gcp applied technologies

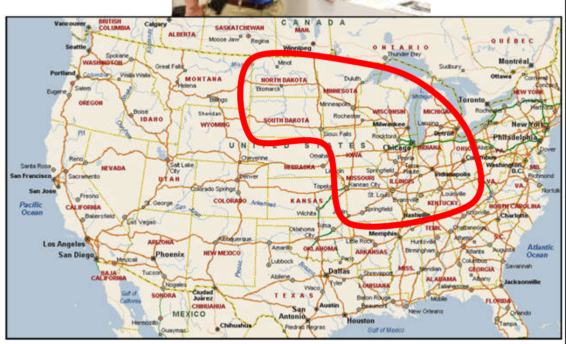
Hot Weather Concrete

A construction products technologies company

1

Ryan Scott

- **20 years in the Industry**
  - 5 years with MRT
    - Developed multiple products based on activated fly ash
  - 10 Years with Essroc Italcementi
    - Cement tech guy
  - 5 years with GCP (WR Grace)
    - Admixture tech guy



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Concrete is an Engineered Material

A few things that will always be true…

…Concrete Cracks

3

Concrete should get hard…

…when is another question…

4

No one will steal it once it is placed…

Fresh concrete is another issue…

5

Basic Concrete Definition:

- A composite material that consists of fine and coarse aggregates that are bound together into a rocklike mass because of a chemical reaction between water and cementitious materials

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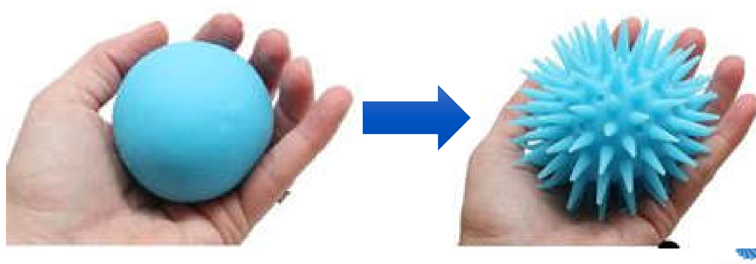
A chemical reaction called Hydration

Cementing Material + Water ⟶ C-S-H + CH



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Hydration, Temperature, Crystals, and Maturity

- **Calcium Silicate Hydrate crystal growth are governed by the Arrhenius equation.**

$$t_e = \sum_{0}^{t} e^{\frac{-E}{R}\left[\frac{1}{273+T_c} - \frac{1}{273+T_r}\right]} \cdot \Delta t$$

- Developed ~1890, by Svante Arrhenius
  - Won the 1903 Nobel Peace Prize for Chemistry
    - Concept is that reaction rates are dependent on temperature
      - The rule of thumb of set time doubling as temperature changes by ~18F

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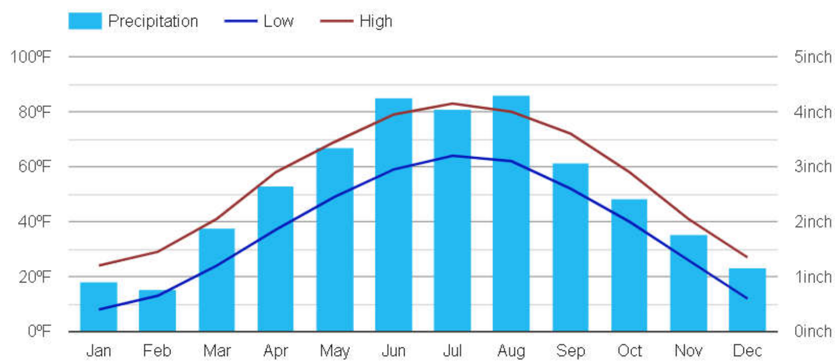
Average Minnesota Weather

Minneapolis Climate Graph - Minnesota Climate Chart



***www.usclimatedata.com 2007-2019 averages**

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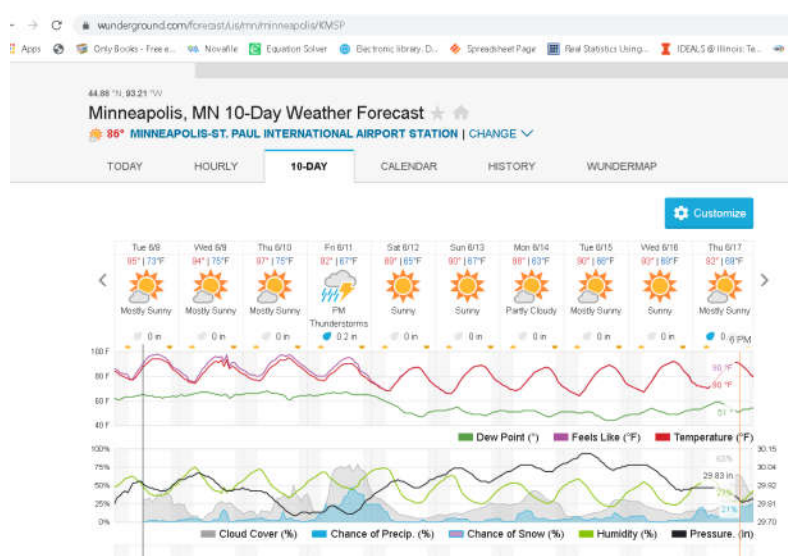
"Current" Minnesota Weather



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Hot Weather Effects on Concrete Quality

- **Hot weather affects concrete because:**
- Accelerates rate of moisture loss
- Accelerates cement hydration

- **ACI 305 Defines as One or a Combination of the following conditions:**
  - High ambient temperature
  - High concrete temperature
  - Low relative humidity
  - High wind speed
  - Solar radiation

Fig. 13-6. Substituting ice for part of the mixing water will substantially lower concrete temperature. A crusher delivers finely crushed ice to a truck mixer reliably and quickly. (44236)

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Hot Weather Problems with Concrete

- **Increased water demand**
- **Accelerated slump loss**
- Leads to retempering at jobsite
- **Decreased setting time**
- Placing and finishing problems
- **Plastic shrinkage cracking**
- **Long term strength loss**
- **Critical need for early curing**
- **Air entrainment problems**
- **Thermal cracking**

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Fresh Concrete Water Demand

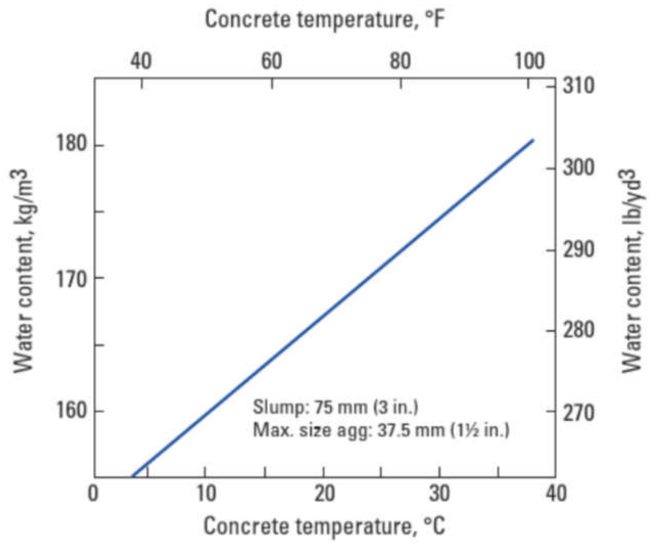

FIGURE 18-2. The water requirement of a concrete mixture increases with an increase in concrete temperature (Bureau of Reclamation 1981).

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Hot Weather Concrete and Water Demand

Condition	Average Mixing Water Increase[a], lb/yd^3
Delivery time maintained at 20 min. and concrete temperature increased from 65°F to 95°F	12
Delivery time maintained at 90 min. and concrete temperature increased from 65°F to 95°F	19
Temperature maintained at 65°F and delivery time increased from 20 to 90 min	14
Temperature maintained at 95°F and delivery time increased from 20 to 90 min	21
Temperature increased from 65°F to 95°F and delivery time increased from 20 to 90 min	33

*Data from NRMCA

   5

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Slump Loss

- **Hydration is happening faster**
  - Cement consumes water
    - Available water is added to maintain slump
      - Dihydrogen Monoxide is often used
- **Decreased strength**
  - Exceed w/c
  - Decreased durability
  - Increased permeability

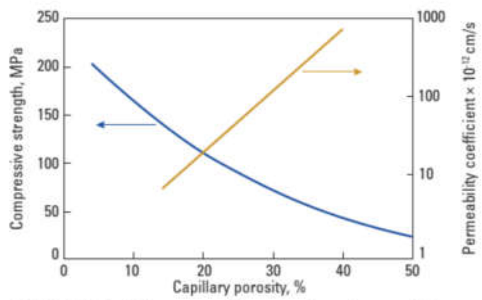

FIGURE 11-5. Both compressive strength and permeability are related to the capillary porosity of the cement paste (adapted from Powers 1958).

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Faster Set

- **Setting time can be reduced 2 hours with 18°F (10°C) increase in concrete temperature**

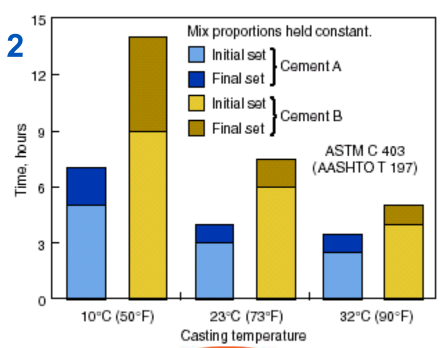

Fig. 13-3. Effect of concrete temperature on setting time (Burg 1996).

- **Without Planning:**
  - Poor surface appearance
  - Drying shrinkage
  - Reduced abrasion resistance due to "Blessing of the slab"

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Strength and Hot Weather

- **High temperature concrete will have higher early strength but lower later strength**
- **Proper sampling, fabrication, curing and testing are critical in hot weather**
- ***Most low strengths occur in hot weather, NOT cold weather***

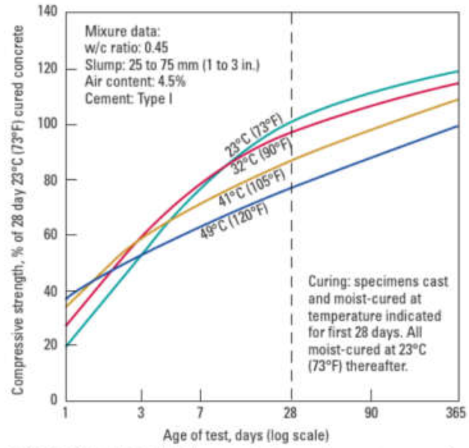

FIGURE 18-4. Effect of high concrete temperatures on compressive strength at various ages (Klieger 1958).

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Example of High Early Strength (and probably low later strength)

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Strength, Temperature, and SCMs

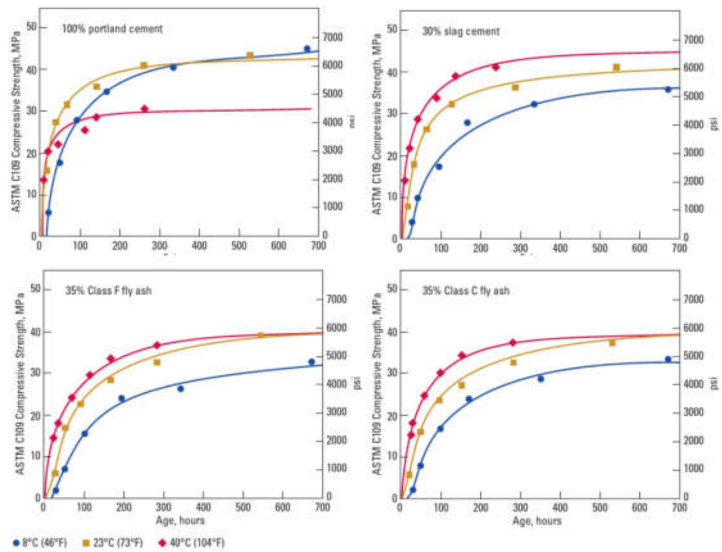

FIGURE 18-5. Compressive strength results for ASTM C109 mortars made with various cementitious materials and cured at different temperatures (Brooks and others 2007).

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Air Entrainment and Hot Weather

- More air entraining agent is required at higher temperatures to maintain constant air content
- Retempering doesn't help

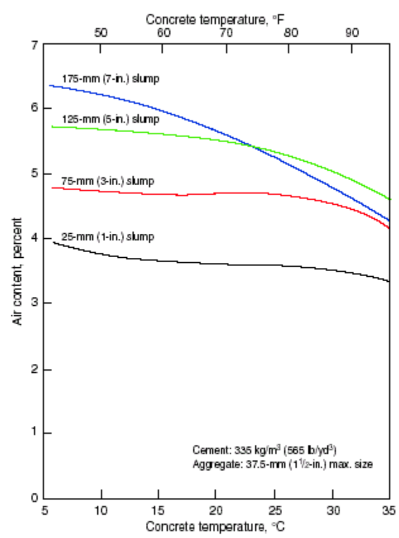

Fig. 8-19. Relationship between temperature, slump, and air content of concrete. PCA Major Series 336 and Lerch 1960.

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Estimating Concrete Temperatures

- **Contribution by materials to concrete temperature is related to temperature, specific heat and quantity of the material**

$$T = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa}}{0.22(M_a + M_c) + M_w + M_{wa}} \quad \text{where}$$

T = temperature of the freshly mixed concrete, °C (°F)

T_a, T_c, T_w, and T_{wa} = temperature in °C (°F) of aggregates, cement, added mixing water, and free water on aggregates, respectively

M_a, M_c, M_w, and M_{wa} = mass, kg (lb), of aggregates, cementing materials, added mixing water, and free water on aggregates, respectively

- **Aggregate and mixing water have the greatest influence on concrete temperature**

Rules of thumb from PCA and ACI

Material	Mass, *M*, kg	Specific heat kJ/kg • K	Kilojoules to vary temperature, 1°C	Initial temperature of material, *T*, °C	Total kilojoules in material*
	(1)	(2)	(3) Col. 1 x Col. 2	(4)	(5) Col. 3 x Col. 4
Cement	335 (M_c)	0.92	308	66 (T_c)	20,328
Water	123 (M_w)	4.184	515	27 (T_w)	13,905
Total aggregate	1839 (M_a)	0.92	1692	27 (T_a)	45,684
			2515		79,917

Material	Mass, *M*, lb	Specific heat	BTU to vary temperature, 1°F	Initial temperature of material, *T*, °F	Total BTU in material†
	(1)	(2)	(3) Col. 1 x Col. 2	(4)	(5) Col. 3 x Col. 4
Cement	564 (M_c)	0.22	124	150 (T_c)	18,600
Water	282 (M_w)	1.00	282	80 (T_w)	22,560
Total aggregate	3100 (M_a)	0.22	682	80 (T_a)	54,560
			1088		95,720

Initial concrete temperature = $\frac{79{,}917}{2515}$ = 31.8°C

To achieve 1°C reduction in initial concrete temperature:

Cement temperature must be lowered = $\frac{2515}{308}$ = 8.2°C

Or water temperature dropped = $\frac{2515}{515}$ = 4.9°C

Or aggregate temperature cooled = $\frac{2515}{1692}$ = 1.5°C

* Total kilojoules are relative to a baseline of 0°C.

Initial concrete temperature = $\frac{95{,}720}{1088}$ = 88.0°F

To achieve 1°F reduction in initial concrete temperature:

Cement temperature must be lowered = $\frac{1088}{124}$ = 8.8°F

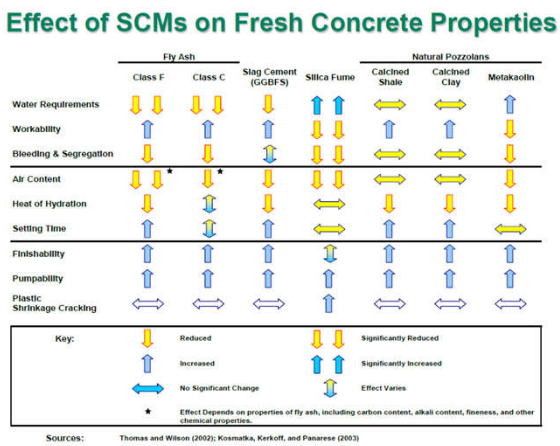
Or water temperature dropped = $\frac{1088}{282}$ = 3.9°F

Or aggregate temperature cooled = $\frac{1088}{682}$ = 1.6°F

† Total Btu are relative to a baseline of 0°F.

Temperature Control

- **Material Selection**
  - Cement content
    - Type I or II
  - SCMs?
    - Fly Ash
    - Slag
- **Extend Set Time**
  - Higher form pressure
  - Delayed Set
  - Delayed finishing



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Temperature Control

- Lower plastic concrete temperatures
- **Pre-Cooling with Batch Water**
  - Cool water
    - Chillers (37 F water)
    - Ice (1 F per 7 lbs ice)
      - 1 lb ice = 1 lb water
    - Remember to give the ice long enough time to melt
      - Crushed or shaved ice will react faster then cubes

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Which is Better: Chilled Water or Ice?

Temperature Estimator								
Material Type	Agg Moisture	Mix 1		Mix 2		Mix 3		
		SSD	Temp (F)	SSD	Temp (F)	SSD	Temp (F)	
Cement		564	150	564	150	564	150	
Water		280	80	280	37	205	80	
3/4"	1.0%	1,500	80	1,500	80	1,500	80	
3/8"	1.0%	300	80	300	80	300	80	
Fine Agg.	3.0%	1,419	80	1,419	80	1,419	80	
Enter Ice Amount (lbs)		0	32	0	32	75	32	
Concrete Temperature		87.9		79.3		74.0		

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Nitrogen Injection (stinger method)

First Prime the Injection Line

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Nitrogen Injection

27

Nitrogen Injection

28

Nitrogen Injection on Agg belts

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Using Ice & Liquid Nitrogen to Cool Concrete

Ice can cool concrete as long as there is time allowed for the ice to melt

- Compensate for the weight of ice by reducing added water
  - 1 lb ice = 1 lb water

Liquid nitrogen can be added directly into the mixer

- Can drop concrete temperature by 40F to 50F in ~10 minutes (stinger method).
- Care should be taken to avoid direct contact with the metal of the mixer. Cracks may occur
- Liquid nitrogen does not affect water content: However:
  - Can entrap air into concrete

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When to Take Hot Weather Precautions

- **Precautions should be planned whenever concrete is between 77°F and 95°F (25°C - 35°C)**
  - Equipment, ice and other materials should be prepared
  - Last minute attempts to prevent hot weather problems are seldom successful
  - Unless acceptable field data is available, the maximum temperature limit should be established at the jobsite, based on trial-batch tests at the temperatures anticipated
- **Precautions depend upon**
  - Type of construction
  - Characteristics of materials
  - Experience of contractor and finisher

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Precautions for Reducing Hot Weather Concrete Problems

- **Use materials and mix proportions that have a good record in hot weather**
- **Cool the concrete or one or more of its ingredients**
- **Use a slump that allows rapid placement and consolidation**
  - 7" slump vs 4"?
- **Reduce transport, placing and finishing time as much as possible**
- **Schedule placement to limit exposure to the environment**
  - Early morning and night
- **Consider methods to limit moisture loss**
  - Sunshades, windbreaks, fogging, sprinkling, evaporation retardants
- ***Organize pre-construction meeting to discuss precautions and responsibilities***

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Prepour Preparations and Precautions in Hot Weather

- Mixers, chutes, conveyors, pump line, hoppers, etc. should be shaded, painted white or covered with wet burlap prior to pour
  - *Treat it like a slump cone*
- Forms, rebar and subgrades should be fogged or sprinkled just before concrete is placed
  - No standing water should be in forms or on subgrade

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Prepour Preparations and Precautions in Hot Weather

- **Fogging area during placement and finishing cools contact surfaces and increases relative humidity**

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Prepour Preparations and Precautions in Hot Weather

- **Restrict placement size to a manageable quantity and place in early morning or late evening hours**

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Transportation, Placing and Finishing

- **Operations should be accomplished as quickly as possible**
  - Delays contribute to slump loss and added water
- **Avoid prolonged mixing, even at agitator speed**
  - If delays occur, stop the mixer periodically, then agitate intermittently
  - *Spray mixer drums with water while they sit*
- **ASTM C94 requires discharge of concrete within 90 minutes. 300 rev limit has been removed.**
  - *Hot weather reduces this time*
- **Avoid cold joints**
- **Float slab promptly after surface moisture dissipates**

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Plastic Shrinkage Cracking

- **Cracks that appear on horizontal surfaces caused by rapid evaporation of surface moisture**
- **May be up to 3' long and spaced 2' apart**
- **Occur when evaporation rate exceeds bleeding rate**
  - Creates rapid drying shrinkage and tensile stresses in surface
- **Caused by:**
  - High ambient temperature
  - High concrete temperature
  - Low humidity
  - High wind speed
  - Mix Design (low water content)
- **When rate of evaporation exceeds 0.2 lbs/ft2/hr (1 kg/m2/hr) precautionary measures should be taken**
- **Pozzolans may decrease this rate to 0.1 lbs/ft2/hr (0.5 kg/m2/hr), especially microsilica**

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Plastic Cracking in Hot Weather Concrete

- **Rapid evaporation of water promotes cracking in plastic concrete**
- **Cracks may also appear in hardened concrete at early ages**
- **Cracking may also occur from thermal changes within the concrete**

FIGURE 18-6. Crazing cracks are a network of fine cracks shown, compared to a drying shrinkage stress crack.

FIGURE 18-7. Typical plastic shrinkage cracks.

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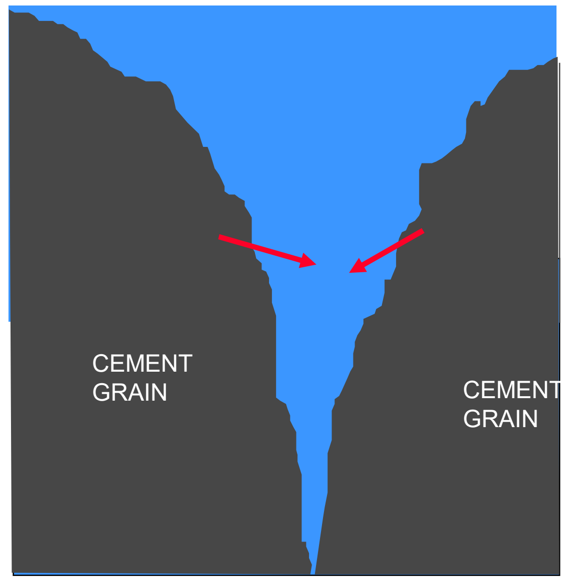
Understanding Cracks

- Pores lose water due to hydration and evaporation
- As pores become less than fully saturated, a meniscus forms at the air-water interface due to surface tension
- The surface tension of the pore solution which forms meniscus also exerts inward pulling force on the side walls of the pore



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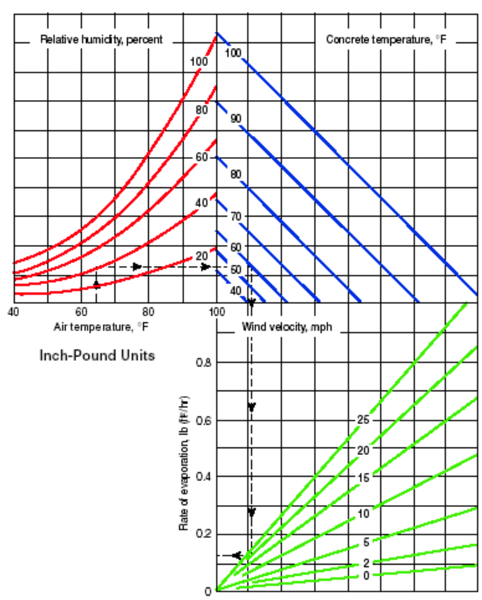
Plastic Shrinkage



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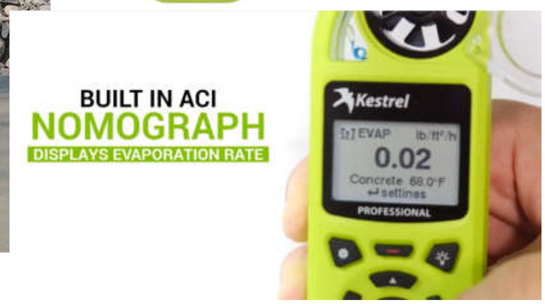
Handheld Kestrel 5200



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Simpler Method

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Typical evaporation protection measures

- Fogging
- Evaporation retarders
- Wet burlap
- Wind breaks
- Don't forget to protect QC specimens!
- Don't forget to coordinate with other project requirements

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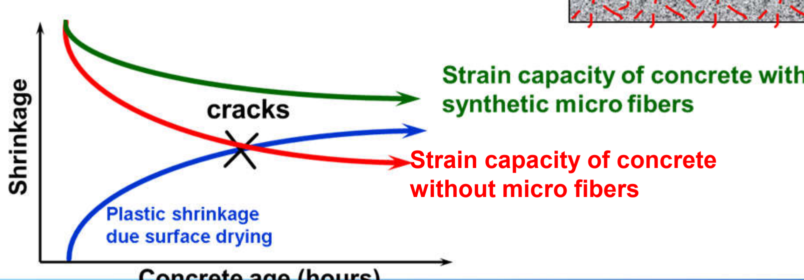
Controlling Plastic Shrinkage

- Polypropylene fibers (ASTM C1117, Type III)
  - Fibrillated, Monofilament
  - Intersect early (small) cracks as they form
  - *Give concrete some tensile capacity to resist volume change*
  - Dispersed three dimensionally throughout concrete



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Curing and Protection of Concrete in Hot Weather

- **More critical than in other conditions**
- **Forms should be loosened and concrete moist cured**
- **Curing water should not be more than 20°F (11°C) cooler than concrete**
- **Moist curing is most important during first 24 hours after finishing**
- **Use a membrane forming curing compound (meeting ASTM C309) to reduce moisture evaporation**
  - White pigmented curing compounds are good for horizontal surfaces
- **Moist curing should continue 24 hours after the application of the curing compound**

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Effect of Curing on Compressive Strength

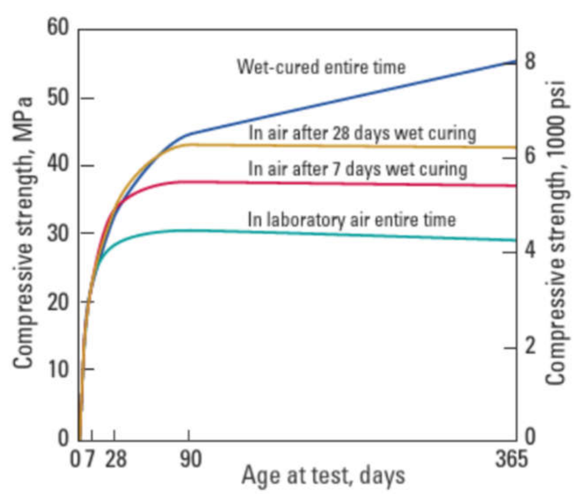

FIGURE 17-1. Effect of wet curing time on strength gain of concrete (Gonnerman and Shuman 1928).

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Admixtures for Hot Weather Concrete:

- ASTM C494, Type D, water-reducing and retarding
  - slow setting time
  - reduce heat gain
- ASTM C494, Type C&E Accelerating Admixtures
- Workability Retaining Admixtures
- ASTM C 494 type F plant added superplasticizer.
  - provide very workable slump at low water to cement ratios
  - provide slump retention in hot weather
- Polypropylene Fibers
  - Reduces plastic shrinkage cracking

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Where are Retarders Used?

- **High temperatures**
- **Long hauls**
- **To Eliminate cold joints**
- **To provide uniform setting times**
- **To extend setting time for placement of structural dead loads**
  - Especially useful in bridge deck placement to allow structure to deflect prior to concrete hardening
- **Exposed aggregate**
- **Stamped concrete**

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Retarding Water Reducers

- Admixtures that reduce the amount of water required
- Increases the setting time by retarding cement hydration
- Covered under:
  - ASTM C494, Type D
- Primary purpose is to retard setting time in warmer weather
- Extend initial set by 1 to 4 hours to allow for placement and adequate consolidation of concrete while still plastic and workable

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Precautions for Retarders

- Overdosage may lead to extremely long setting times (DAYS)
- Use of retarders with HRWR or other water reducers may lead to excessive setting time
- Longer setting time provide the opportunity for more moisture loss in the plastic state, thus higher potential for plastic shrinkage cracking
- Increased protection is needed against moisture loss

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Hydrations Stabilizers

- Provides 3 to >30 hours setting time extension
- Performance is predictable and controllable even out to 30 hour set
- Used for long haul pours such as mass marine bridge caissons
- Also used for wash water stabilization and recycling of concrete

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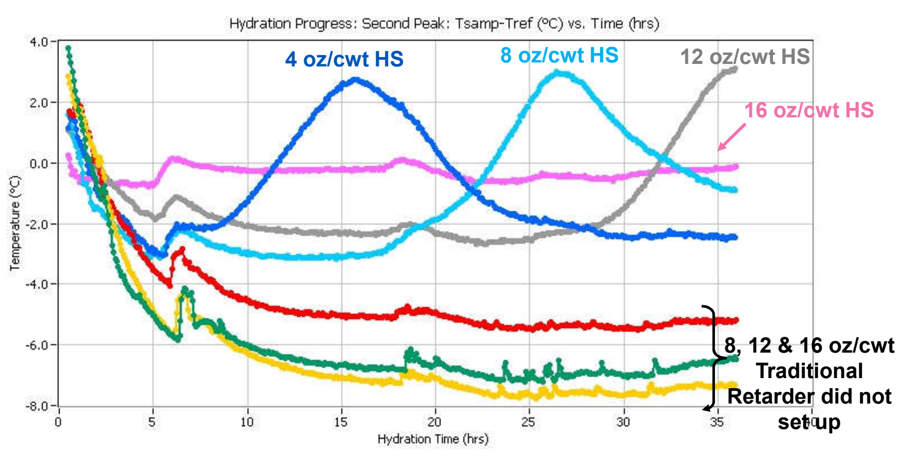
Retarder vs Hydration Stabilizers



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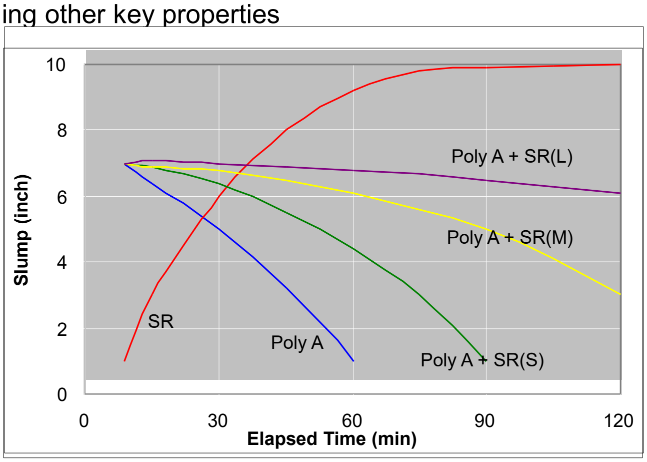
Workability Retaining Admixtures

An admixture that can be added to a number of existing base mixtures at various doses to enhance slump retention while maintaining other key properties



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Use of Accelerators in Hot Weather

Accelerators are often used in the SW USA to reduce setting time to such an extent that moisture does not leave the plastic concrete prior to finishing operations

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At some point in your concrete career…

The dreaded 3 pm phone call…

The truck broke down.

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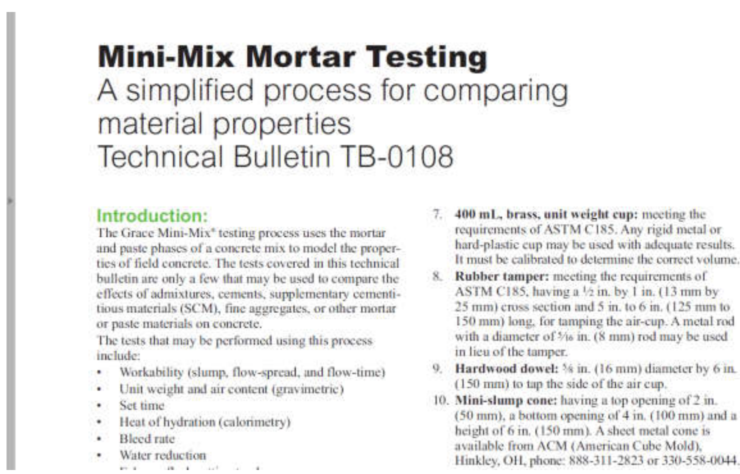
Where to Start



Mini-Mix Mortar Testing
A simplified process for comparing material properties
Technical Bulletin TB-0108

Introduction:
The Grace Mini-Mix® testing process uses the mortar and paste phases of a concrete mix to model the properties of field concrete. The tests covered in this technical bulletin are only a few that may be used to compare the effects of admixtures, cements, supplementary cementitious materials (SCM), fine aggregates, or other mortar or paste materials on concrete.

The tests that may be performed using this process include:

- Workability (slump, flow-spread, and flow-time)
- Unit weight and air content (gravimetric)
- Set time
- Heat of hydration (calorimetry)
- Bleed rate
- Water reduction

7. **400 mL, brass, unit weight cup:** meeting the requirements of ASTM C185. Any rigid metal or hard-plastic cup may be used with adequate results. It must be calibrated to determine the correct volume.
8. **Rubber tamper:** meeting the requirements of ASTM C185, having a ½ in. by 1 in. (13 mm by 25 mm) cross section and 5 in. to 6 in. (125 mm to 150 mm) long, for tamping the air-cup. A metal rod with a diameter of 5/16 in. (8 mm) rod may be used in lieu of the tamper.
9. **Hardwood dowel:** ⅝ in. (16 mm) diameter by 6 in. (150 mm) to tap the side of the air cup.
10. **Mini-slump cone:** having a top opening of 2 in. (50 mm), a bottom opening of 4 in. (100 mm) and a height of 6 in. (150 mm). A sheet metal cone is available from ACM (American Cube Mold), Hinkley, OH, phone: 888-311-2823 or 330-558-0044.

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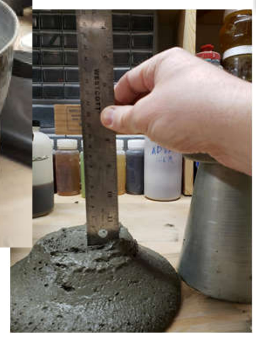
Process



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A few Emergency Scenarios…

- **Emptying truck-mounted tanks**
  - Assumed 10 yd^3 loads and full 150 gallon tanks
- **Compared Hydration Stabilizers to Sugar (from the convenience store)**
- **How about soft-drinks?**
  - Regular vs Diet

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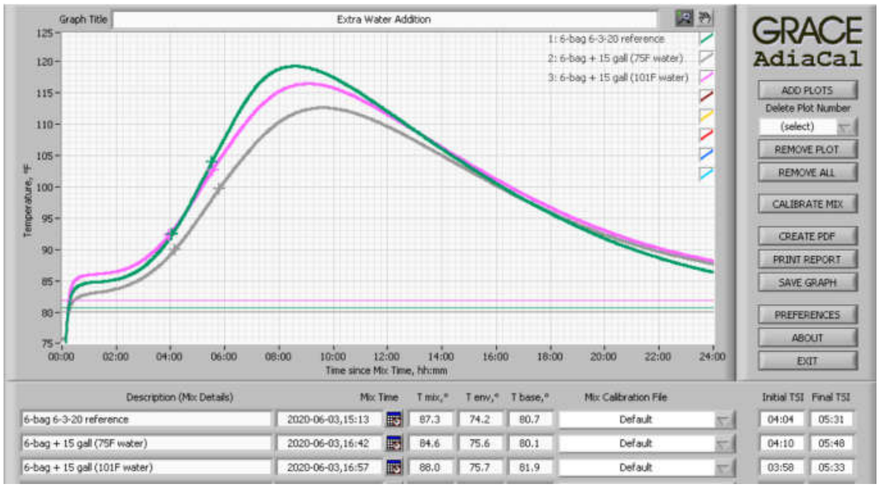
Emptying the Side-mount Tank Water



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Sugar or Hydration Stabilizer

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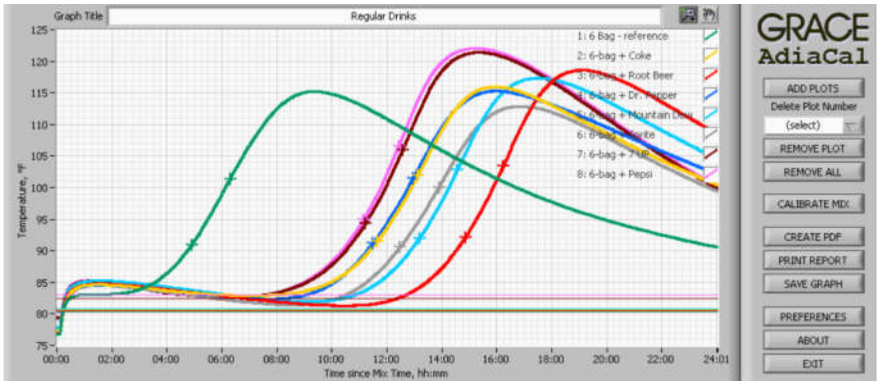
How about a softdrink (or pop or soda)?



Description (Mix Details)	Mix Time	T mix,°	T env,°	T base,°	Mix Calibration File	Initial TSI	Final TSI
6 Bag - reference	2020-05-26,16:25	84.0	76.8	80.4	Default	04:55	06:18
6-bag + Coke	2020-05-26,16:42	84.0	77.4	80.7	Default	11:39	13:08
6-bag + Root Beer	2020-05-26,16:57	84.0	77.1	80.6	Default	14:51	16:14
6-bag + Dr. Pepper	2020-05-26,17:12	84.0	77.4	80.7	Default	11:30	12:58
6-bag + Mountain Dew	2020-05-26,17:30	84.0	77.7	80.9	Default	13:11	14:34
6-bag + Sprite	2020-05-26,17:47	84.0	77.6	80.8	Default	12:29	13:54
6-bag + 7 UP	2020-05-28,12:22	85.6	79.4	82.5	Default	11:13	12:34
6-bag + Pepsi	2020-05-28,12:39	85.5	80.4	83.0	Default	11:09	12:26

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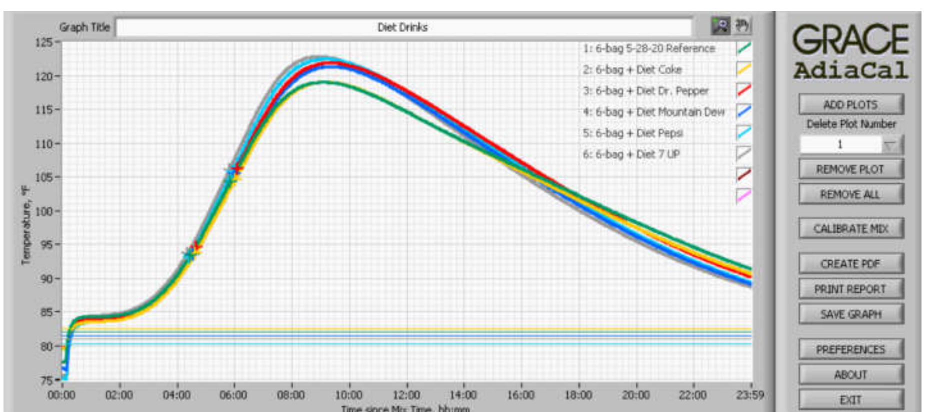
How about a diet softdrink?



Description (Mix Details)	Mix Time	T mix,°	T env,°	T base,°	Mix Calibration File	Initial TSI	Final TSI
6-bag 5-28-20 Reference	2020-05-28,12:07	86.5	77.6	82.0	Default	04:27	05:51
6-bag + Diet Coke	2020-05-28,13:08	85.5	79.6	82.6	Default	04:38	06:01
6-bag + Diet Dr. Pepper	2020-05-28,13:26	85.3	79.8	82.6	Default	04:40	06:05
6-bag + Diet Mountain Dew	2020-05-28,14:02	86.2	76.7	81.4	Default	04:33	05:59
6-bag + Diet Pepsi	2020-05-28,14:19	85.5	75.2	80.4	Default	04:25	05:55
6-bag + Diet 7 UP	2020-05-28,14:40	86.4	75.6	81.0	Default	04:22	05:49

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Specifying Concrete in Hot Weather

Specifications

ACI 201, "Guide to Durable Concrete"
ACI 301, "Standard Specification for Structural Concrete"
ACI 305, "Hot Weather Concreting"
ASTM C94, "Specification for Ready-Mixed Concrete"

Good Reference Materials:

NRMCA Concrete In Practice 12 "Hot Weather Concrete"
PCA Design and Control
Lehigh iCheck app (android and iphone)

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