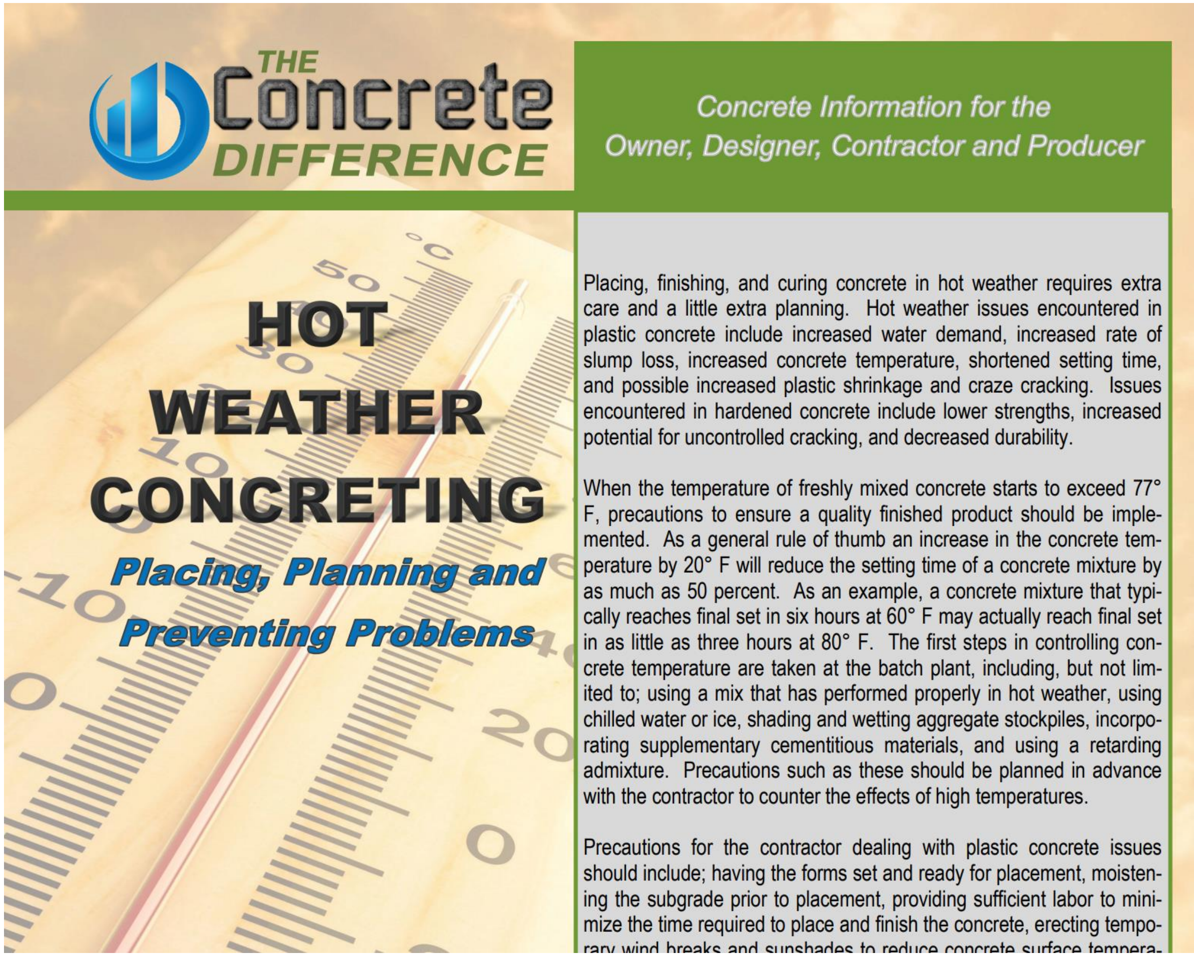
Concrete Placement in Hot Weather
Planning, Placing, and Preventing Problems!

Susan Armstrong – Central Builders Supply
Mark Moyer – New Enterprise Stone & Lime Co.
Rob Howard – Geo-Technology Associates, Inc.
Pat Gallagher – Admixtures, Inc.
Jim Casilio, P.E. – PA Aggregates & Concrete Assoc.

For the producer, the contractor, and the specifier

- Effect of Temperature on Concrete Strength
- Hot Weather Preparation for the Producer
  - What you can at the plant
  - What can you do with the mix design
- Preparation and best practices at the jobsite
- Problems
  - Cracking
  - Low strength
  - Not durable finishes
- Field Testing issues in Hot Weather

PACA's Concrete Difference



THE Concrete DIFFERENCE

Concrete Information for the Owner, Designer, Contractor and Producer

HOT WEATHER CONCRETING

Placing, Planning and Preventing Problems

Placing, finishing, and curing concrete in hot weather requires extra care and a little extra planning. Hot weather issues encountered in plastic concrete include increased water demand, increased rate of slump loss, increased concrete temperature, shortened setting time, and possible increased plastic shrinkage and craze cracking. Issues encountered in hardened concrete include lower strengths, increased potential for uncontrolled cracking, and decreased durability.

When the temperature of freshly mixed concrete starts to exceed 77° F, precautions to ensure a quality finished product should be implemented. As a general rule of thumb an increase in the concrete temperature by 20° F will reduce the setting time of a concrete mixture by as much as 50 percent. As an example, a concrete mixture that typically reaches final set in six hours at 60° F may actually reach final set in as little as three hours at 80° F. The first steps in controlling concrete temperature are taken at the batch plant, including, but not limited to; using a mix that has performed properly in hot weather, using chilled water or ice, shading and wetting aggregate stockpiles, incorporating supplementary cementitious materials, and using a retarding admixture. Precautions such as these should be planned in advance with the contractor to counter the effects of high temperatures.

Precautions for the contractor dealing with plastic concrete issues should include; having the forms set and ready for placement, moistening the subgrade prior to placement, providing sufficient labor to minimize the time required to place and finish the concrete, erecting temporary wind breaks and sunshades to reduce concrete surface tempera-

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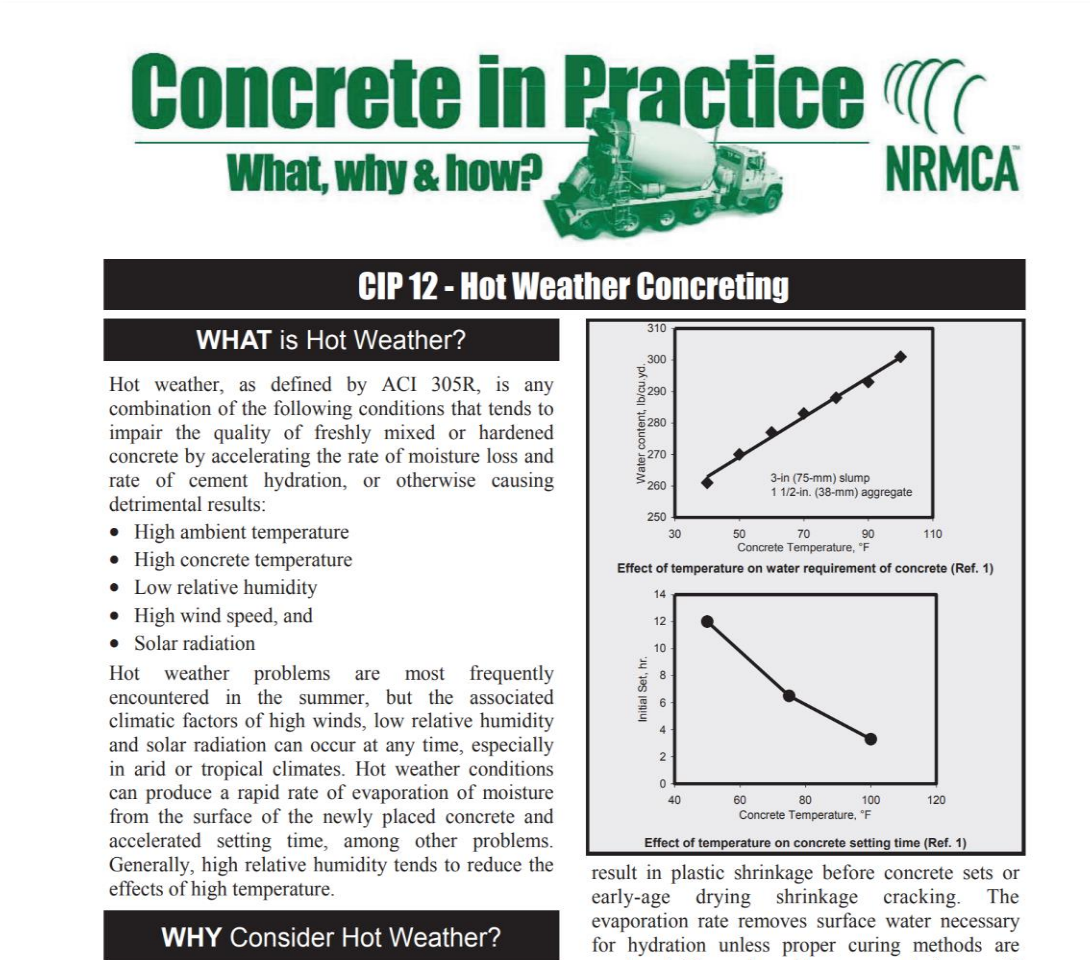
NRMCA's Concrete in Practice #12



Concrete in Practice

What, why & how?

NRMCA

CIP 12 - Hot Weather Concreting

WHAT is Hot Weather?

Hot weather, as defined by ACI 305R, is any combination of the following conditions that tends to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration, or otherwise causing detrimental results:

- High ambient temperature
- High concrete temperature
- Low relative humidity
- High wind speed, and
- Solar radiation

Hot weather problems are most frequently encountered in the summer, but the associated climatic factors of high winds, low relative humidity and solar radiation can occur at any time, especially in arid or tropical climates. Hot weather conditions can produce a rapid rate of evaporation of moisture from the surface of the newly placed concrete and accelerated setting time, among other problems. Generally, high relative humidity tends to reduce the effects of high temperature.

WHY Consider Hot Weather?

Effect of temperature on water requirement of concrete (Ref. 1)

Effect of temperature on concrete setting time (Ref. 1)

result in plastic shrinkage before concrete sets or early-age drying shrinkage cracking. The evaporation rate removes surface water necessary for hydration unless proper curing methods are employed. Thermal cracking may result from rapid

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Hot Weather References

In the handout section of your Goto Webinar Control Panel

Hot Weather Concreting

Guidance Documents

ACI 305R-10

Guide to Hot Weather Concreting

Reported by ACI Committee 305

James N. Cornell II, Chair — G. Terry Harris, Sr., Secretary

James M. Aldred, Godwin Q. Amekuedi, Philip Brandt, D. Gene Daniel, Kirk K. Deadrick, Darrell F. Elliot, Michael Faubel, Richard D. Gaynor, Antonio J. Guerra, Kenneth C. Hover, Frank A. Kozeliski, Darmawan Ludirdja, David R. Nau, Dan Ravina, Robert J. Ryan, Bruce G. Smith, Edward G. Sparks, Boris Y. Stein, Louis R. Valenzuela

Environmental factors, such as high ambient temperature, low humidity, high wind, or both low humidity and high wind, affect concrete properties and the construction operations of mixing, transporting, and placing of the concrete materials. This guide provides measures that can be taken to minimize the undesirable effects of these environmental factors and reduce the potential for serious problems.

This guide defines hot weather, discusses potential problems, and presents practices intended to minimize them. These practices include selecting materials and proportions, precooling ingredients, and batching. Other topics discussed include length of haul, consideration of concrete temperature as placed, facilities for handling concrete at the site, and, during the early curing period, placing and curing techniques, and appropriate testing and inspection procedures in hot weather conditions.

The materials, processes, quality control measures, and inspections described in this document should be tested, monitored, or performed as applicable only by individuals holding the appropriate ACI certifications or equivalent.

Keywords: air entrainment; cooling; curing; evaporation; high temperature; hot weather construction; plastic shrinkage; production methods; retempering; slump tests; water content.

ACI Committee Reports, Guides, Manuals, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

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ACI 305R-10 supersedes ACI 305R-99 and was adopted and published October 2010.

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ACI 305.1-14

Specification for Hot Weather Concreting

An ACI Standard

Reported by ACI Committee 305

G. Terry Harris Sr., Chair — Oscar R. Antommattei, Secretary

James M. Aldred, Godwin Q. Amekuedi, Philip Brandt, James N. Cornell II, D. Gene Daniel, Kirk K. Deadrick, Darrell F. Elliot, Michael Faubel, Antonio J. Guerra, Kenneth C. Hover, Frank A. Kozeliski, Darmawan Ludirdja, David R. Nau, Jonathan L. Poole, Robert J. Ryan, Bruce G. Smith, Boris Y. Stein, Diep T. Tu

Consulting Members: Richard D. Gaynor, William C. Moore, George V. Teodoru

This reference specification provides requirements for hot weather concreting that the architect/engineer can apply to any construction project involving hot weather concreting by citing it in the project specification. Checklists are provided to assist the architect/engineer in supplementing the provisions of this reference specification as needed by designating or specifying customized project requirements.

This specification includes hot weather requirements for production preparations, delivery, placement, finishing, bleed-water evaporation, curing, and concrete protection. Provisions governing a preplacement conference, concrete mixture proportions, maximum allowable concrete temperature, rate of surface evaporation measurements, evaporation control measures, and acceptance of a concrete mixture from past field experience or preconstruction testing are also included.

The materials, processes, quality control measures, and inspections described in this document should be tested, monitored, or performed as applicable only by individuals holding the appropriate ACI Certifications or equivalent.

Keywords: bleeding; curing; evaporation; finishing; mixture proportioning; plastic shrinkage cracking; protection period; trial batch

CONTENTS

(mandatory portion follows)

PACA

www.pacaweb.org

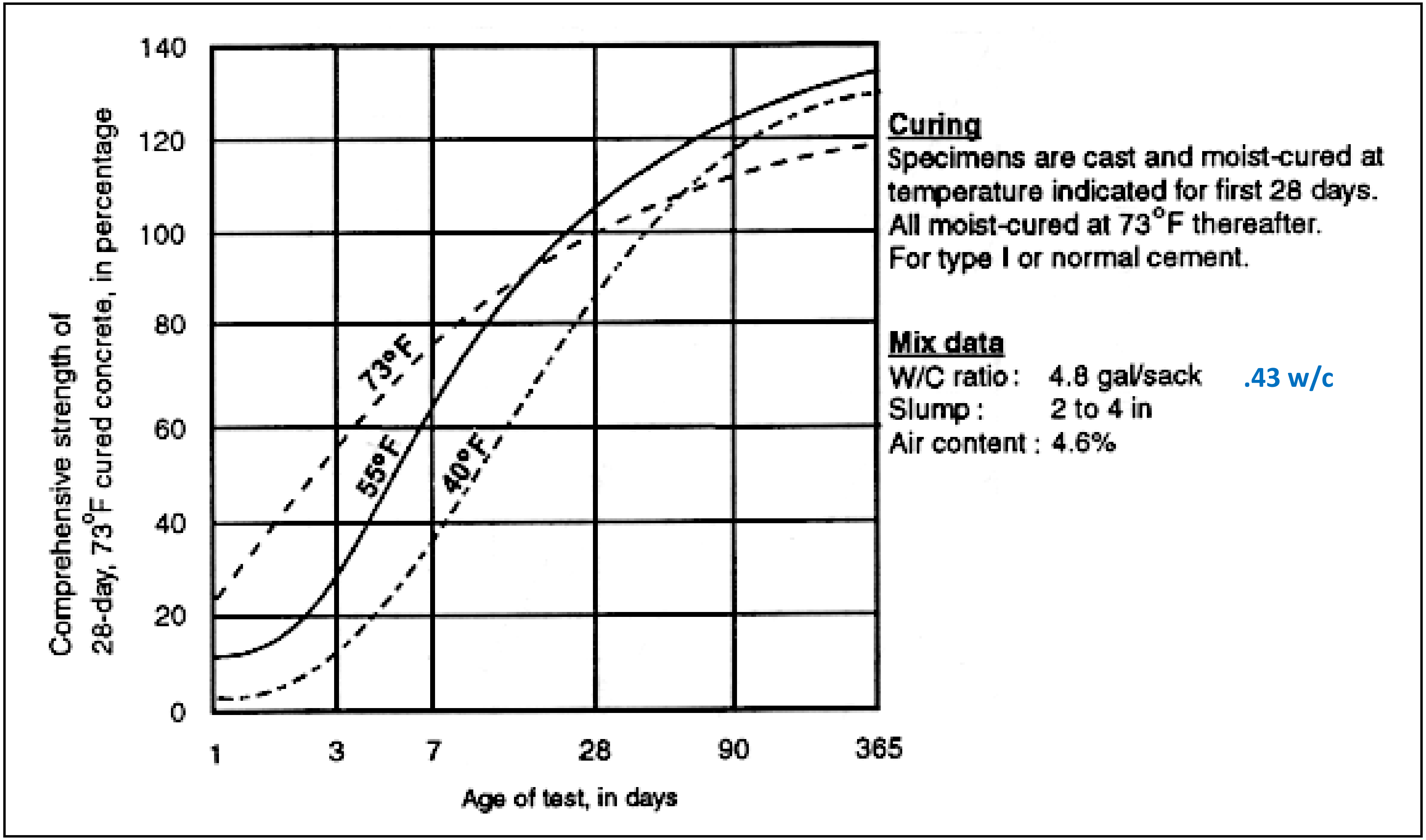
www.specifyconcrete.org

Hot Weather Concreting (ACI 305R-10 - Definition)

"any combination of the following conditions that tends to impair the quality of fresh concrete or hardened concrete by accelerating the rate of moisture loss and rate of cement hydration.

- *High ambient temperature*
- *High concrete temperature*
- *Low relative humidity*
- *Wind speed*
- *Solar radiation"*

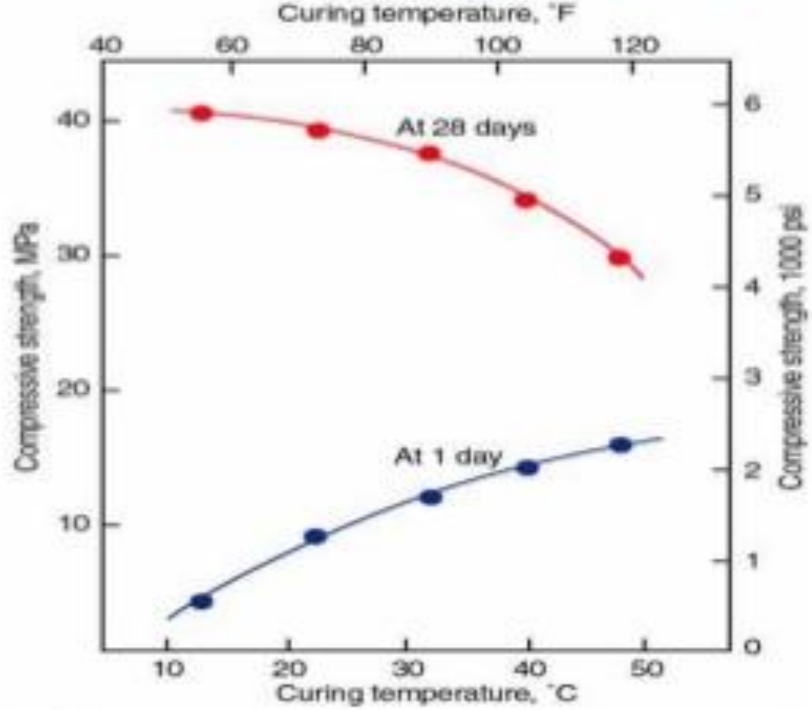
Effect of Temperature



The effect of Temperature

Strength vs. Curing Temperature

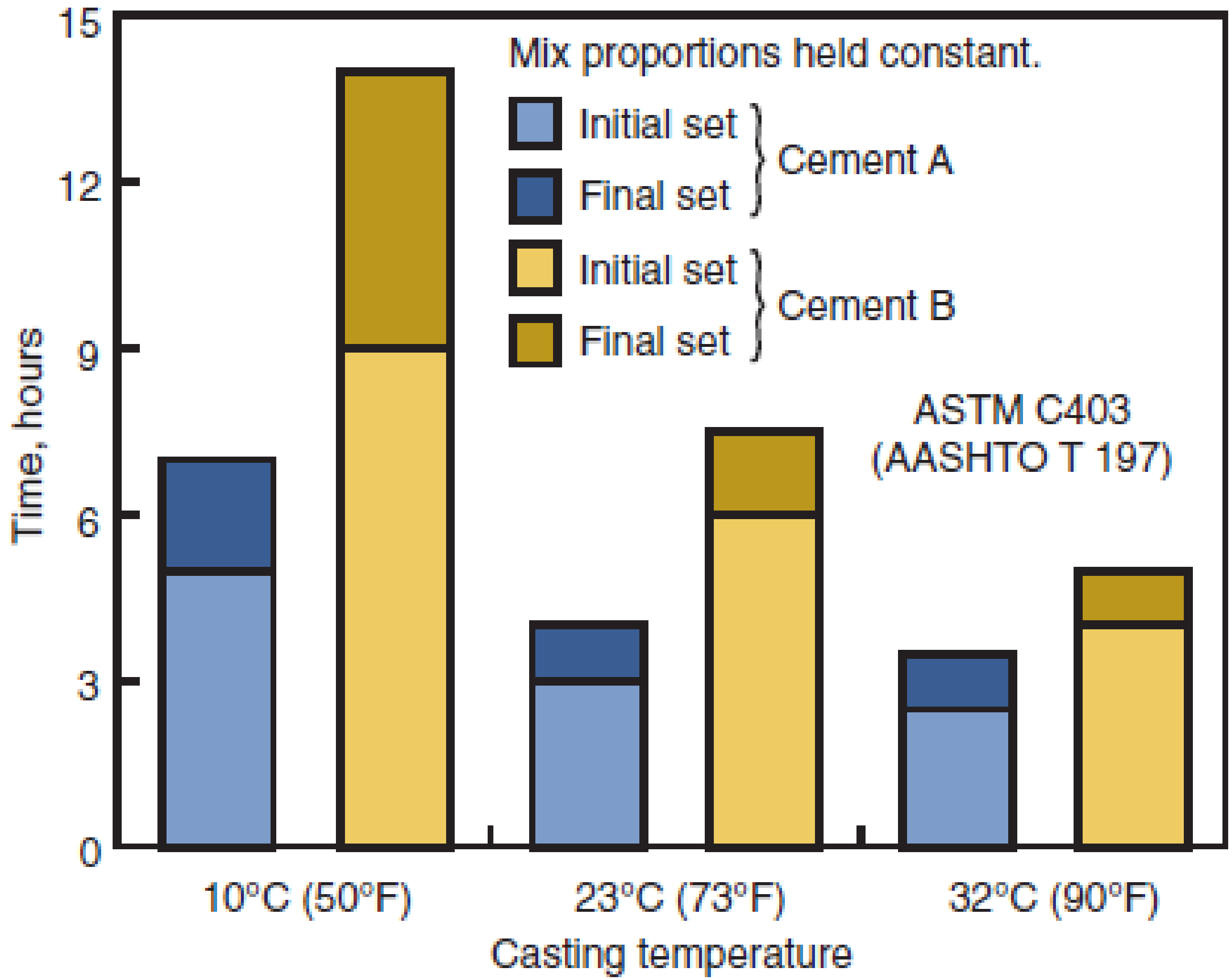
One-day strength increases with increasing curing temperature, but 28-day strength decreases with increasing curing temperature .



The relationship between curing temperature and compressive strength for 1 day and 28 days curing time.

1

Effects of High Temperature



Burg 1996
Courtesy of PCA

Hot Weather Concreting

(ACI 305R-10)

What can be done with the mix design?

- Make sure that your concrete supplier knows that there is a very good possibility of placement(s) during the "Heat of Summer", so he can have the logistics figured out, not every supplier has a "mini-ice factory on site". Also, the specifying engineer may want to review any changes to the design prior to placement, be proactive vs. reactive.

Hot Weather Concreting
(ACI 305R-10)

- In terms of the mix design adjustments.
  - You may increase the coarse aggregate volume up to 10% with adjusting the W/C down, this can help overcome some shrinkage potentials. NEVER ADD MORE WATER, this only exasperates the issue.
  - Use of Slump retention admixture (does not affect hydration or set time whatsoever) my personal favorite
  - Use of Retarders (only affects 2 phases of hydration)

Hot Weather Concreting (ACI 305R-10)

- In terms of the mix design adjustments.
  - Use of Hydration Stabilizers (affects all 5 phases of hydration)
  - Use of micro-fibers (will discuss in “Cracking section”)
  - These are the only things that can be done “on paper”, everything else is of the physical nature to the constituents (raw materials).

Hot Weather Concreting

(ACI 305R-10)

Other items that can be adjusted via mix design:

- Cement
  - Type 2 or Type 4* are typically a lower rate of heat of hydration.
  - Control of temperature of raw cement delivered to plant
- Use of SCM's (Fly Ash, GGBFS or Silica Fume) as a replacement to reduce heat of hydration
- Cool the plastic concrete through the use of ice or liquid nitrogen** (via the mix or aggregates)

- *Good Luck finding this one!
- **BE VERY CAREFUL with this one, very dangerous and special permitting is sometimes required.

Hot Weather Concreting
(ACI 305R-10)

Production Concerns:

- Use materials and mix proportions that have a good record in hot weather conditions
- Reducing Concrete Temperature
- Concrete Consistency
- Transporting, Placing, and Finishing

Hot Weather Concreting

(ACI 305R-10)

Production Concerns:

- Minimize Moisture Loss of Concrete
- Scheduling Concrete Placements
- Consider the methods to limit moisture loss during placing and finishing such as sunshades, wind screens, fogging, and spraying.

Hot Weather Concreting

(ACI 305R-10)

- To achieve a 1 F decrease in concrete temperature, cool one or more of its ingredients:

  - 8 F reduction in Cement Temperature
  - 4 F reduction in Water Temperature
  - **2 F Reduction in Aggregate Temperature**

Hot Weather Concreting

Estimating Concrete Temperature

- $T = \frac{[0.22(T_sW_s + T_aW_a + T_cW_c) + T_wW_w + T_wW_{wa} - 112W_i]}{[0.22(W_s + W_a + W_c) + W_w + W_i + W_{wa}]}$
- T = final temperature of concrete mixture (deg F)
  Tc = temperature of cement (deg F)
  Ts = temperature of fine aggregate (deg F)
  Ta = temperature of coarse aggregate (deg F)
  Tw = temperature of added mixing water (deg F)
  Wc = weight of cement (lb)
  Ws = weight of fine aggregate (lb)
  Wa = weight of coarse aggregate (lb)
  Wwa = mass of free and absorbed moisture in aggregate
  Ww = weight of mixing water (lb)
  Wi = weight of ice (lb)
- Note: The equation was modified. Temperatures and amount of free moisture on the aggregates were not used. The coarse and fine aggregates are entered separately.

Hot Weather Concreting

(ACI 305R-10)

Production Concerns:

- Use a concrete consistency that allows rapid placement and consolidation.
- Mixer Control
- Reduce the time of transporting, placing, and finishing as possible.

Hot Weather Concreting

(ACI 305R-10)

Production Concerns:

- Slump Control
  - Hold Water
  - Set Retarding Admixture
  - Slump Retention Admixture

Hot Weather Concreting

(ACI 305R-10)

Jobsite Considerations: Planning

- Prepare for Ambient Conditions - Monitor weather to increase awareness of potential issues at/during placement
- Schedule concrete placements to avoid extreme weather, such as at night or during favorable weather conditions.
- Assure equipment and placement crew size is adequate for the job

Hot Weather Concreting

(ACI 305R-10)

Jobsite Considerations: Planning

- Consolidation Equipment
- Have all curing materials staged and ready for immediate use after the concrete has been placed and finished
- Plan for any incidental work that will need to be performed (application of a surface retarder if necessary, joint cutting, etc.)

Hot Weather Concreting

(ACI 305R-10)

Preparation

- Forms, reinforcing steel, and subgrade should be fogged or sprinkled with cool water just before concrete is placed

- Expedite all elements of the placement (includes delivery and placement)

Hot Weather Concreting

(ACI 305R-10)

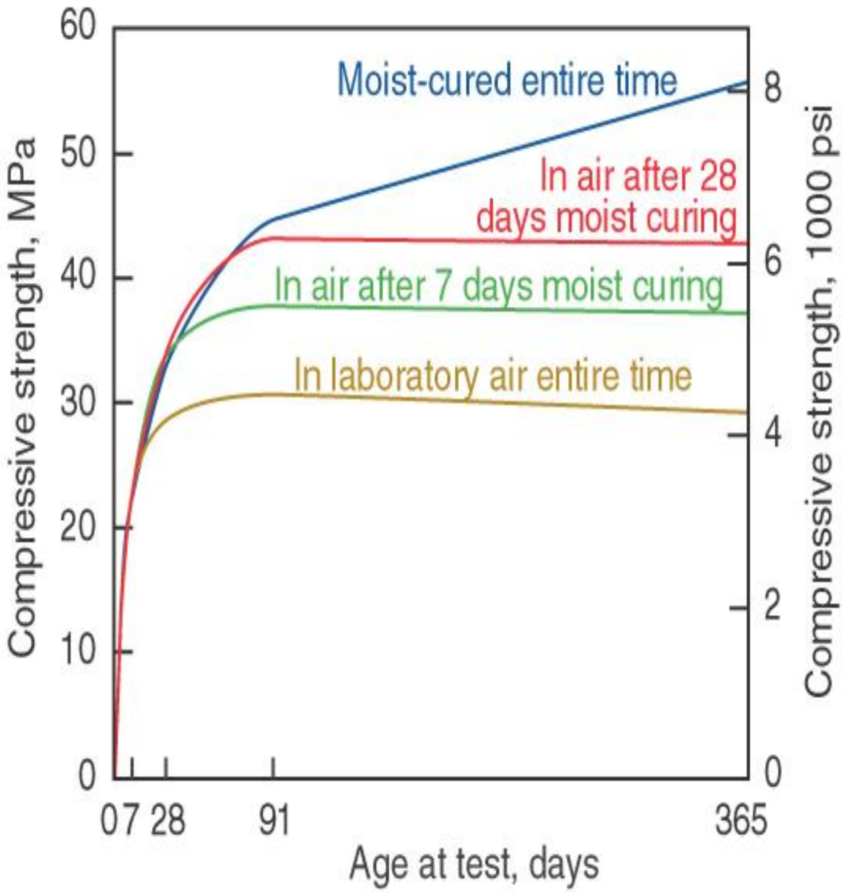
- Placement and Finishing
- Formed Concrete - Shallower layers
- Flatwork –
  - Moist subgrade
  - Keep operations confined to a small area
  - Fog nozzle to cool the air, forms and steel immediately ahead of placement

Hot Weather Concreting

(ACI 305R-10)

<u>Curing is Critical</u>

- The need for moist curing of concrete slabs is greatest during the first few hours after finishing
- To prevent the drying of exposed concrete surfaces, moist curing should commence as soon as the surfaces are finished and continued for at least 7 days



Wet Curing - The old way is the best way

Hot Weather Concreting

(ACI 305R-10)

Membrane Curing

- Most practical method if moist curing is not an option
- Use a white pigmented (reflective) compound where concrete will be exposed to the sun
- Be sure to coat all exposed areas (edges are critical)

Membrane (spray on)Curing

Hot Weather Concreting

(ACI 305R-10)

Protecting Concrete in Formwork

- Forms should be covered and kept continuously moist during the early curing period
- Form Removal – repair and cure

Hot Weather Concreting

(ACI 305R-10)

Effects

- Drying shrinkage cracking/volume changes
  - Caused by the concrete losing its moisture rapidly
  - Shrinkage, when combined with restraint and concrete's inherent low tensile strength, will cause cracking
  - Aggregate content reduces the relative volume of cement paste and provides an internal restraint that reduces the magnitude of volume changes in the concrete (mix design portion)
  - Other contributing factors may include:
    - Relative Humidity
    - Paste content and/or w/c of the mix
    - Size and shape of the member – Shrinkage is greatest at the surface and there may be moisture gradients created, depending on the ratio of the surface area to the volume of the member

Picture of Dry Shrinkage Cracks

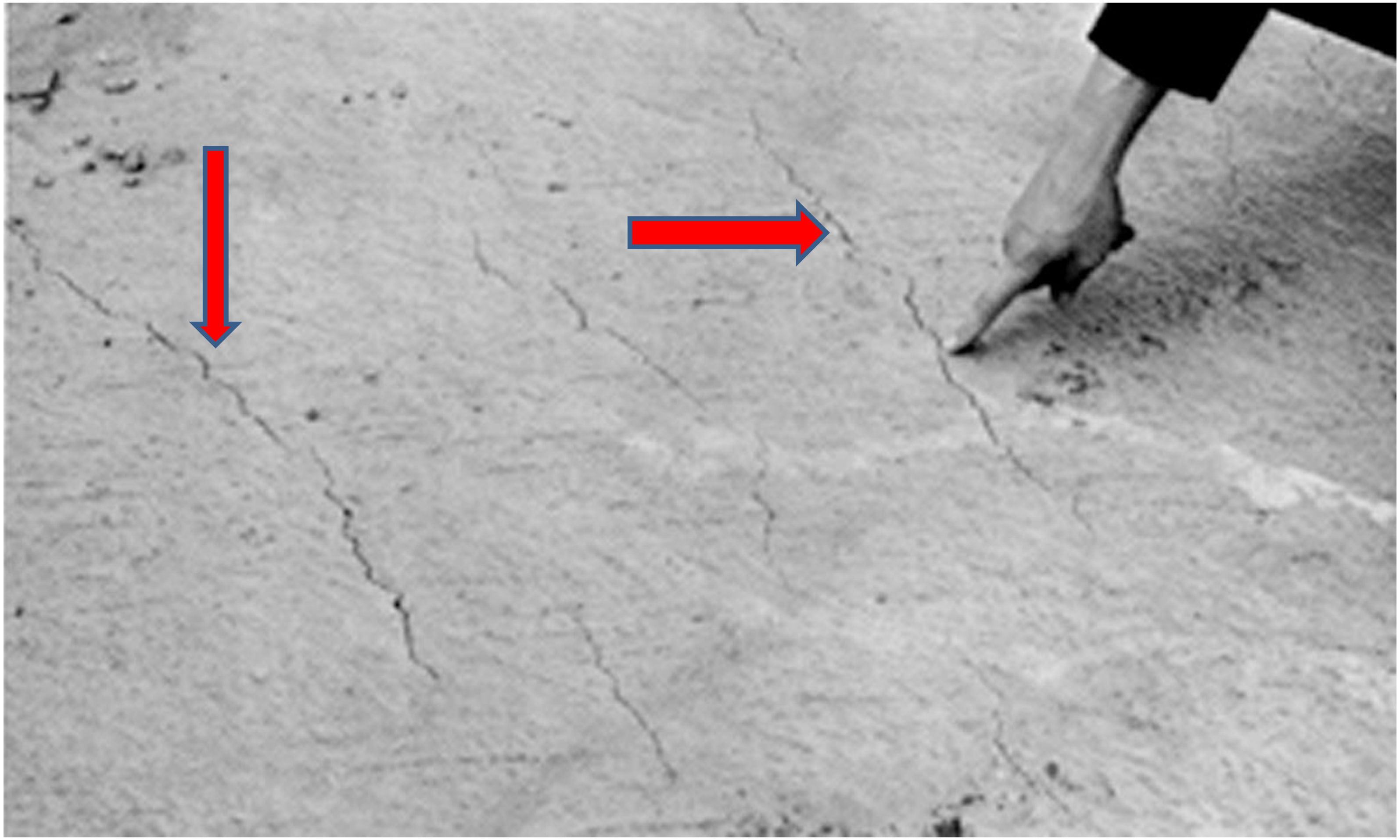
Hot Weather Concreting

(ACI 305R-10)

Effects

- Plastic shrinkage cracking
  - Although primarily associated with hot-weather concrete, these typically occur within 30 minutes up to 6 hours. Plastic Shrinkage cracks can and do occur during cool and cold weather also
  - It can occur any time ambient conditions produce rapid evaporation of moisture from the concrete surface. These cracks occur when water evaporates from the surface faster than it can rise to the surface during the bleeding process, recommend using a evaporation retarder, also see **CIP #5 from NRMCA**
  - The rapid drying shrinkage creates tensile stresses in the surface that often result in short, irregular cracks, hence they rarely are a structural concern
  - Don't confuse this with Delamination

Plastic Shrinkage Cracks

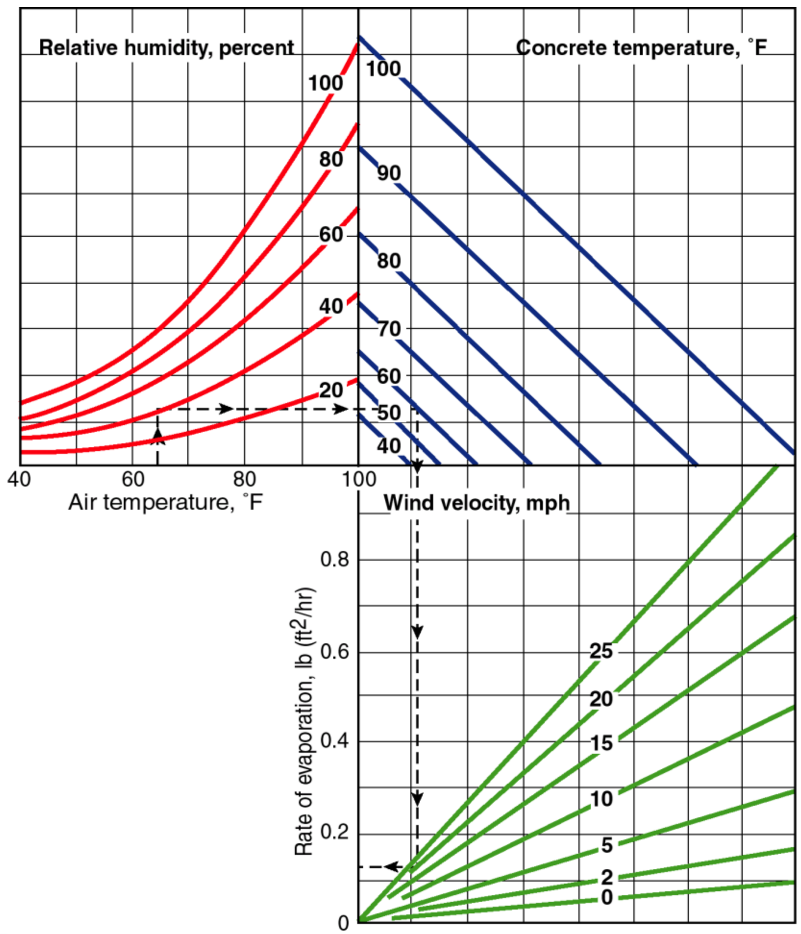


Hot Weather Concreting

(ACI 305R-10)

Effects

- Plastic shrinkage cracking probability increases with:
  - Low air temperature
  - High concrete temperature
  - Low humidity
  - High wind speed
- If rate exceeds .2 evaporation protection methods should be employed



Hot Weather Concreting

(ACI 305R-10)

The Kestrel Meter

Where do you hold it when you take the measurement?

Hot Weather Concreting

(ACI 305R-10)

Effects on Low Strength

- High initial concrete temperatures has significant effect on compressive strength in a negative manner
- ASTM C31 requires 60°- 80°F curing temperature up to 48 hours for concrete specified under 6000 psi. Concrete greater than 6000 psi is to be 68° - 78°F up to the first 48 hours.
- Last part of webinar is field issues (stay tuned)

Hot Weather Concreting

(ACI 305R-10)

Effects on Low Strength

- High initial concrete temperatures has significant effect on compressive strength. The concrete temperatures at the time of mixing, casting, and curing were 23°F (73F), 32°C (90F), 41°C (106F), and 49°C (120F). After 28 days, the specimens were all moist-cured at 23°C until the 90-day and one-year test ages.

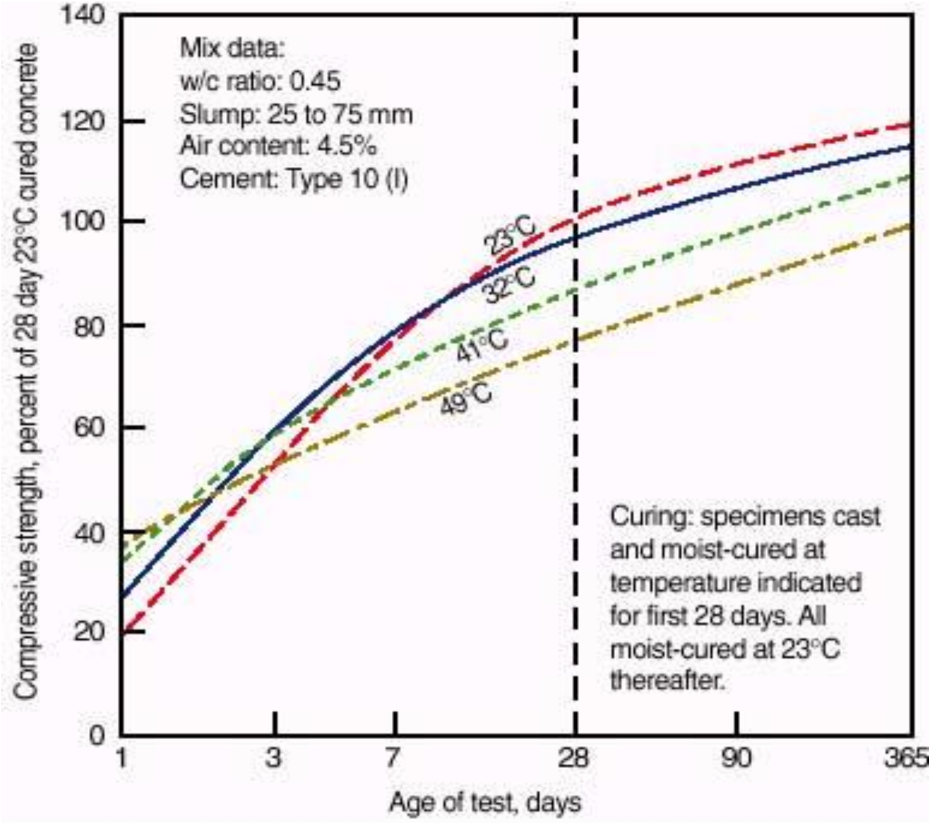


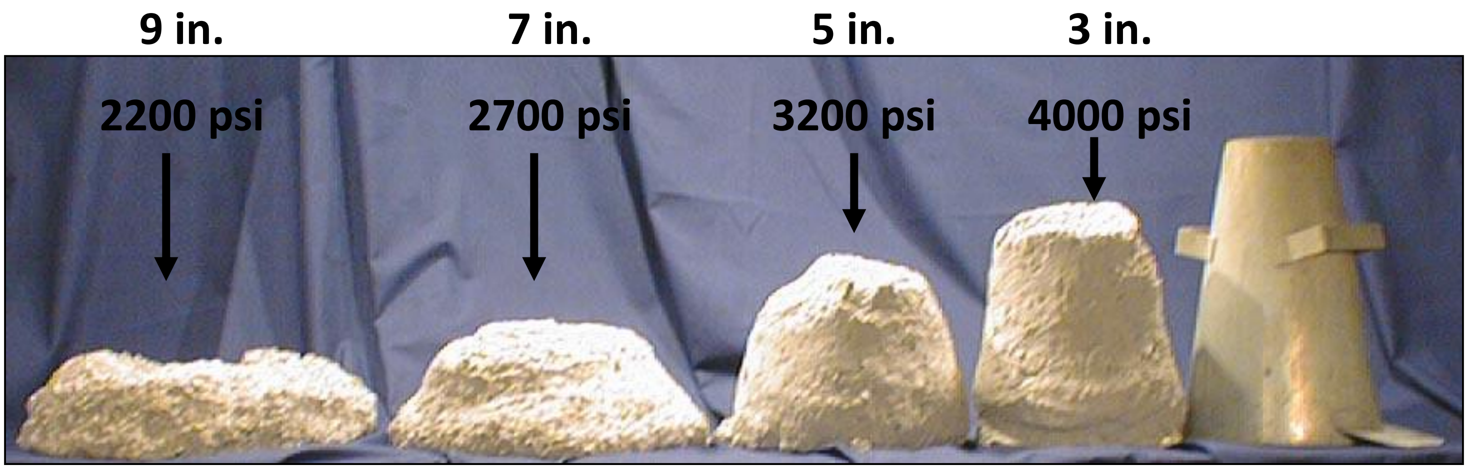
Fig. 13-4. Effect of high concrete temperatures on compressive strength at various ages (Klieger 1958).

Hot Weather Concreting

(ACI 305R-10)

Water

- As concrete temperature increases **there is a loss in slump** that is often unadvisedly compensated for by adding water to the concrete at the jobsite. At higher temperatures a greater amount of water is required to hold slump constant than is needed at lower temperatures.



Hot Weather Concreting

(ACI 305R-10)

Potential Surface Durability issues:

- Overworked surface lends to weaker and less durable surface.
- Amount of time needed to finish, consider smaller placements
- Concrete should not be placed faster than it can be properly consolidated and finished, the quality of the work suffers without and can result in cold joints and uneven surfaces to name just a few.

Ok – How not to get a durable surface!

Hot Weather Concreting

(ACI 305R-10)

Potential Surface Durability issues:

- Again, an evaporative retarder can be placed during finishing (even though they are not supposed to be a finishing aid)
- Also, a quality curing compound should be applied after final finish if a water cure is not feasible or conducive to the element placed.

Surface Evaporation Retarder

Hot Weather Concreting
(ACI 305R-10)

Placement – Minimize Crack Potential

- Dampen the subgrade and fog forms prior to placing concrete
- Erect temporary windbreaks to reduce wind velocity over the concrete surface
- Erect temporary sunshades to reduce concrete surface temperatures
- Protect the concrete with temporary coverings, such as polyethylene sheeting, during any appreciable delay between placing and finishing

Hot Weather Concreting

(ACI 305R-10)

Placement – Minimize Crack Potential

- Fog the slab immediately after placing and before finishing, taking care to prevent the accumulation of water that may reduce the quality of the cement paste in the slab surface
- Add plastic fibers to the concrete mixture to help reduce plastic shrinkage crack formation
- Reduce the amount of time between placing and the start of curing by eliminating delays during construction

Concrete Cylinders (ASTM C 31)

- **There are two different purposes for field concrete cylinder testing.**
  - One test is for determining the strength potential for the concrete as delivered to the job.
  - The other is for determining the strength of the concrete in place at a given time.
- **Both tests are covered by ASTM C 31 "Standard Practice for Making and Curing Concrete Test Specimens in the Field."**
  - One very important difference between the two test procedures is the method of curing required for the cylinders.
  - Because correct cylinder curing is commonly neglected, invalid test results are often misinterpreted as test failures.

Standard Cure Cylinders

The first purpose of cylinder testing is to confirm that the strength of the concrete, as delivered to the job, meets the specified design strength, typically at 28 days.

This procedure requires that:

- During the first 24 hours all cylinders will be stored in a surrounding temperature of 60°F – 80°F for less than 6000 psi concrete and 68°F – 78°F for concrete with a strength greater or equal to 6000 psi.
- Within 16 to 24 hours all cylinders will be removed from the molds and stored in a moist condition until time of test at a temperature of 73.5 ± 3.5 °F.

Field Cure Cylinders

The second purpose of cylinder testing is to confirm the time at which concrete in place is strong enough for forms to be removed or for the structure to be put into service.

This procedure directs that:

- Cylinders are stored as near as possible to the concrete in place.
- Cylinder molds are removed at the time forms are removed.
- Cylinders are cured to duplicate, as nearly as possible, the curing of the concrete in place until the time of test.

This test procedure is not intended to be used as a basis for determining whether or not the strength specification for the concrete has been met.

NRMCA Publication No. 171

"Effect of Temperature and Delivery
Time on Concrete Proportions"
Publication prepared by E.Goeb

"The effect of hot-weather on concrete cylinder tests –Why low cylinders tests in hot weather?

…of several causes, testing procedure may be number one…

NRMCA Study

Two of three primary variables investigated in the NRMCA research were the effect of concrete temperature and the effect of delivery time (batching to time of delivery) on 28-day cylinder strengths.

- The higher concrete temperature caused only a minor reduction in 28-day strength.
- The reduction in strength when the time of delivery was extended from 20 to 90 minutes was 2 to 3 times greater.
- Loss in strength for extended mixing time was no greater at 95 ° F than at 65° F.
- **The third variable, the temperature at which cylinders were cured on the job, had by far the greatest effect on cylinder strengths.**

NRMCA Study

- Cylinders molded from various mixes were exposed to two different curing conditions for the first day. One set was cured for the first 16 to 20 hours at 70° F and the other set was cured at 100° F.
- After the first day both sets were cured in the standard moist room until tested.
- The loss of strength caused by early exposure of cylinders to the 100° F temperature averaged 10 percent of the 28-day strength for all mixes tested. This was double the loss that occurred with longer delivery time and almost 6 times the loss of strength that occurred with higher concrete temperatures.
- **The strength loss caused by nonstandard curing of cylinders was consistent for every one of the various mixes tested.**
- The approximate 10 percent loss in cylinder strength attributable to the difference in first day curing was common to all mixes.

NRMCA Study Summary

Based upon the test results, it is not difficult to speculate about what happens on the many projects where cylinders stand unprotected from the sun.

- Ambient temperatures need not be extremely high for temperatures to reach 100° F in direct sunlight.
- If exposure for one day can reduce 28-day strength by 10 percent, what happens to cylinders molded from a Friday pour or on the day before a holiday?
- We have always known and long accepted the generalization that hot weather reduces 28-day concrete strengths.
- This report provides evidence that the major part of that loss is very often not in the potential strength of the concrete mix as delivered to the job… which the cylinder test is supposed to be measuring.
- It is only a loss in cylinder strengths caused by nonstandard curing of cylinders while stored on the job.

NRMCA Test Results

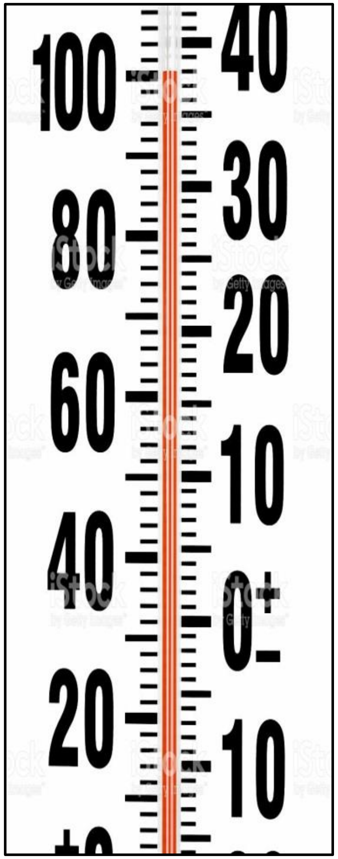
SUMMARY OF TEST RESULTS

Test variable	Average strength loss at 28 days	Added cement needed to maintain strength
Increase concrete temperature from 65 to 95 degrees F	2 percent*	8 pounds/ cubic yard
Extend delivery time from 20 to 90 minutes	5 percent	23 pounds/ cubic yard
Cure cylinders at 100 degrees F for the first day	10 percent	45 pounds/ cubic yard

* Strength loss of the mix with the cement that was troublesome in hot weather was greater when no admixture was used. When used with fly ash or the water reducer the performance was average.

Testing
(ACI 305R-10)

- If the initial 24-hour curing is at 100°F (38°C), the 28-day compressive strength of the test specimens may be 10 to 15% lower than if cured at the required ASTM C31/C31M curing temperature (Gaynor et al. 1985).
- If the cylinders are allowed to dry at early ages, strengths will be reduced even further (Cebeci 1987).
- Proper curing of the test specimens during hot weather is critical, and steps should be taken to ensure that the specified procedures are followed.



Hot Weather Testing Considerations

- Carefully read and understand project specifications
- Pre-construction meeting can address hot weather concrete testing practice
- Frequently document air, concrete, and subgrade/subbase temperatures, humidity, wind, and evaporation rate
- Document placement and curing procedures
- Field notes should be part of the permanent project records
- Collect and review material delivery tickets

Hot Weather Testing Considerations

- Sample and test in accordance with applicable ASTM standards
- Increase testing frequency
- Avoid moisture loss in composite sample
- Avoid moisture loss in strength specimens
- Maintain proper curing temperatures for strength specimens
  - use min-max thermometers

Keep it Cool

- Cover plastic molds with water-tight lids or plastic …use with wet burlap
- **Total immersions in water is the best curing method for cylinders cast in plastic molds**!
- One study has shown it's the only method that prevents all moisture loss during initial curing
- Use water-filled insulated coolers or tanks, sawed-off 50 gal. drums, insulated temperature-controlled chests
  - ***be creative…ask contractor for help***
- Use shaded areas, canopies or tents, wet burlap covered canopy or tank

Summary

- Never place cylinders where direct sunlight can hit them.
- In hot weather radiant heat combined with the heat of hydration will most likely drive the cylinder temperature above 80°F which can reduce the 28 day strength.
- Care in handling, shipment, and storage of cylinders is very important for accurate test results.
- Any storage method that increases the chance of a low test result is not a good method

Concrete Placement in Hot Weather
Planning, Placing, and Preventing Problems!