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ICRI 2022 Spring Convention

Making Concrete Stand the Test Time: Testing Applications, Admixtures, and Technology Overview

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Restore | Repurpose | Renew

Learning Objectives

1. Laboratory testing applications of mix designs.
2. Learn about different admixtures that have weather applications.
3. Be able to identify concrete distress caused by weather.
4. Learn how thermal monitoring can save a project.

Laboratory Testing – Mix Designs

Table 1 - Concrete Design Requirements		
Prescriptive requirements	Minimum	Maximum
ASTM C666/C666M Method A Durability Factor at 300 cycles	90	--
Concrete ASTM C157/C157M Drying Shrinkage percent, at 28 days except for high volume fly ash (HVFA) at 56 days.	--	0.05 percent
Initial acid-soluble chloride content in cast-in-place concrete per ASTM C1152/C1152M, percent/cement	--	0.10
Initial acid-soluble chloride content in prestressed concrete determined following ASTM C1152/C1152M, percent/cement	--	0.08

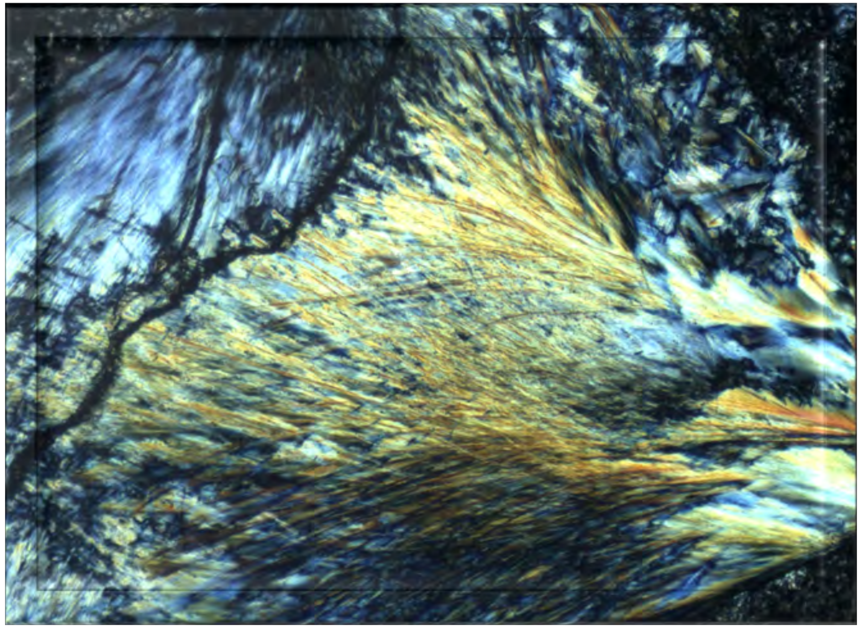
Laboratory Testing- Plastic State Testing

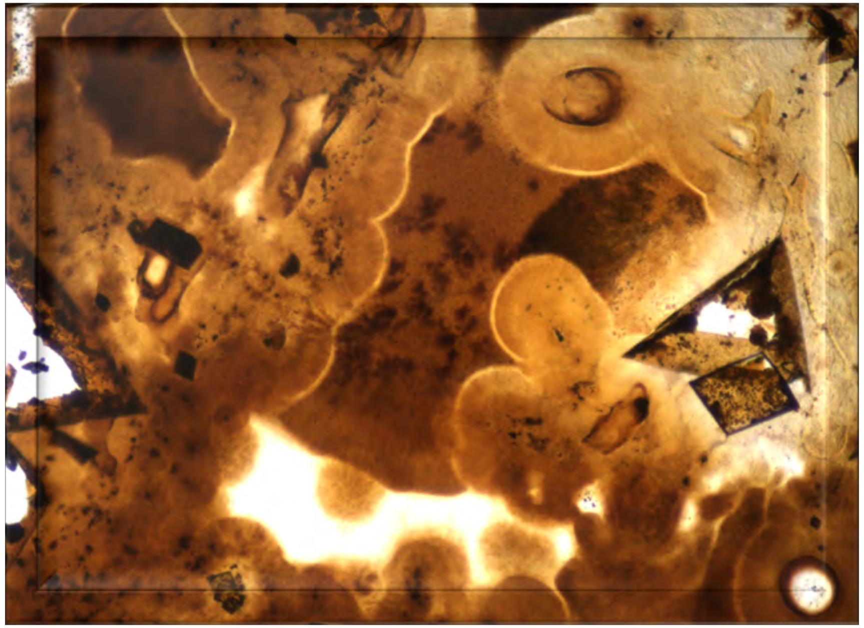
ASTM C143

ASTM C231

ASTM C1064

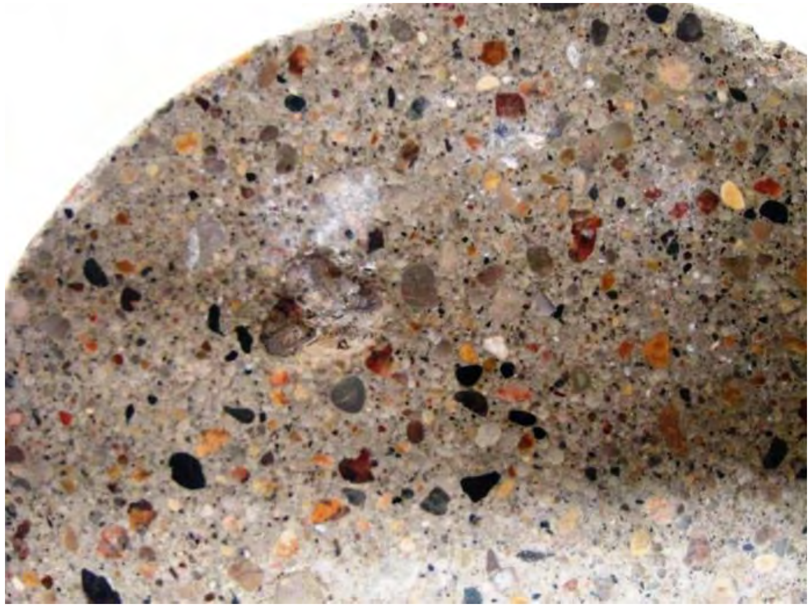
ASTM C39



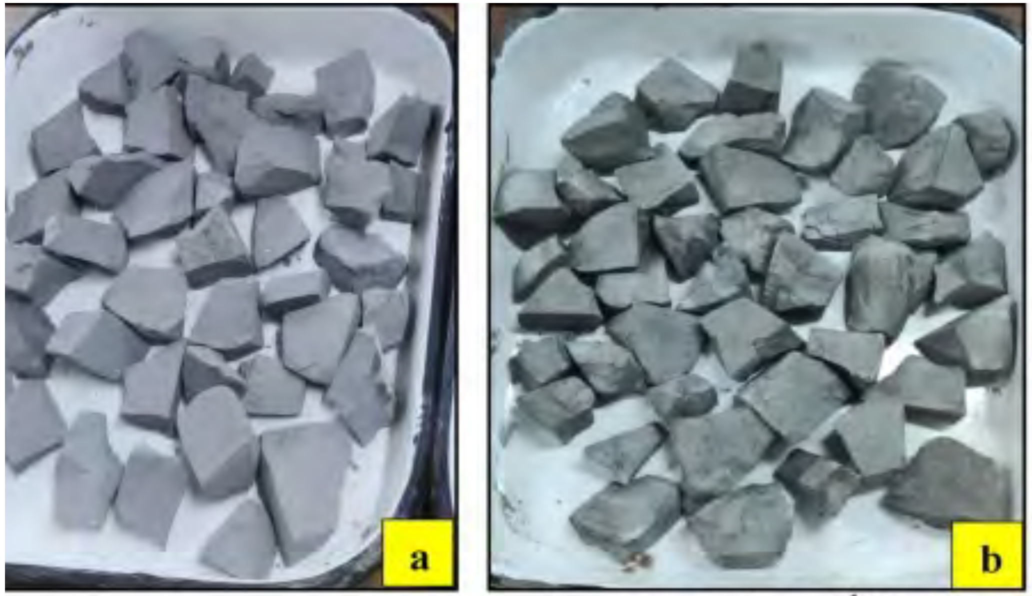
Laboratory Testing-
Aggregate Testing

Laboratory Testing-Aggregate Testing



Laboratory Testing-Aggregate Testing

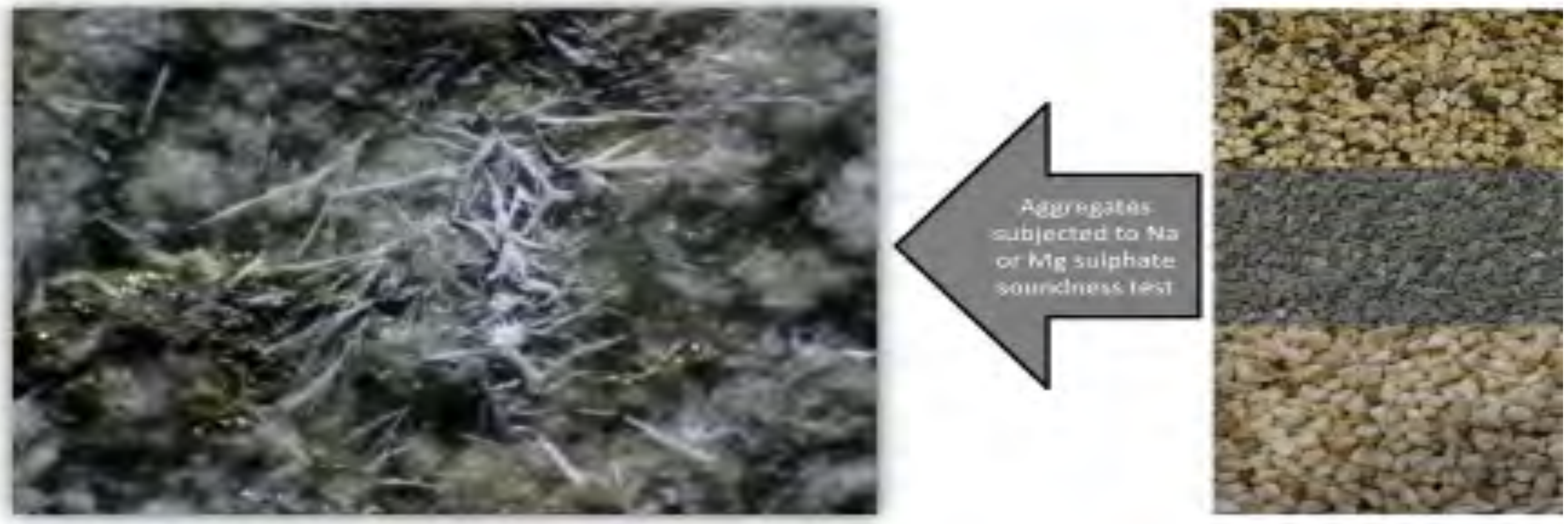
- **Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (ASTM C88)**



Virgin Aggregate

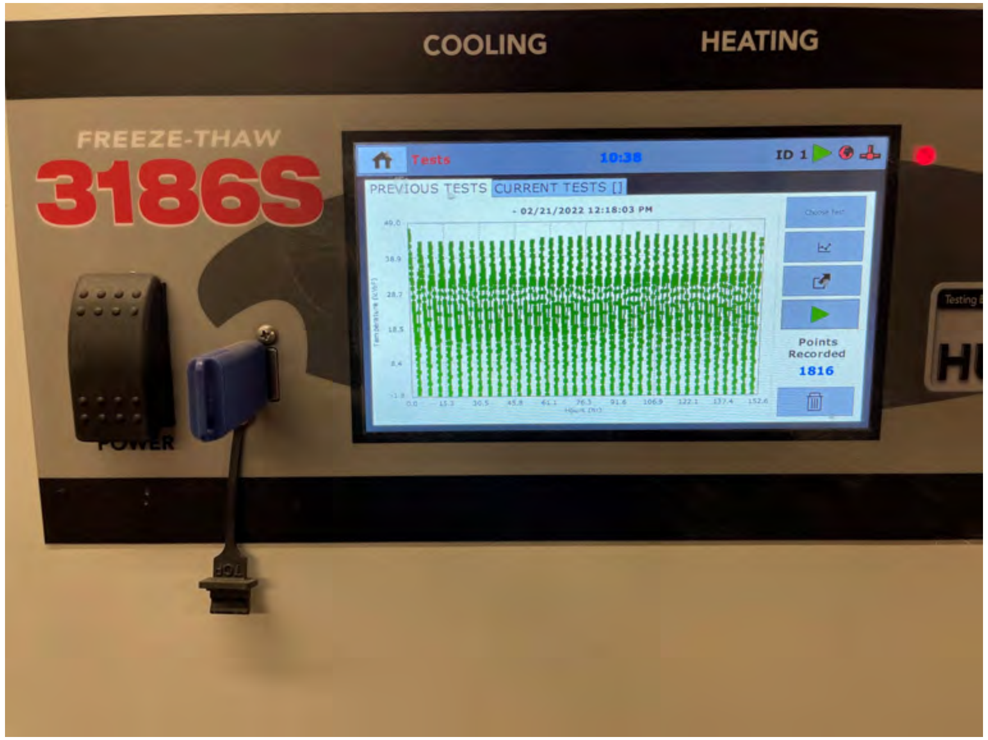
Aggregate after 3rd Cycle

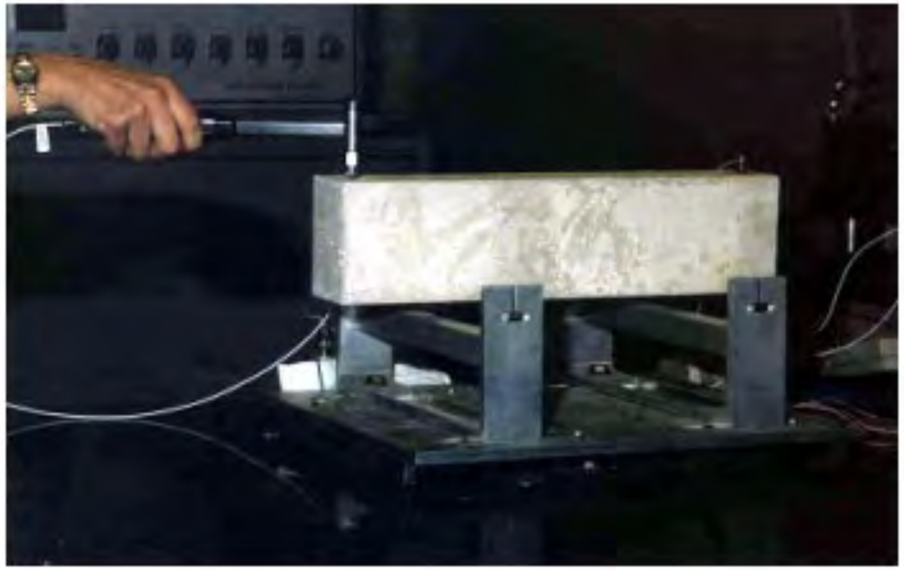
Aggregate after 5th Cycle



Laboratory Testing

- Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing (ASTM C666)



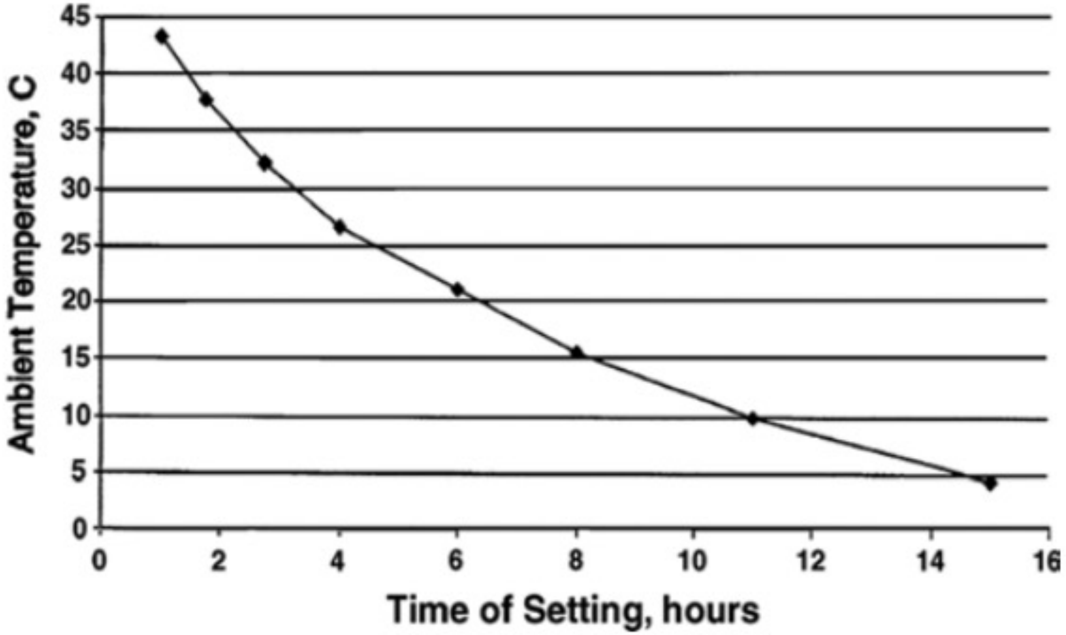


Laboratory Testing

- Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals (ASTM C672)

Concrete Admixtures – Water Reducers

- Water Reducers
  - Reducing W/CM = Durability
  - Retarders
    - Extend Setting Time (Hot Weather Applications)
  - Accelerators
    - Increase Setting Time (Cold Weather Applications)
  - Superplasticizers (HRWR)
    - Reduction of water of up to 30%
- Chloride Content



Concrete Admixtures - Air Entrainment

- Air Entrainment
  - Entrained vs Entrapped Air
  - Stabilization of "Bubbles"
- Benefits
  - Freeze-Thaw Resistance
  - Increase resistance to scaling from deicing salts
  - Improve workability-Cohesiveness

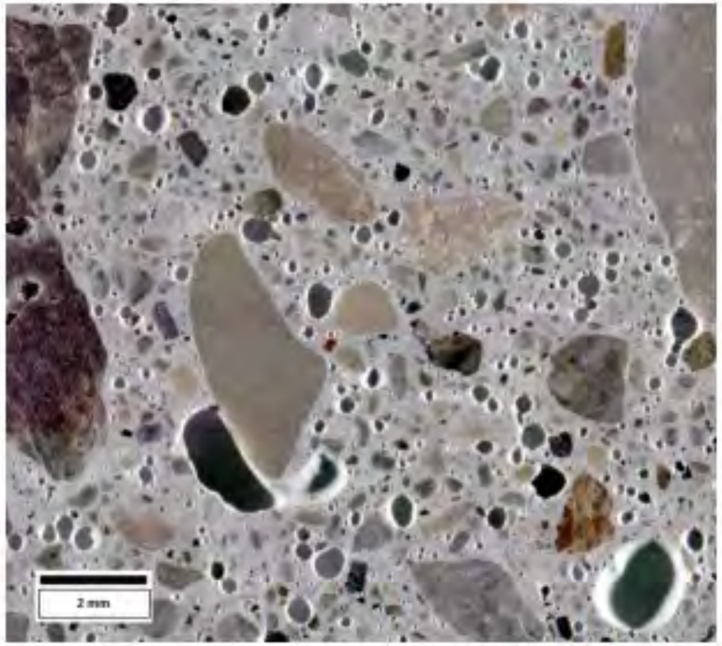


Figure 1. Stereo micrograph of entrained air voids (spherical bubbles) in hardened concrete. Larger, irregular voids are entrapped air.

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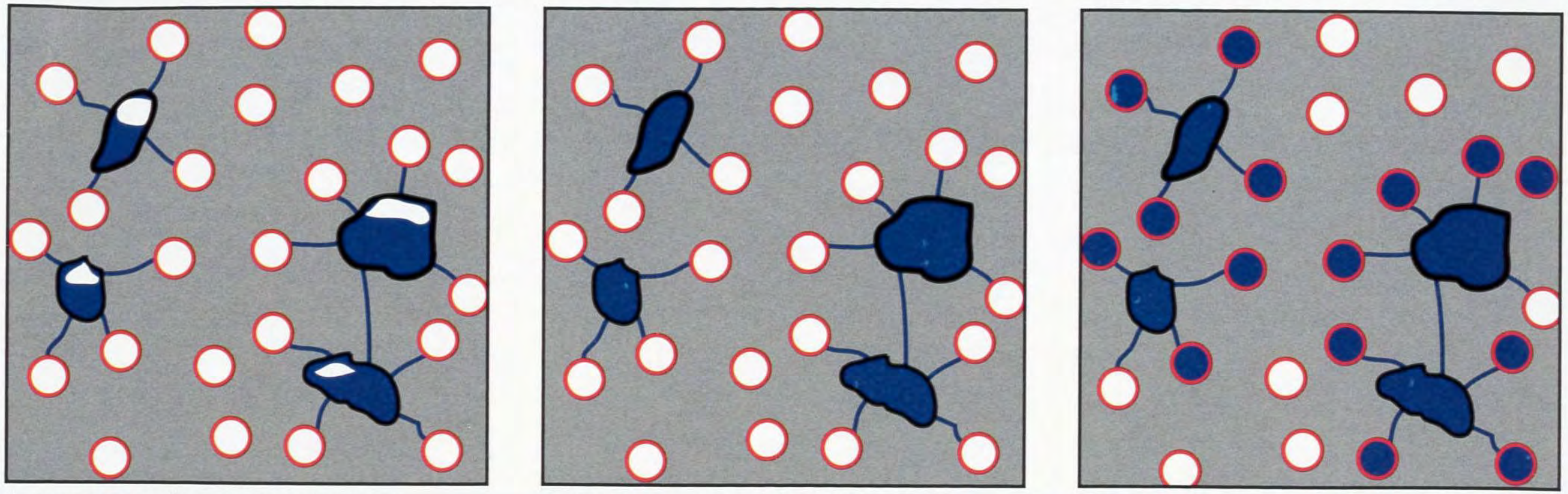
Concrete Admixtures - Air Entrainment

- Expansion of ice is ~9% in volume

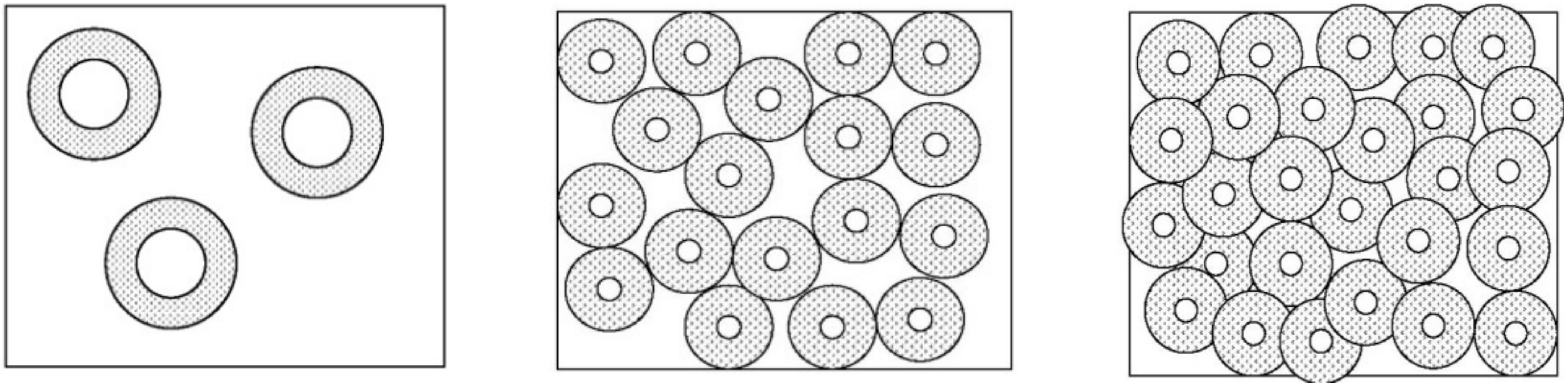


As temperatures drop, pores created by air entrainment allow the water a place to go as it freezes.

During freezing, water in the capillary pores expands; however, water is also going toward air-entrained pores.

Under pressure, the water will be pushed into the air entrainment pores and not crack the concrete matrix.

Concrete Admixtures - Air Entrainment



Concrete Admixtures

Exposure Class	Severity	Condition
F0	Not applicable	Concrete not exposed to freezing conditions
F1	Moderate	Concrete exposed to freezing and thawing conditions, but very low probability of concrete being near saturation at time of exposure*
F2	Severe	Concrete exposed to freezing and thawing conditions, with a high probability of concrete being near saturation at time of exposure, but no deicing chemical exposure†
F3	Very severe	Concrete exposed to freezing and thawing conditions as well as deicing chemicals‡

Freezing-and-thawing exposure classes

Cementitious materials	Maximum percent of total cementitious materials by mass*
Fly ash or other pozzolans conforming to ASTM C618	25
Slag conforming to ASTM C989/C989M	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or other pozzolans, slag, and silica fume	50†
Total of fly ash or other pozzolans and silica fume	35†

Cementitious materials limitations for Exposure Class F3b

Concrete Admixtures

Exposure Class	Minimum $\overline{f_c}$',[†] MPa (psi)	Maximum w/cm[†]	Air content	Limits on cementitious materials
F0	No restriction	No restriction	No restriction	No restriction
F1	25 (3500)	0.50	Table 4.2.3.2.4	No restriction[‡]
F2	25 (3500)	0.45	Table 4.2.3.2.4	No restriction[‡]
F3a[§]	32 (4500)	0.45**	Table 4.2.3.2.4	Table 4.2.3.1c[‡]
F3b[#]	32 (4500)	0.45**	Table 4.2.3.2.4	No restriction[‡]

Requirements by freezing-and-thawing exposure class

Nominal maximum aggregate size, in. (mm)	Air content, percent*	
	Exposure Class F1	Exposure Class F2 and F3
3/8 (9.5)	7	7.5
1/2 (12.5)	7	7
3/4 (19)	6.5	7
1 (25)	6.5	6.5
1-1/2 (37.5)	6	6.5
2 (50)	6	6
3 (75)	5	5.5

Recommended air contents

Concrete Admixtures - Air Entrainment

Thermal Monitoring – Applications

Maturity Testing

Concrete Curing

Weather Protection

Technological Advances in Concrete Testing

The 'MODERN' ERA of concrete thermal measurement should not limit us on progress.

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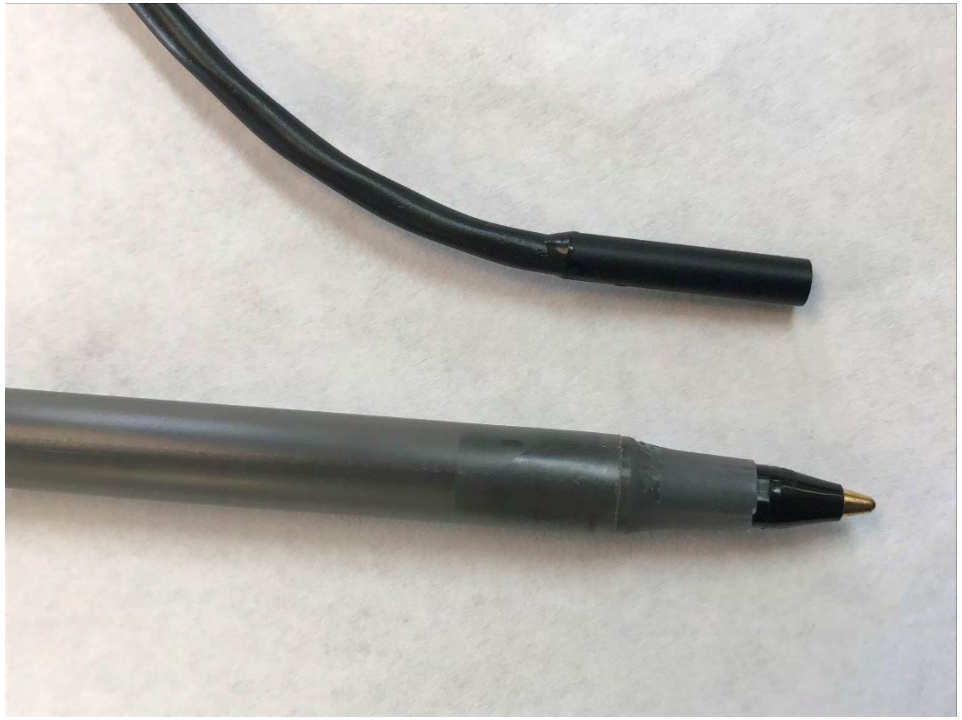
Technological Advances in Concrete Testing



Thermal Monitoring – Applications

Maturity Testing

-

- ASTM C 1074-04 – *Standard Practice for Estimating Concrete Strength by the Maturity Method*
- DOT Supplement Specifications and Modified Procedures
- Basically, any case where the in-place strength of the concrete and thermal curing history is to be known or monitored
- Applications include:

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Post tensioned concrete stressing

Maturity results from thermal monitoring can be used to determine appropriate time for tendon stressing.

Photo Credit:
https://www.youtube.com/watch?v=PDgfnGqPj1c

Early form/shoring removal

Maturity results from thermal monitoring can be used to determine the appropriate time to strip concrete forms.

Early loading

Maturity results from thermal monitoring to allow for early loading when strength results meet specification.

Thermal Monitoring – Maturity Method

Application includes:

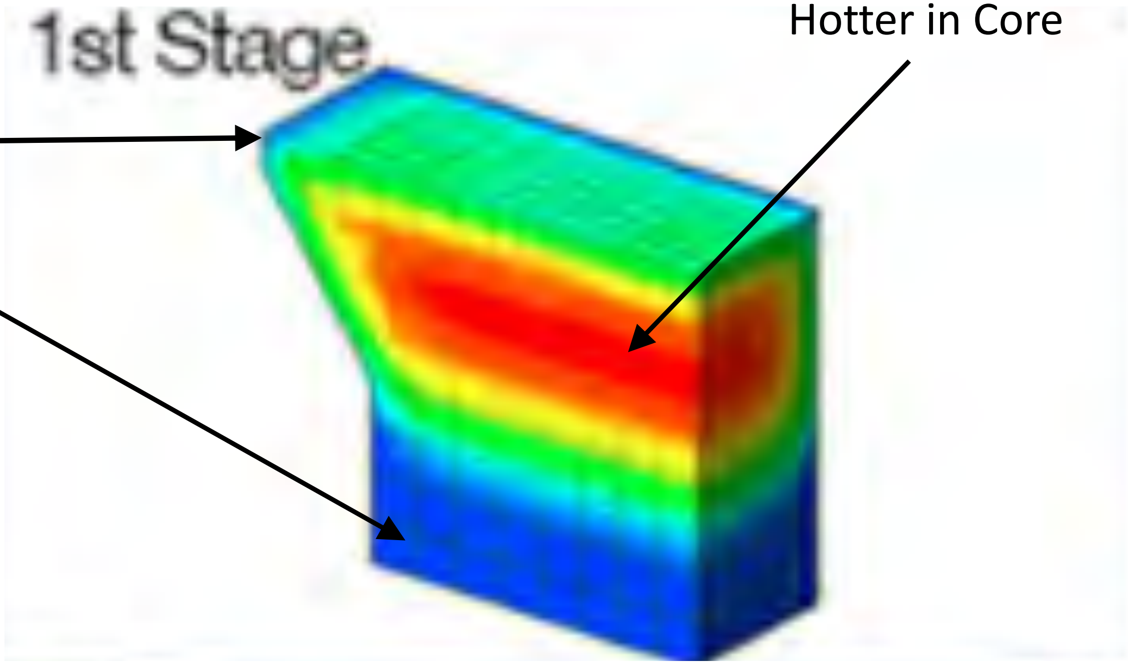
Benefit for both *Engineer* and *Contractor*

Saves construction schedule time

Saves construction dollars

Thermal Monitoring – Maturity Method

Cooler at exterior/skin



Hotter in Core

Concrete typically heats to 110-180 deg. F internally after placement, depending on curing and protection.

Thermal Monitoring – Maturity Method

- Maturity - principle that concrete strength is directly related to both age and its temperature history, as the cement hydrates and releases heat
- Measured maturity of in-place concrete is used to estimate its strength development based on a pre-determined 'calibration' of the time-temperature strength relationship developed in a laboratory

"Maturity-Strength Correlation Curve"

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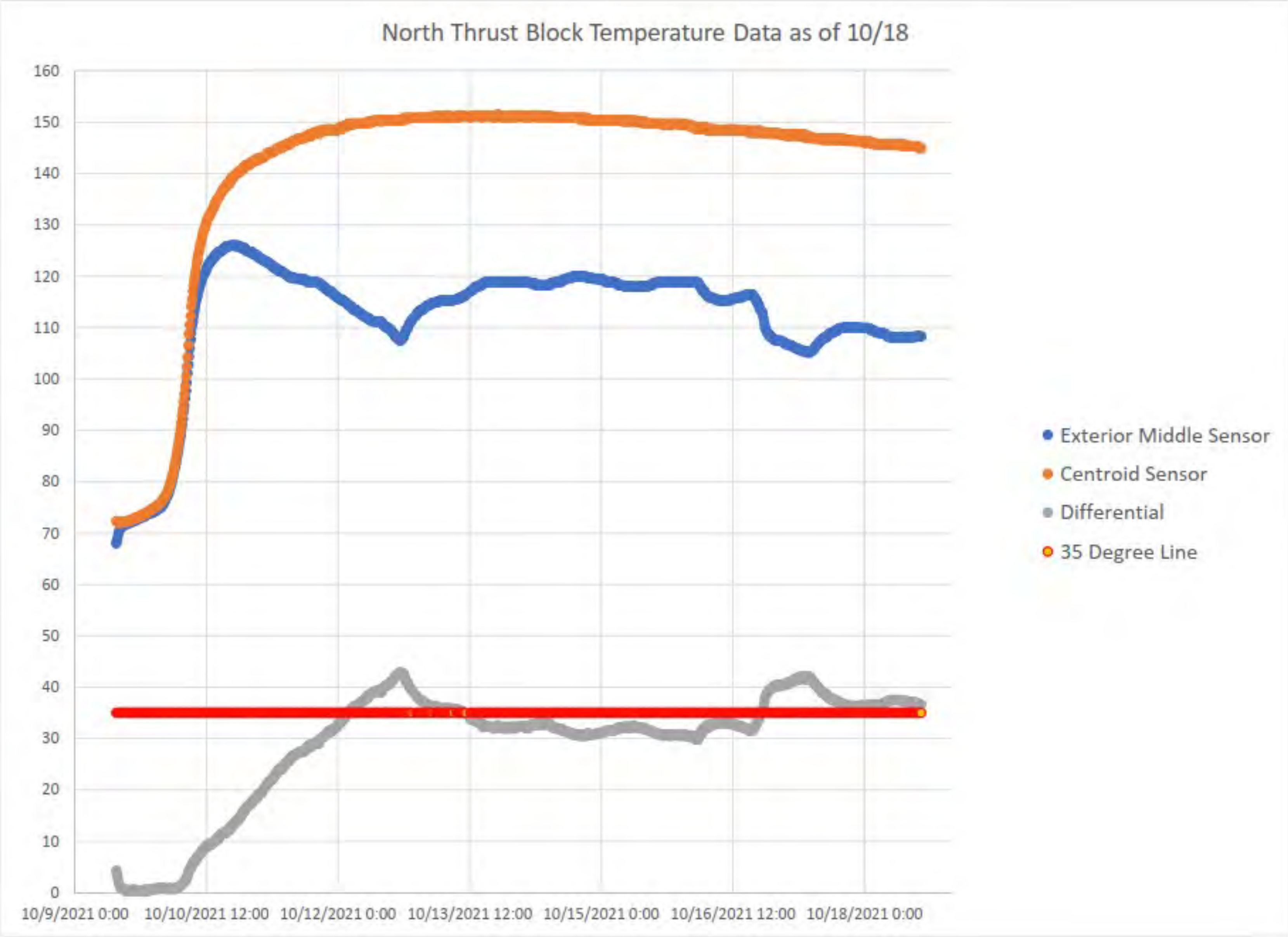
Thermal Monitoring – Maturity Method

- Rate of strength gain at early ages is related to rate of cement hydration and heat generation (temperature rise in the concrete)
- Heat generation takes into account environmental factors influencing temperature and mass of concrete (dimensions of element)
- Maturity uses actual temperature profile of concrete in structure to estimate strength
- Traditional field cured cylinders do not replicate the same temperature profile of the concrete in-place, and thus may not truly reflect in-place strength


North Thrust Block Temperature Data as of 10/18
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
10/9/2021 0:00
10/10/2021 12:00
10/12/2021 0:00
10/13/2021 12:00
10/15/2021 0:00
10/16/2021 12:00
10/18/2021 0:00
Exterior Middle Sensor
Centroid Sensor
Differential
35 Degree Line

Thermal Monitoring – Maturity Method

- Maturity, in addition with other non-destructive tests, is used to facilitate decision making for construction operations to proceed more quickly, safely, and economically
- Designed to account for environmental and design factors that will affect the in-place concrete strength compared to field cured cylinders, thus providing more accurate information about actual concrete strength
- Not intended to replace laboratory cured cylinders

Old Way vs. New Way

Example…

Depending on the calibration, concrete cured at a temperature of 50º F for 7 days may have the same maturity, and thus strength, as the same mix cured at 80º F for 3 days

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Thermal Monitoring – Maturity Method

- ‘Correlation Study’
- Cylinder fabrication and testing at specified ages
    - Typically 12 hours, 24 hours, 36 hours, 3, 5, 7, 14 and 28 days
- Three cylinders tested at each age and strength is averaged (for 4″ x 8″)
    - Or Two 6” x 12”
- Thermocouples are embedded into two cylinders and activated
- Maturity index is read at each time cylinders are tested in laboratory

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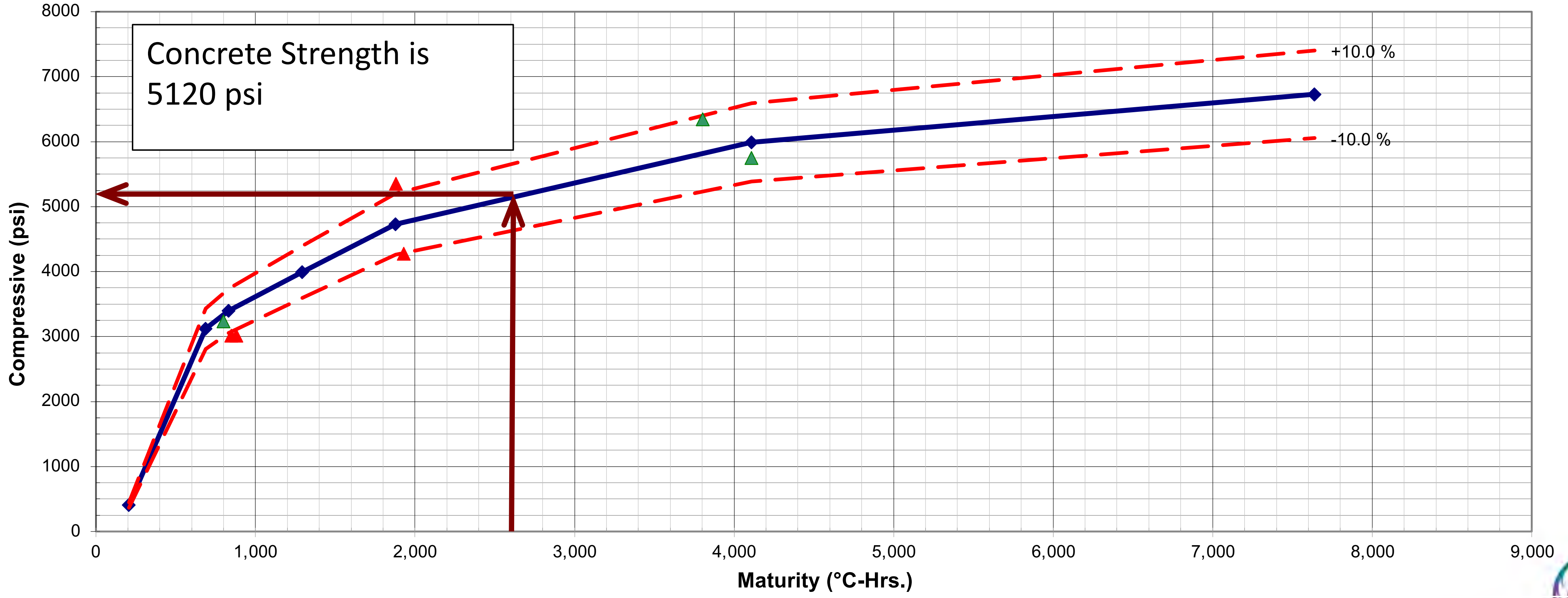
Strength-Maturity Correlation Curve



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Thermal Monitoring – Cold Weather Concrete

- Concrete work can be accomplished during even the coldest weather as long as the appropriate precautions are taken.

- The objectives are to prevent damage from early-age freezing (when the concrete is still saturated), to make sure the concrete develops the needed strength, and to limit rapid temperature changes or large temperature differentials that cause cracking.

- Concrete generates its own heat during hydration--over the first one to three days, and how long it lasts depends of the mass and level of protection.

Thermal Monitoring – Cold Weather Concrete

ACI 306-10

- “Cold weather exists when the air temperature has fallen to, or is expected to fall below 40° F during the protection period. The protection period is defined as the time required to prevent concrete from being affected by exposure to cold weather.”

Thermal Monitoring – Cold Weather Concrete

DOT Specification Example

- Maintain the concrete surface temperature between 50 ° F and 100° F for a period of not less than 5 days…
- After the minimum cure period of 5 days, reduce the concrete surface temperature at a rate not to exceed 20 ° F in 24 hours until the concrete surface temperature is within 20 ° F of atmospheric temperature.
- **Install sufficient high-low thermometers to readily determine the concrete surface temperature.** For deck slabs, install high-low thermometers to measure deck bottom surface, deck fascia surfaces, and deck top surfaces.
- How often can high-low thermometers be checked? What happens if the tolerances are exceeded?

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Thermal Monitoring – Cold Weather Concrete

- Concrete must be protected from freezing until it has reached a minimum strength of 500 pounds per square inch (psi), which typically happens within the first 24 hours.
- Early freezing can result in a reduction of up to 50 percent in the ultimate strength.

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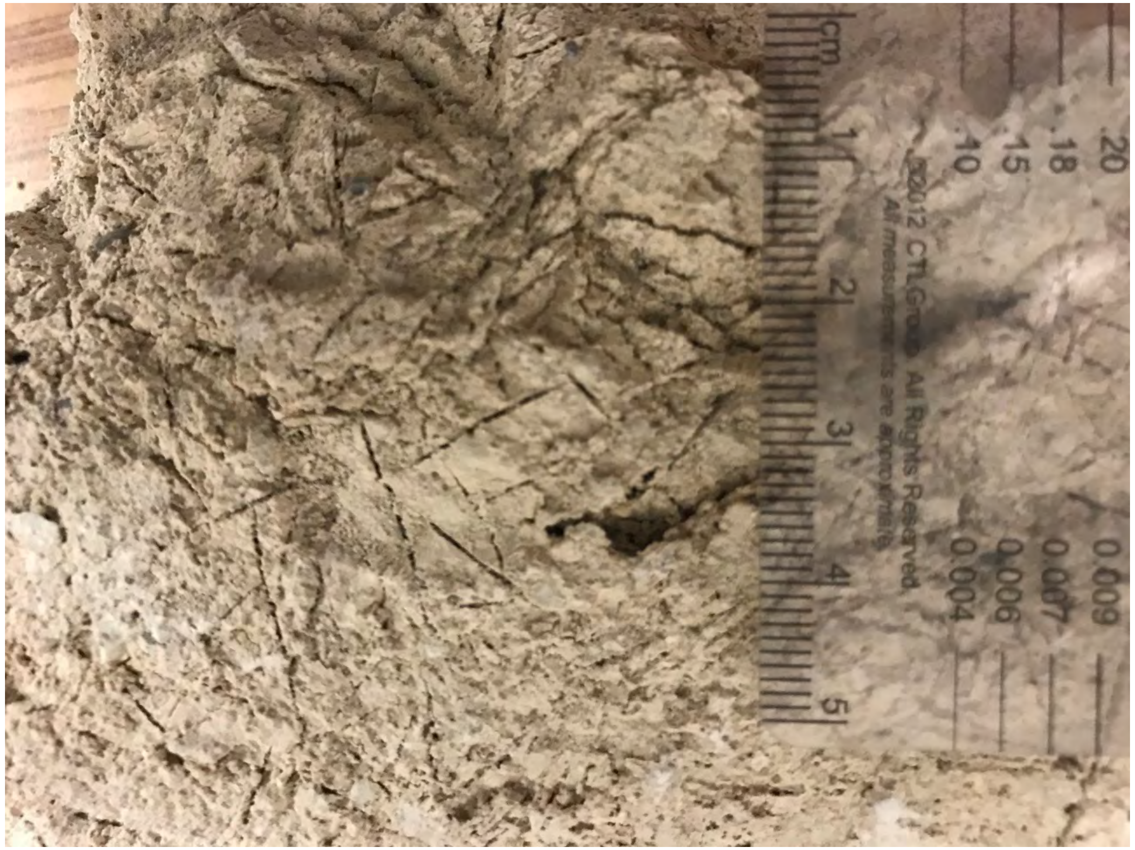
Thermal Monitoring – Cold Weather Concrete



"Crows Feet", or ice crystal casts that occur during freezing in plastic state

Thermal Monitoring – Cold Weather Concrete

- It is also important to prevent rapid cooling of the concrete upon termination of the heating period. Sudden cooling of the concrete surface while the interior is warm may cause thermal cracking.

- Loosen the forms while maintaining cover with plastic sheeting or insulation, gradual decrease in heating inside an enclosure

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How does technology help us?

- *Analog and hand used devices have to be accessed and visually read creating challenges.*

- *Digital systems record an actual temperature and can provide a detailed log over time. These systems are now wireless and operate over the cloud, and thus able to accessed anytime from anywhere.*

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Equipment

- Wireless Systems
- Reusable systems
- Nodes transmit thermal information wirelessly to cloud
- Cloud dashboard calculates strength
- Thermocouple data probes
- Record temperature and loads data to cloud every 10 minutes
- Internal back-up if cell network or cloud is not available

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Report Date
08/30/2017 19:59:57

Prepared By
Matt Lehmenkuler

Client
Example

Project
Example

Device #
1125

Structure
Bridge 6

Job Number
P1151000

Placement Name
Pier 5 First Lift

Node Location
Bridge 6

Notes

#	Sensor	Pour Date	Time of Test	Lab File	Act Age	Equivalent Age	Est Strength
1	Pier 5 First Lift	07/08/2017 07:00:00	07/10/2017 18:47:53	Example	2.42 Days	4.13 days @ Ts=73F	3,188 PSI
2	Pier 5 First Lift	07/08/2017 07:00:00	07/10/2017 18:47:53		2.12 Days	5.67 days @ Ts=73F	3,513 PSI
3			07/10/2017 18:47:53		0 Days	0 days @ Ts=73F	0 PSI

Pier 5 First Lift

Lab File:

Pour Date: 07/08/2017 7:00 AM

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Concrete Alerts

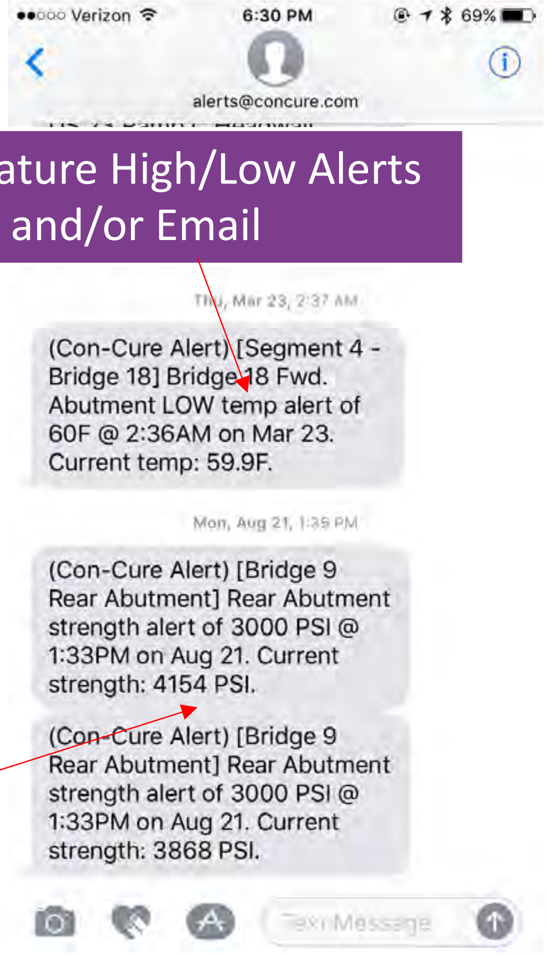
From: Con-Cure [mailto:alerts@concure.com]
Sent: Monday, August 14, 2017 9:25 AM
To: Lehmenkuler, Matthew B
<Matt.Lehmenkuler@terracon.com>
Subject: Strength Target Reached

[Pier 5 Cap] Pier 5 Cap strength alert of 3000 PSI @ 9:25AM on Aug 14. Current strength: 4128 PSI.

The following email is sent to you as a courtesy from Con-Cure. Please let us know if you have any questions. Thank you for your business.

Kindest regards,
Con-Cure Team

Temperature High/Low Alerts via SMS and/or Email



Current Maturity Strength Alerts via SMS and/or Email

Questions?

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