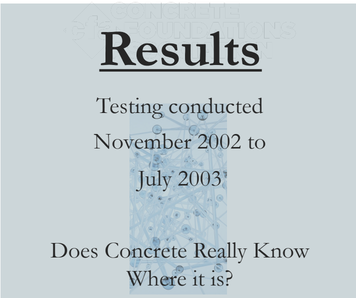


COLD WEATHER CONCRETING

Presented by:
James R. Baty II, Executive Director
jbaty@cfaconcretepros.org

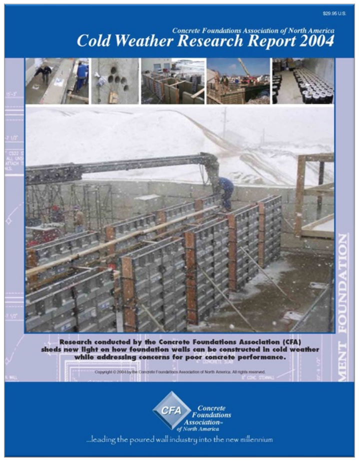
ABOUT THE PRESENTER

- **James Baty** is the Executive Director of the Concrete Foundations Association (CFA) and serves as Manager for Regulatory and Technical Affairs for the Tilt-Up Concrete Association (TCA).
- James has 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.
- He holds a 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, Baty is involved in numerous industry efforts to improve concrete safety, performance and regulations. He 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
TCA TILT-UP CONCRETE ASSOCIATION

TODAY'S LEARNING OBJECTIVES

- 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

Air Temperature is an indicator not a predictor

Surface Temperatures Irrelevant (< #8 bar)

Maturity measurement holds confidence

KEY INFORMATION 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, but…
- Slower strength gain in cold weather – use caution when removing support.
- Pay attention to possible shrinkage problems with hotter mixes.

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.
- 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.

Material Basics

Concrete Facts

1. Gets Hard / Cracks
2. Strength (psi) = Pounds Per Square Inch
3. Compressive strength: 2500 – 5000 psi
4. Tensile strength: (modulus of rupture) approx. 10% of compressive strength
5. Add one sack of cement/CY to increase strength 1000 psi

Concrete Constituents

Large Aggregate

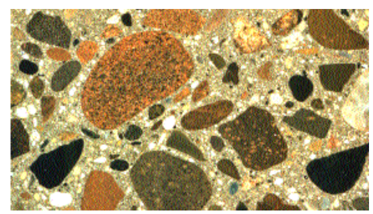
Small Aggregate

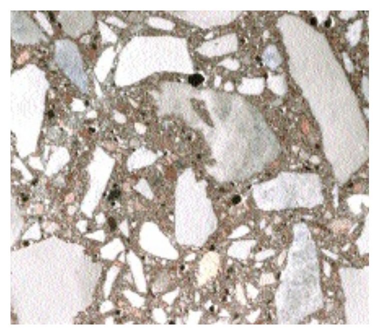
Cementitious material

Potable Water

Air (Entrained vs Entrapped)

Chemical Admixtures





Large Aggregates

- Size
- Graded
- Hardness
- Shape
- Surface/Absorption
- Heated during Cold Weather

Aggregates

Cementitious Materials

Portland Cement

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

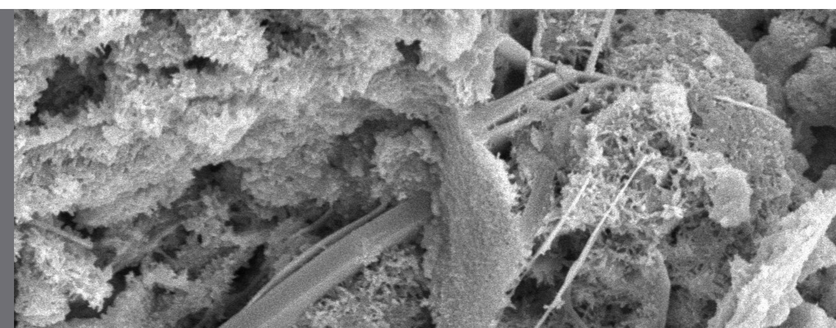
Supplementary-Cementitious Materials

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

Portland Cement

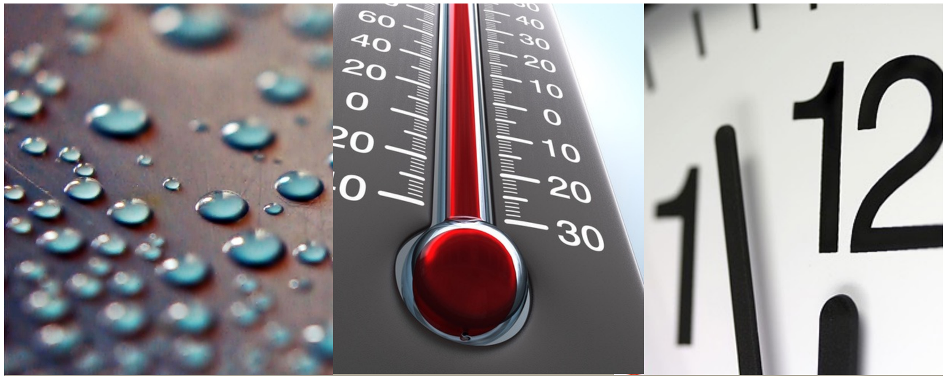
- **Types of Portland Cement**
- Type I & IA –Standard
- Type II & IIA – Moderate Sulfate Resistant
- Type III & IIIA – High Early Strength
- Type IV – Low Heat of Hydration
- Type V – High Sulfate Resistance

Limestone + Shale/Clay + Heat = Portland Cement + CO2



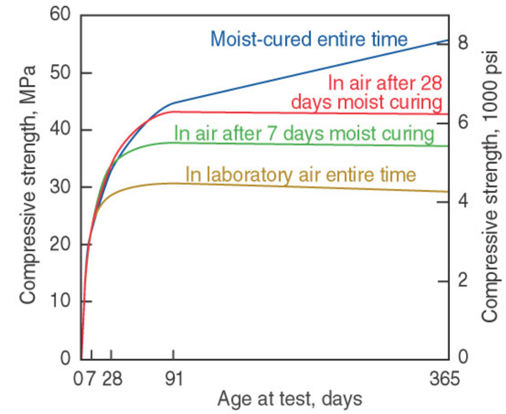
Why Concrete Gets Hard?

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



Concrete Needs…

17



Concrete Properties

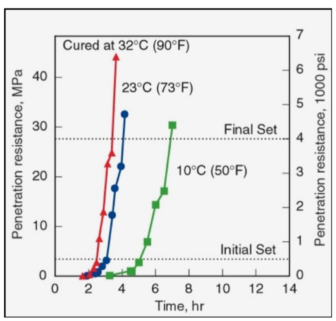
Effect of Age & Curing on Strength

18

Concrete Curing

Temperature

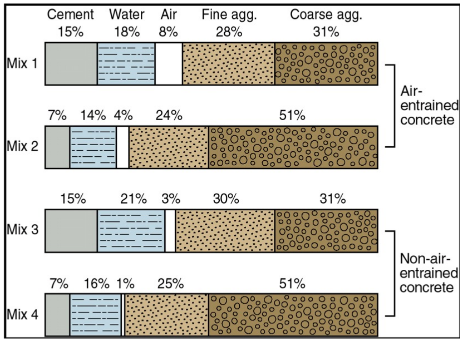
- Higher Temp = Faster Curing
- Protect Fresh Concrete Below 40 Degrees F until 1000 psi



Measuring Strength

- Cylinders measure compressive strength
- Cast from wall mix
- Store on site in conditions similar to wall
- 3 minimum required per sampling
- Average of three consecutive specimen tests must equal or exceed the specified strength
- No single test lower than the specified strength by 500 psi
- Ultimate design strength requirements

20



Concrete: Mix Proportioning/Design

- Cost
- Use
- Strength
- Set Time
- Finishing
- Hot Weather
- Cold Weather
- Sustainability

Ready-Mix Truck

Adding Water to Concrete

Advantages/Requirements

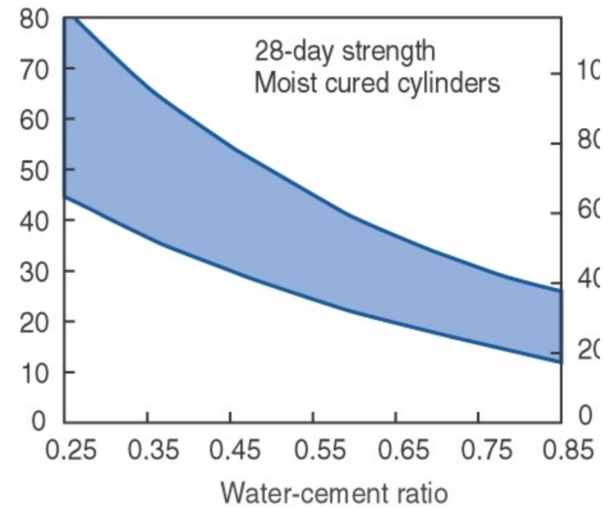
- Hydration = Chemical Reaction
- Flowability

Disadvantages/Impacts

- +1 Gal/CY Increases Slump 1 inch
- Lower Strength
- Higher Permeability
- Decreased Resistance to Weathering
- Poorer Bond Between Concrete and Reinforcement
- Increased Drying Shrinkage and Cracking
- Greater Volume Change from Wetting & Drying

Concrete Properties

- W/C Ratio Effect on Strength
- Low W/C Ratio = Better Concrete

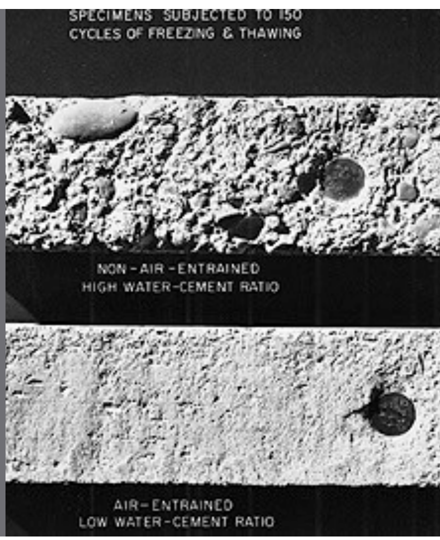


25

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

26



Impact of Admixture:

Entrained Air: Improves Freeze/Thaw Resistance

27

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**

HUMAN FACTORS AND OTHER POTENTIAL PROBLEMS TO BE AWARE OF:

- COLD WEATHER:
- Sub-freezing and sub-zero temps can cause:
  - Frostbite and hypothermia
  - Rapid depletion of energy in workers in very cold conditions

Know when to say when!

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

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

"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:
  - 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

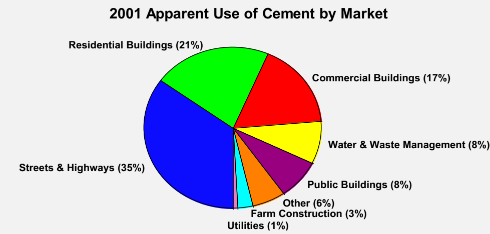
- Concrete can be placed at ANY ambient air temperature, provided:
  - Protection measures are taken, such as:
    - Insulation (blankets, forms, even just poly sheeting)
    - External heat applied
    - Enclosures constructed

OVERVIEW OF PRECIPICE

- Need to understand how "cold weather" impacts the residential concrete foundation wall industry.
- Existing codes – Protective measures *must* be taken; Empirical evidence – they may not be necessary or even helpful.
- Variations in "local" mixture performance mandates a need for method of validation of in place strengths.
- What constitutes cold weather is even debatab… …ls…

How Cold is TOO COLD?

OVERVIEW OF PRECIPICE



- Residential demand equals or exceeds all historical paces.
- Restriction in placement affects over ½ the U.S. for an average of 3 months each year…economically impacting the entire market.

THE RESEARCH PROGRAM

Phase I: The Laboratory

- 36 mix designs
- 44 maturity curves
- over 650 cylinders cast and tested
- Wide range of mixes from very "lean" to very "rich"
- Two different temperatures, 30°F and 50°F

Phase II: The Field

Phase III: Petrography

Qty of Cement (Sacks per CY / PSI)	Cement Type	Admixtures	Curing Temperature
5 / 3,000 psi 5.5 / 3,500 psi 6 / 4,000 psi 6.5 / 4,500 psi	I III	None 1% Calcium 2% Calcium 1% Calcium with MRWR Non-Chloride Accelerator (NCA)	30°F 50°F

PHASE I - LABORATORY: THE MIX MATRIX

Combination of above factors resulted in a total of 44 maturity curves.

CONCRETE STRENGTHS

ACI 332-14

- Minimum recognized compressive strength = 2,500 psi
- Prescriptive designs up to 4,500 psi

ACI 332-20

- RF4 Added with minimum of 5,000 psi

Table 5.3.2—Exposure categories and classes

Exposure class	Maximum slump*	Minimum f_c', psi		
RF0	6	2500		
RF1	5	3000		
RF2	5	3500		
RF3	4	4000		
			Cemer	
			ASTM C150/C150M	AS
RS0	6	2500	No type restriction	N
RS1	6	2500	II	IP(
RS2	5	3000	V‡	IP
RS3	5	3000	V + pozzolan or slag§	IP slag pozz
			Maximum water-soluble chl	
RC0	6	2500		
RC1	6	2500		
RC2	4	4000		

*Maximum specified slump shall have a tolerance for purposes of field testing

APPENDIX A - Phase I Mix Design Proportions

Mix ID	Temp. (°F)	Admixtures[1]	Dose (oz/cwt)	Dose (lb/cwt)	Cmt1 (lb/yd^3)	CA1 (lb/yd^3)	FA1 (lb/yd^3)	H2O (lb/yd^3)	W/C Ratio	Slump Initial	Air % Initial	Unit Wt (lb/ft^3)	Yield	Initial Set	Final Set	Date and Time Cast
1	68	AEA	0.35	NA	471	1754	1397	284	0.60	7	4.7	144.67	0.998	10:55	16:07	11/4/02 8:36 AM
2	68	AEA	0.48	NA	467	1740	1388	283	0.61	7	5.1	143.44	1.007	9:05	13:49	11/4/02 9:42 AM
		CALCIUM CHLORIDE	NA	1%												
3	68	AEA	0.61	NA	464	1727	1378	281	0.61	7	5.3	143.03	1.014	6:52	10:28	11/4/02 10:12 AM
		CALCIUM CHLORIDE	NA	2%												
4	68	AEA	0.4	NA	471	1754	1400	284	0.60	6.5	4.6	144.67	0.998	5:13	8:55	11/4/02 11:14 AM
		NCA	64	NA												
5	68	AEA	0.2	NA	466	1734	1422	263	0.56	6.25	5.5	144.26	1.009	8:34	12:55	11/5/02 8:10 AM
		MRWR-Type A/F	6	NA												
		CALCIUM CHLORIDE	NA	1%												
6	68	AEA	0.4	NA	509	1723	1342	284	0.56	7	5.9	142.62	1.016	11:17	17:47	11/4/02 9:08 AM
7	68	AEA	0.48	NA	513	1734	1351	285	0.56	7	5	143.85	1.009	7:40	12:20	11/4/02 11:41 AM
		CALCIUM CHLORIDE	NA	1%												
8	68	AEA	0.61	NA	511	1730	1348	283	0.55	6.75	5.1	143.85	1.011	5:19	8:57	11/4/02 12:50 PM
		CALCIUM CHLORIDE	NA	2%												
9	68	AEA	0.44	NA	514	1738	1354	280	0.54	7	5.3	143.85	1.007	5:36	9:28	11/4/02 01:24 PM
		NCA	64	NA												
10	68	AEA	0.2	NA	509	1723	1379	272	0.53	6.5	5.5	143.85	1.016	8:18	12:17	11/5/02 8:40 AM
		MRWR-Type A/F	6	NA												
		CALCIUM CHLORIDE	NA	1%												
11	68	AEA	0.38	NA	563	1746	1297	292	0.52	7	5	144.26	1.002	9:22	13:09	11/5/02 9:12 AM
12	68	AEA	0.48	NA	569	1766	1312	296	0.52	6.75	4.5	146.31	0.991	7:05	10:47	11/5/02 10:04 AM
		CALCIUM CHLORIDE	NA	1%												
13	68	AEA	0.62	NA	559	1734	1289	292	0.52	6	0	143.85	1.009	4:59	8:06	11/5/02 10:33 AM
		CALCIUM CHLORIDE	NA	2%												
14	68	AEA	0.44	NA	561	1742	1294	293	0.52	6.25	5.3	144.26	1.005	4:19	6:57	11/5/02 11:00 AM
		NCA	64	NA												
15	68	AEA	0.2	NA	556	1727	1326	280	0.50	6.25	5.5	144.26	1.014	7:25	11:15	11/5/02 11:20 AM
		MRWR-Type A/F	6	NA												
		CALCIUM CHLORIDE	NA	1%												
16	68	AEA	0.39	NA	610	1746	1242	295	0.48	7	5.5	144.26	1.002	8:59	13:00	11/5/02 9:36 AM
17	68	AEA	0.48	NA	606	1736	1233	304	0.50	6.5	5.1	143.85	1.009	6:46	10:09	11/5/02 11:57 AM
		CALCIUM CHLORIDE	NA	1%												
18	68	AEA	0.63	NA	608	1742	1239	307	0.51	6.75	5	144.67	1.005	5:17	8:26	11/5/02 12:26 PM
		CALCIUM CHLORIDE	6	2%												
19	68	AEA	0.4	NA	462	1719	1369	269	0.58	7	5.9	141.39	1.018	7:23	10:34	11/13/02 7:52 AM
20	68	AEA	0.4	NA	513	1734	1351	281	0.55	6.25	5.4	143.85	1.009	6:28	9:34	11/13/02 8:20 AM
21	68	AEA	0.39	NA	558	1730	1286	281	0.50	7	5.8	142.62	1.002	6:55	10:02	11/13/02 8:45 AM
22	68	AEA	0.39	NA	607	1738	1236	298	0.49	6.5	5.1	143.85	0.998	6:10	8:45	11/13/02 9:11 AM
23	68	AEA	1.1	NA	467	1738	1377	282	0.60	6.5	5	143.03	1.007	12:44	19:46	11/20/02 7:50 AM
24	68	AEA	1.5	NA	458	1704	1349	284	0.62	6.5	6.4	140.57	1.027	7:36	11:56	11/20/02 9:02 AM
		CALCIUM CHLORIDE	NA	1%												

APPENDIX A - Phase I Mix Design Proportions (cont.)

Mix ID	Temp. (°F)	Admixtures	Dose (oz/cwt)	Dose (lb/cwt)	Cmt1 (lb/yd^3)	CA1 (lb/yd^3)	FA1 (lb/yd^3)	H2O (lb/yd^3)	W/C Ratio	Slump Initial	Air % Initial	Unit Wt (lb/ft^3)	Yield	Initial Set	Final Set	Date and Time Cast
25	68	AEA	1.5	NA	459	1709	1352	278	0.61	6.5	6.5	140.98	1.025	4:53	7:55	11/20/02 9:30 AM
26	68	AEA	1.15	NA	463	1723	1364	281	0.61	6.5	6.2	141.8	1.016	3:51	6:40	11/20/02 10:15 AM
		NCA	64	NA												
27	68	AEA	0.54	NA	461	1715	1398	260	0.56	6.25	5.8	142.21	1.021	7:17	11:07	11/20/02 10:51 AM
		MRWR-Type A/F	6	NA												
		CALCIUM CHLORIDE	NA	1%												
28	68	AEA	1.1	NA	510	1727	1331	295	0.58	6	5	143.03	1.014	12:02	19:48	11/20/02 8:32 AM
29	68	AEA	1.4	NA	509	1723	1328	311	0.61	6	5	143.44	1.016	6:17	10:02	11/20/02 11:23 AM
		CALCIUM CHLORIDE	NA	1%												
30	68	AEA	1.5	NA	502	1700	1310	292	0.58	6.5	6.3	141.39	1.030	3:48	5:42	11/20/02 11:49 AM
		CALCIUM CHLORIDE	NA	2%												
31	68	AEA	1.15	NA	508	1719	1325	307	0.60	6	5.8	143.03	1.018	3:17	5:11	11/20/02 12:22 PM
		NCA	64	NA												
32	68	AEA	0.54	NA	507	1715	1360	289	0.57	6	5.5	143.44	1.021	6:57	11:03	11/20/02 12:54 PM
		MRWR-Type A/F	6	NA												
		CALCIUM CHLORIDE	NA	1%												
33	68	AEA	1	NA	553	1716	1261	311	0.56	6	5.7	142.21	1.020	10:37	16:46	11/11/02 8:56 AM
34	68	AEA	1.37	NA	552	1712	1258	292	0.53	6.75	6.3	141.39	1.022	7:01	10:22	11/11/02 9:38 AM
		CALCIUM CHLORIDE	NA	1%												
35	68	AEA	1.4	NA	556	1724	1267	284	0.51	6.5	6.1	142.21	1.015	3:44	5:51	11/11/02 10:34 AM
		CALCIUM CHLORIDE	NA	2%												
36	68	AEA	1.15	NA	556	1724	1267	284	0.51	6.75	6.3	142.21	1.015	3:29	5:28	11/11/02 11:02 AM
		NCA	64	NA												
37	68	AEA	0.53	NA	557	1729	1314	279	0.50	6.25	5.5	143.85	1.012	7:13	11:18	11/11/02 11:33 AM
		MRWR-Type A/F	6	NA												
		CALCIUM CHLORIDE	NA	1%												
38	68	AEA	1	NA	602	1724	1227	301	0.50	6	5.7	142.62	1.015	9:54	16:26	11/11/02 12:03 PM
39	68	AEA	1.3	NA	599	1716	1221	294	0.49	6.5	5.5	142.21	1.020	5:41	8:56	11/11/02 12:28 PM
		CALCIUM CHLORIDE	NA	1%												
40	68	AEA	1.35	NA	599	1716	1221	293	0.49	7	5.7	142.21	1.020	3:34	5:52	11/11/02 12:59 PM
		CALCIUM CHLORIDE	6	2%												
41	68	AEA	1	NA	467	1738	1377	287	0.61	6	4.9	143.44	0.998	6:14	9:02	11/13/02 9:40 AM
42	68	AEA	1	NA	509	1723	1328	304	0.60	6	5.4	143.03	1.007	5:59	8:38	11/13/02 10:10 AM
43	68	AEA	1.1	NA	554	1719	1263	315	0.57	6	5.2	142.62	1.009	5:55	8:15	11/13/02 10:38 AM
44	68	AEA	1.1	NA	596	1707	1214	322	0.54	6.5	5.3	142.21	1.016	6:02	8:19	11/13/02 11:06 AM

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.

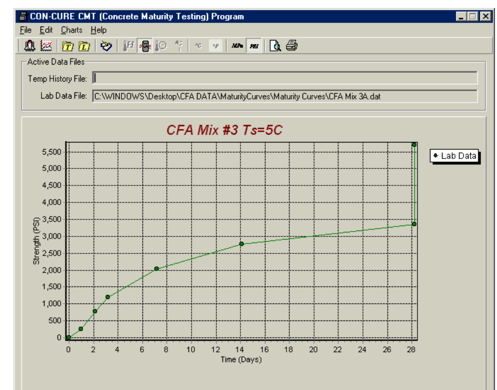
PHASE I: THE LABORATORY

Important Facts about this testing

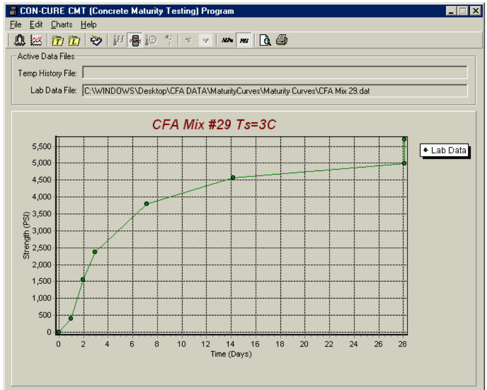
- Followed a "worst-case" scenario in curing test cylinders (Phase I) and walls (Phase II).
- Testing represented a significant deviation from standard conditions (70° moist cure).
- All 44 maturity curves were checked and entered into the maturity testing software.

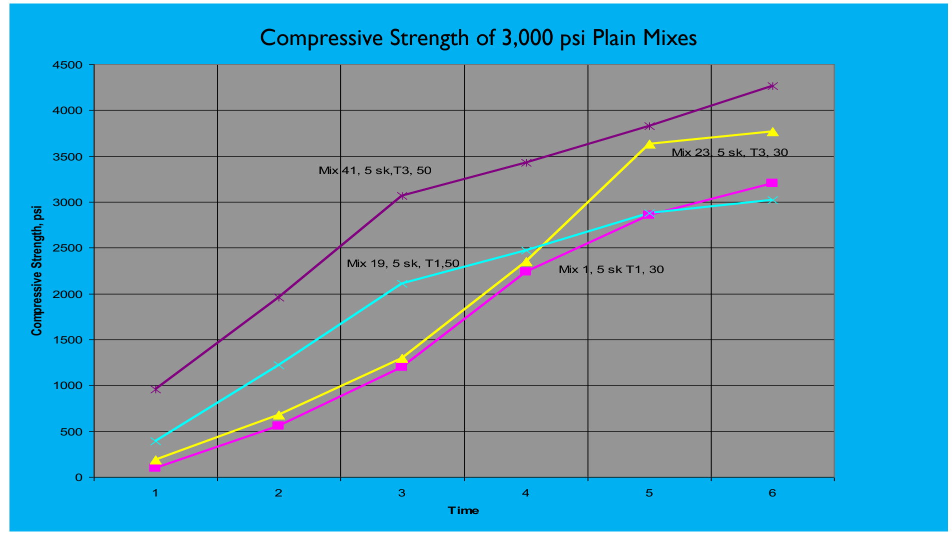
Mix ID	Init Set	Final Set	1D Age,hrs	1D AVGCS psi	2D Age,hrs	2D AVG CS psi	3D Age,hrs	3D CS psi	7D Age,hrs	7D CS psi	14D Age,hrs	14D CS psi	28D Age,hrs
1	10:55	16:07	24.07	100	52.40	560	76.90	1200	172.90	2240	340.40	2860	678.40
2	9:05	13:49	24.05	190	51.47	770	76.13	1300	171.97	2240	339.47	2950	677.55
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

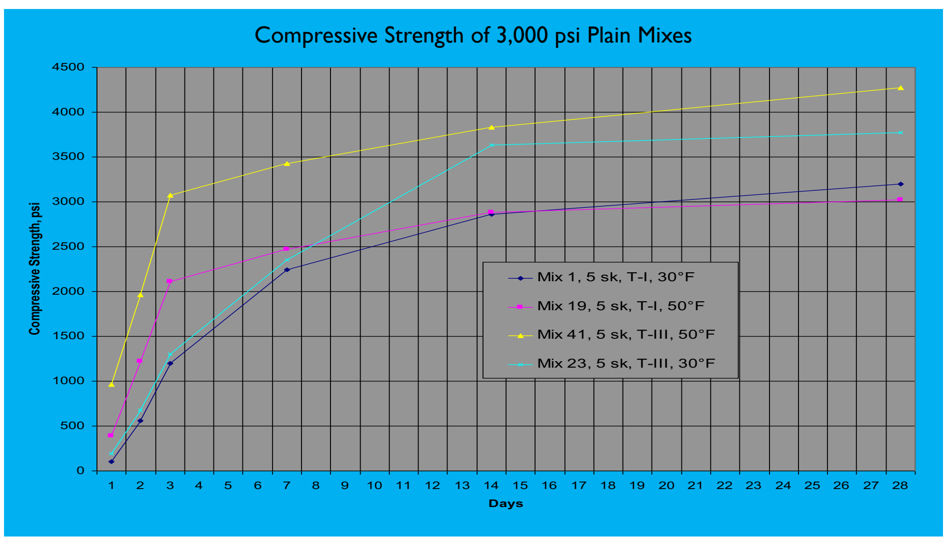
TYPE I 5-SACK MIX WITH 2% CACL

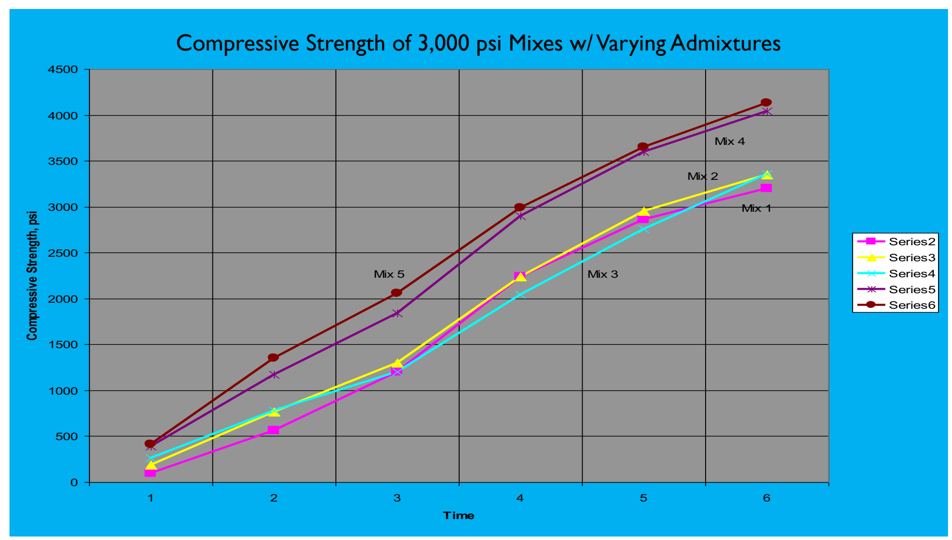


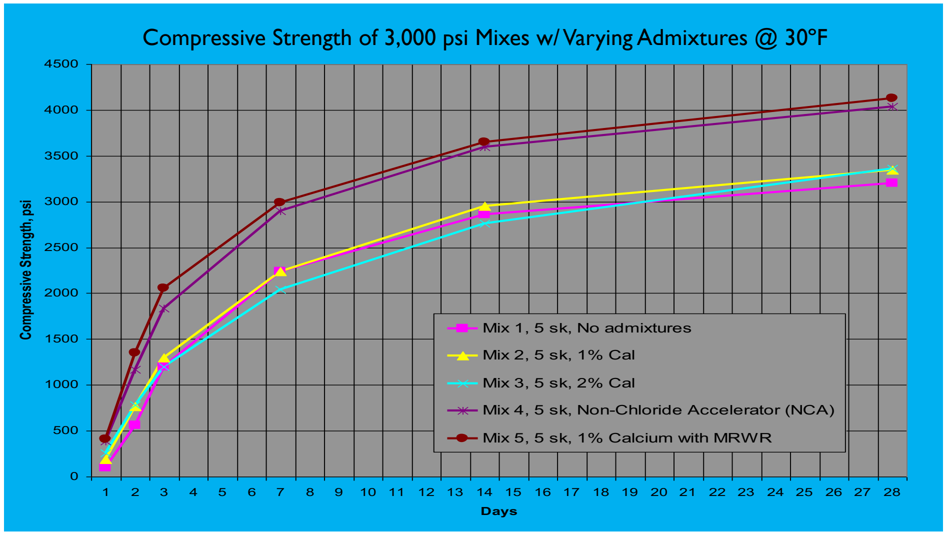
TYPE III 5.5-SACK MIX WITH 1% CACL





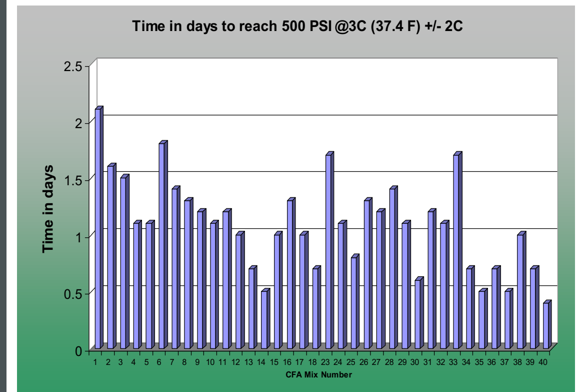


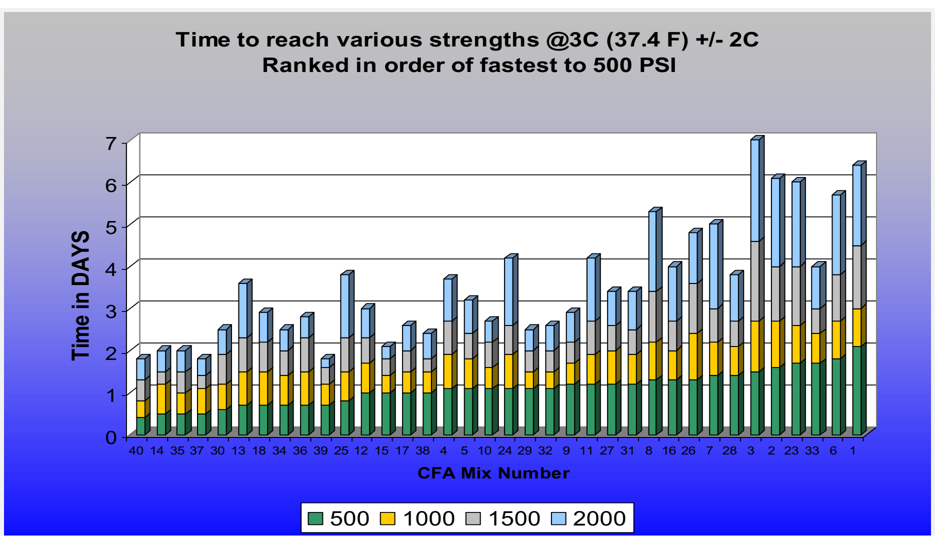


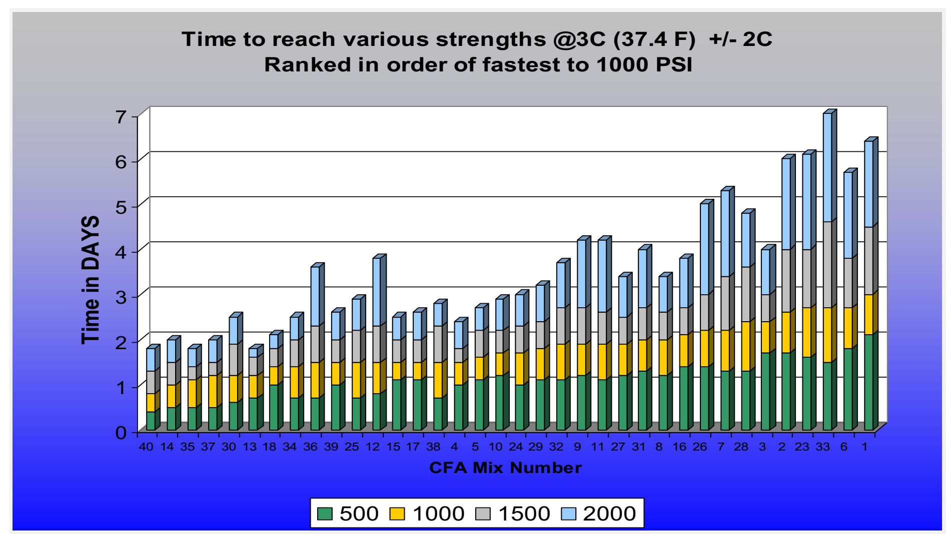


TIME (IN DAY) TO REACH 500 PSI.

TEMP. HELD AT 3 C (37.4 F)







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.


Tri-County


HILTI
DD-160 E

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

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

CFA Mix ID	1 Day (~30 hrs.)	2 Day (~48 hrs.)	3 Day (~73 hrs.)	7 Day (~170 hrs.)	28 Day (~702 hrs.)	180 Day
3	330	560	1040	1740	3410	5530
8	410	600	1020	1650	3460	5695
13	510	700	1160	1840	3800	6955
24	500	840	1350	1750	3150	5750
29	990	1320	1840	2220	4140	5550
34	1400	1870	2500	3030	5250	6500

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

CFA Mix ID	1 Day (~30 hrs.)	2 Day (~48 hrs.)	3 Day (~73 hrs.)	7 Day (~170 hrs.)	28 Day (~702 hrs.)	180 Day
3	340	600	1060	1850/1730*	3260/3320*	5765
8	400	590	1000	1960/1670*	3570/3470*	6250
13	520	740	1280	2020/1990*	3660/3550*	Unavailable
24	510	870	1470	2090/1980*	3380/3160*	5450
29	990	1370	2110	2820/2600*	4280/4080*	5750
34	1550	1970	2620	3290/3430*	5010/4920*	6850

COMPARING THE PHASES
COMPRESSIVE STRENGTH DATA

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

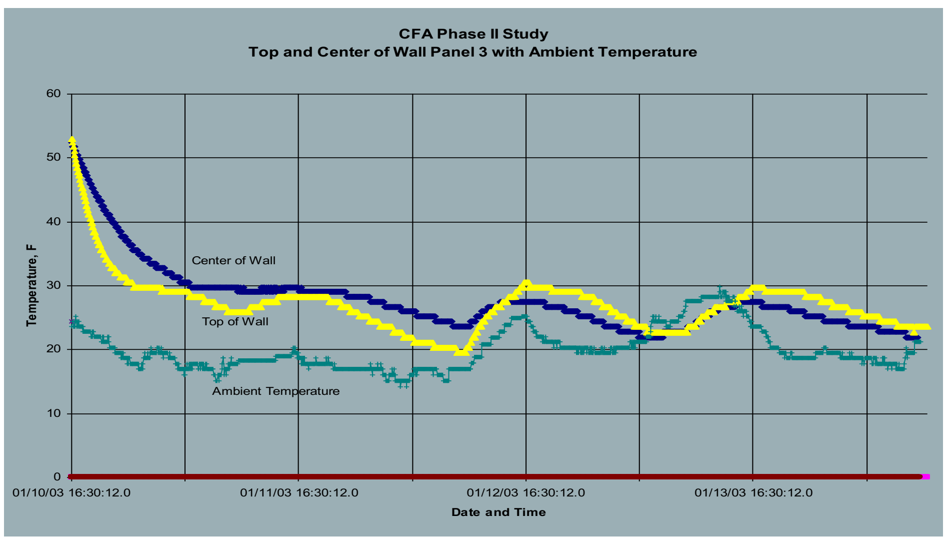
CFA Mix ID	Day 1 (-27 hrs.)	Day 2 (-46 hrs.)	Day 3 (-72 hrs.)	Day 7 (-168 hrs.)
3	400	1150	1730	3320
8	580	1480	2070	3540
13	650	1760	2310	3690
24	1080	2330	2800	3890
29	1670	3080	3610	4580
34	2130	3420	4150	5345

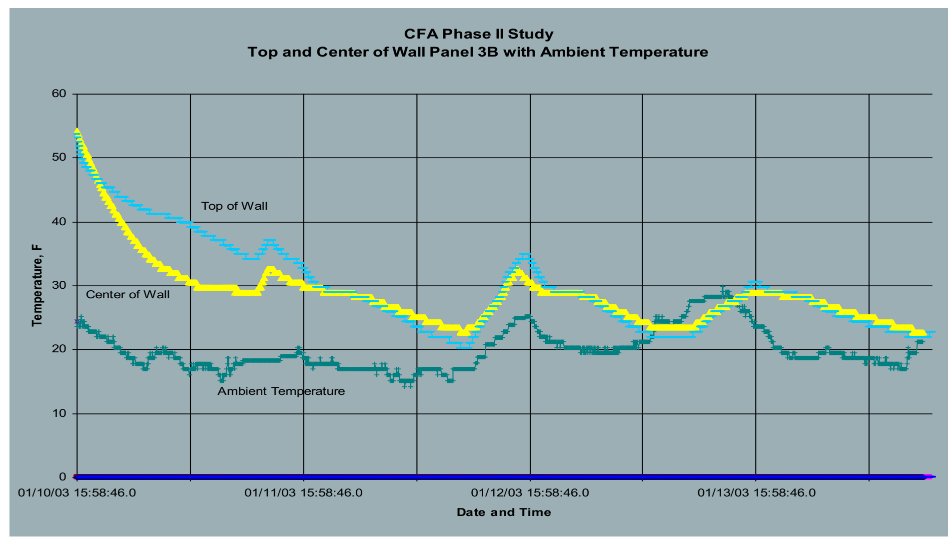
B. 4" Cores from Uncovered Panel (Avg. of 2 samples)

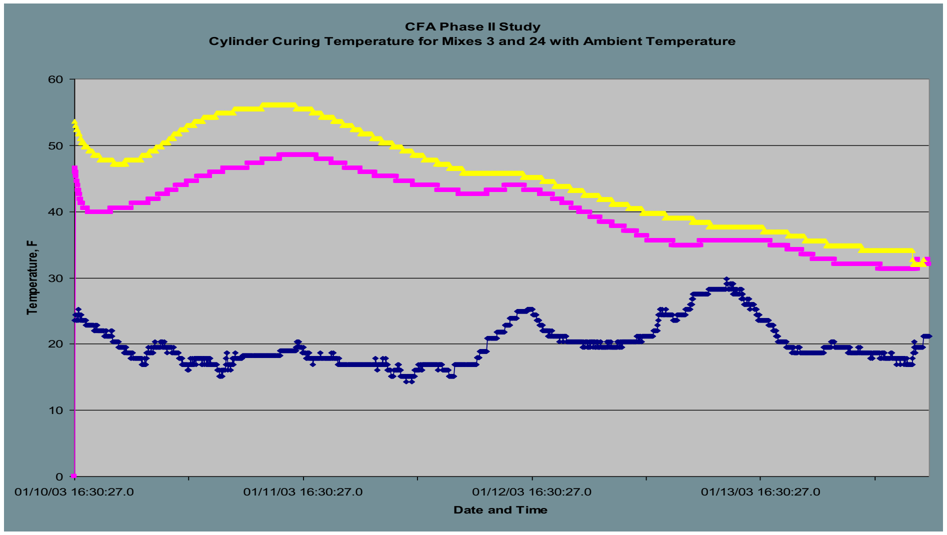
CFA Mix ID	Day 1 (-27 hrs.)	Day 2 (-46 hrs.)	Day 3 (-72 hrs.)	Day 7 (-168 hrs.)
3	330	560	1040	1740
8	410	600	1020	1650
13	510	700	1160	1840
24	500	840	1350	1750
29	990	1320	1840	2220
34	1400	1870	2500	3030

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*







USING MATURITY

Predicted Compressive Strengths

Using Lab Curves with 7-day wall panel temperatures (Center of covered panels)

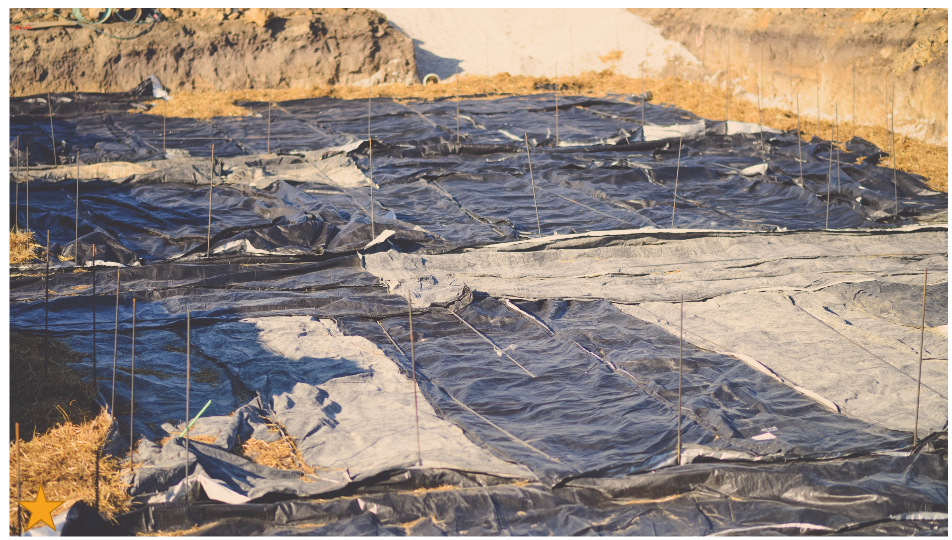
Predicted vs. Measured Compressive Strengths

CFA Mix ID	1-Day		2-Day		3-Day		7-Day	
	Mat.	Core*	Mat.	Core*	Mat.	Core*	Mat.	Core*
3 (Ts = 4)	230	330	500	560	810	1040	1450	1740
8 (Ts = 5)	280	410	580	600	940	1020	1690	1650
13 (Ts = 5)	560	510	950	700	1350	1160	2100	1840
24 (Ts = 0)	450	500	1050	840	1560	1350	2070	1750
29 (Ts = 0)	550	990	1530	1320	2280	1840	2990	2220
34 (Ts = 0)	1180	1400	2060	1870	2760	2500	3820	3030

* = Cores taken from full-scale wall samples uncovered the duration of the research.

CONCLUSIONS FOR RESIDENTIAL WALLS

- 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
  - Watch delivery temperatures with accelerating admixtures!!!
- 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.

INVEST IN KNOWLEDGE

RESEARCH LOCAL MIXES AND UNDERSTAND PERFORMANCE BEHAVIOR


TAYLOR
32.0

JAMES R BATY II

- FACI, FTCA – Executive Director for Concrete Foundations Association
- jbaty@sb2management.com | 319-895-8827
- Office Location: Mount Vernon, IA (Cedar Rapids)

CONCRETE FOUNDATIONS ASSOCIATION

TCA TILT-UP CONCRETE ASSOCIATION