CHAPTER 13

Hot-Weather Concreting

Weather conditions at a jobsite—hot or cold, windy or calm, dry or humid—may be vastly different from the optimum conditions assumed at the time a concrete mix is specified, designed, or selected, or from laboratory conditions in which concrete specimens are stored and tested. Hot weather conditions adversely influence concrete quality primarily by accelerating the rate of moisture loss and rate of cement hydration that occur at higher temperatures. Detrimental hot weather conditions include:

- high ambient temperature
- high concrete temperature
- low relative humidity
- high wind speed
- solar radiation

Hot weather conditions can create difficulties in fresh concrete, such as:

- increased water demand
- accelerated slump loss leading to the addition of water on the jobsite
- increased rate of setting resulting in placing and finishing difficulties
- increased tendency for plastic cracking
- critical need for prompt early curing
- difficulties in controlling entrained air
- increased concrete temperature resulting in long-term strength loss
- increased potential for thermal cracking

Adding water to the concrete at the jobsite can adversely affect properties and serviceability of the hardened concrete, resulting in:

- decreased strength from higher water to cement ratio
- decreased durability due to cracking
- increased permeability
- nonuniform surface appearance
- increased tendency for drying shrinkage
- reduced abrasion resistance from tendency to sprinkle water during finishing

Only by taking precautions to alleviate these difficulties in anticipation of hot-weather conditions can concrete work proceed smoothly. For more information on the above topics, see ACI Committee 305 (1999).

WHEN TO TAKE PRECAUTIONS

During hot weather the most favorable temperature for achieving high quality freshly mixed concrete is usually lower than can be obtained without artificial cooling. A concrete temperature of 10°C to 15°C (50°F to 60°F) is desirable to maximize beneficial mix properties, but such temperature are not always practical. Many specifications require only that concrete when placed should have a temperature of less than 29°C to 32°C (85°F to 90°F). The ASTM C 94 (AASHTO M 157) specifications for ready

Fig. 13-1. Liquid nitrogen added directly into a truck mixer at the ready mix plant is an effective method of reducing concrete temperature for mass concrete placements or during hot-weather concreting. (69954)

mixed concrete notes in some situations difficulty may be encountered when concrete temperatures approach 32°C (90°F). However, this specification does not mandate a maximum concrete temperature unless heated aggregates or heated water are used.

Precautions should be planned in advance to counter the effects of a high concrete temperature when the concrete placed is somewhere between 25°C and 35°C (77°F and 95°F). Last-minute attempts to prevent hot-weather damage are rarely performed soon enough. If acceptable field data is not available, the maximum temperature limit should be established for conditions at the jobsite; this should be based on trial-batch tests at the temperature and for the typical concrete section thickness anticipated, rather than on ideal temperatures of 20°C to 30°C (68°F to 86°F) cited in ASTM C 192 (AASHTO T 126). If possible, large batches should be made to measure mix properties at time intervals to establish the relationship for the property of interest as a function of time at various batch temperatures of interest. This process will establish the maximum allowable time to discharge concrete after batching for various concrete temperatures.

More than controlling the maximum temperature is required to determine when to employ precautions to produce concrete with the required strength and durability. For most work it is too complex to simply limit only the maximum temperature of concrete as placed; circumstances and concrete requirements vary too widely. For example, a temperature limit that would serve successfully at one jobsite could be highly restrictive at another. Atmospheric conditions, including air temperature, relative humidity and wind speed, in conjunction with site conditions influence the precautions needed. For example, flatwork done under a roof that blocks solar radiation with exterior walls in place that screen the wind could be completed using a high temperature concrete; this concrete would cause difficulty if placed outdoors on the same day where it would be exposed to direct sun and wind.

Which precautions to use and when to use them will depend on: the type of construction; characteristics of the materials being used; and the experience of the placing and finishing crew in dealing with the atmospheric conditions on the site. The following list of precautions will reduce or avoid the potential problems of hot-weather concreting:

- use materials and mix proportions that have a good record in hot-weather conditions
- cool the concrete or one or more of its ingredients (Fig. 13-1)
- use a concrete consistency that allows rapid placement and consolidation
- reduce the time of transport, placing and finishing as much as possible
- schedule concrete placements to limit exposure to atmospheric conditions, such as at night or during favorable weather conditions
- consider methods to limit moisture loss during placing and finishing, such as sunshades, windscreens, fogging, or spraying
- apply temporary moisture-retaining films after screeding
- organize a preconstruction conference to discuss the precautions required for the project

The above precautions are discussed in further detail throughout this chapter.

EFFECTS OF HIGH CONCRETE TEMPERATURES

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. Adding water without adding cement results in a higher water-cement ratio, thereby lowering the strength at all ages and adversely affecting other desirable properties of the hardened concrete. This is in addition to the adverse effect on strength at later ages due to the higher temperature, even without the addition of water. Adding cement to compensate for the use of additional mix water may not be enough to achieve the desired concrete properties because additional cement will further increase the concrete temperature and water demand.

As shown in Fig. 13-2, if the temperature of freshly mixed concrete is increased from 10°C to 38°C (50°F to 100°F), about 20 kg/m³ (33 lb/yd³) of additional water is needed to maintain the same 75-mm (3-in.) slump. This additional water could reduce strength by 12% to 15% and

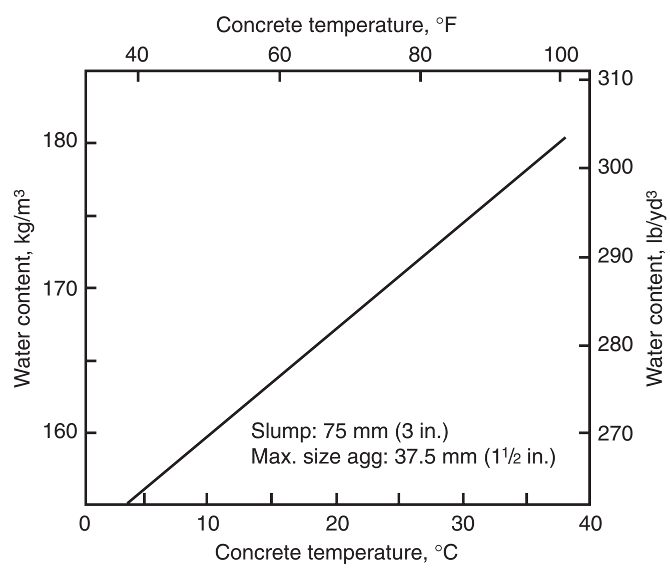


Fig. 13-2. The water requirement of a concrete mixture increases with an increase in concrete temperature Bureau of Reclamation (1981).

produce a compressive strength cylinder test result that may not comply with specifications.

High temperatures of freshly mixed concrete increase the rate of setting and shorten the length of time within which the concrete can be transported, placed, and finished. Setting time can be reduced by 2 or more hours with a 10°C (18°F) increase in concrete temperature (Fig. 13-3). Concrete should remain plastic long enough so that each layer can be placed without development of cold joints or discontinuities in the concrete. Retarding admixtures, ASTM C 494 (AASHTO M 194) Type B, and hydration control admixtures can be beneficial in offsetting the accelerating effects of high temperature.

In hot weather, there is an increased tendency for cracks to form both before and after hardening. Rapid evaporation of water from freshly placed concrete can cause plastic-shrinkage cracks before the surface has hardened (discussed in more detail later in this chapter). Cracks may also develop in the hardened concrete because of increased drying shrinkage due to higher water contents or thermal volume changes as the concrete cools.

Air entrainment is also affected in hot weather. At elevated temperatures, an increase in the amount of air-entraining admixture is required to produce a given air content.

Fig. 13-4 shows the effect of high initial concrete temperatures on compressive strength. The concrete temperatures at the time of mixing, casting, and curing were 23°C (73°F), 32°C (90°F), 41°C (105°F), and 49°C (120°F). After 28 days, the specimens were all moist-cured at 23°C (73°F) until the 90-day and one-year test ages. The tests, using identical concretes of the same water-cement ratio, show that while higher concrete temperatures give higher early strength than concrete at 23°C (73°F), at later ages concrete strengths are lower. If the water content had been increased to maintain the same slump (without increasing

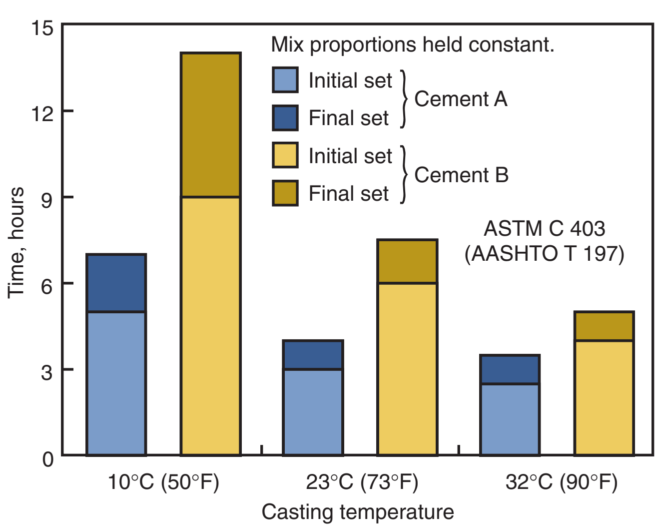


Fig. 13-3. Effect of concrete temperature on setting time (Burg 1996).

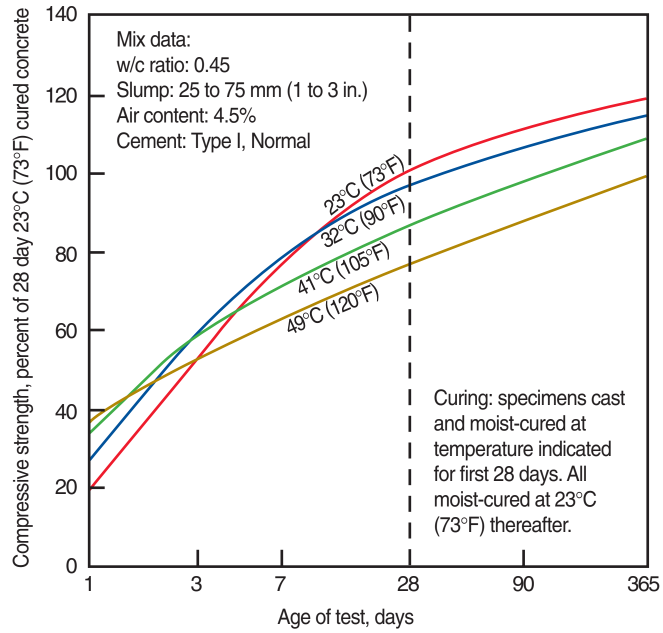


Fig. 13-4. Effect of high concrete temperatures on compressive strength at various ages (Klieger 1958).

cement content), the reduction in strength would have been even greater than shown.

The proper fabrication, curing, and testing of compression test specimens during hot weather is critical. Steps should be taken to make sure ASTM C 31 (AASHTO T 23) procedures are followed regarding initial curing of strength specimens for acceptance or quality control testing at 16ºC to 27ºC (60ºF to 80ºF). If the initial 24 hour curing is at 38ºC (100ºF), the 28-day compressive strength of the test specimens may be 10% to 15% lower than if cured at the required ASTM C 31 (AASHTO T 23) curing temperatures (Gaynor 1985).

Because of the detrimental effects of high concrete temperatures, all operations in hot weather should be directed toward keeping the concrete as cool as possible.

COOLING CONCRETE MATERIALS

The usual method of cooling concrete is to lower the temperature of the concrete materials before mixing. One or more of the ingredients should be cooled. In hot weather the aggregates and mixing water should be kept as cool as practicable; these materials have a greater influence on concrete temperature after mixing than other ingredients.

The contribution of each ingredient in a concrete mixture to the temperature of the freshly mixed concrete is related to the temperature, specific heat, and quantity of each material. Fig. 13-5 shows graphically the effect of temperature of materials on the temperature of fresh concrete. It is evident that although concrete temperature is primarily dependent upon the aggregate temperature, cooling the mixing water can be effective.

The approximate temperature of concrete can be calculated from the temperatures of its ingredients by using the following equation (NRMCA 1962):

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

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

Example calculations for initial concrete temperature are shown in Table 13-1A.

Of all the materials in concrete, water is the easiest to cool. Even though it is used in smaller quantities than the other ingredients, cold water will produce a moderate reduction in the concrete temperature. Mixing water from a cool source should be used. It should be stored in tanks that are not exposed to the direct rays of the sun. Tanks and pipelines carrying mixing water should be buried, insulated, shaded, or painted white to keep water as cool as practical. Water can be cooled by refrigeration, liquid nitrogen, or ice. Cooling the mix water temperature 2.0°C to 2.2°C (3.5°F to 4°F) will usually lower the concrete temperature about 0.5°C (1°F). However, because mix water is such a small percentage of the total mixture, it is difficult to lower concrete temperatures more than about 4.5°C (8°F) by cooling the water alone.

Ice can be used as part of the mixing water provided it is completely melted by the time mixing is completed.

Table 13-1A (Metric). Effect of Temperature of Materials on Initial Concrete Temperatures

Material	Mass, *M*, kg	Specific heat kJ/kg • K	Joules to vary temperature, 1°C	Initial temperature of material, *T*, °C	Total joules 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

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

Table 13-1A (Inch-Pound Units). Effect of Temperature of Materials on Initial Concrete Temperatures

Material	Mass, *M*, lb	Specific heat	Btu to vary temperature, 1°F	Initial temperature of material, *T*, °F	Total Btu's 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 = $\frac{95,720}{1088}$ = 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

When using crushed ice, care must be taken to store it at a temperature that will prevent the formation of lumps.

When ice is added as part of the mixing water, the effect of the heat of fusion of the ice must be considered; so the equation for temperature of fresh concrete is modified as follows:

$$T\ (C°) = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa} - 80 M_i}{0.22(M_a + M_c) + M_w + M_{wa} + M_i}$$

$$T\ (F°) = \frac{0.22(T_a M_a + T_c M_c) + T_w M_w + T_{wa} M_{wa} - 112 M_i}{0.22(M_a + M_c) + M_w + M_{wa} + M_i}$$

where M_i is the mass in kg (lb) of ice (NRMCA 1962 and Mindess and Young 1981).

The heat of fusion of ice in metric units is 335 kJ per kg (in British thermal units, 144 Btu per pound). Calculations in Table 13-1B show the effect of 44 kg (75 lb) of ice in reducing the temperature of concrete. Crushed or flaked ice is more effective than chilled water in reducing concrete temperature. The amount of water and ice must not exceed the total mixing-water requirements.

Fig. 13-6 shows crushed ice being charged into a truck mixer prior to the addition of other materials. Mixing time should be long enough to completely melt the ice. The volume of ice should not replace more than approximately 75% of the total batch water. The maximum temperature reduction from the use of ice is limited to about 11°C (20°F).

If a greater temperature reduction is required, the injection of liquid nitrogen into the mixer may be the best alternative method.

The liquid nitrogen can be added directly into a central mixer drum or the drum of a truck mixer to lower concrete temperature. Fig. 13-1 shows liquid nitrogen added directly into a truck mixer near a ready mix plant. Care should be taken to prevent the liquid nitrogen from contacting the metal drum; the super cold liquid nitrogen may crack the drum. The addition of liquid nitrogen does not in itself influence the amount of mix water required except that lowering the concrete temperature can reduce water demand.

Aggregates have a pronounced effect on the fresh concrete temperature because they represent 70% to 85% of the total mass of concrete. To lower the temperature of concrete 0.5°C (1°F) requires only a 0.8°C to 1.1°C (1.5°F to 2°F) reduction in the temperature of the coarse aggregate.

There are several simple methods of keeping aggregates cool. Stockpiles should be shaded from the sun and

Table 13-1B (Metric). Effect of Ice (44 kg) on Temperature of Concrete

Material	Mass, *M*, kg	Specific heat kJ/kg • K	Joules to vary temperature, 1°C	Initial temperature of material, *T*, °C	Total joules 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
Ice	44 (M_i)	4.184	184	0 (T_i)	0
			2699		
minus	44 (M_i) x heat of fusion, (335 kJ/kg) =				–14,740
					65,177

Concrete temperature = $\frac{65,177}{2699}$ = 24.1°C

Table 13-1B (Inch-Pound Units). Effect of Ice (75 lb) on Temperature of Concrete

Material	Mass, *M*, lb	Specific heat	Btu to vary temperature, 1°F	Initial temperature of material, *T*, °F	Total Btu's 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	207 (M_w)	1.00	207	80 (T_w)	16,560
Total aggregate	3100 (M_a)	0.22	682	80 (T_a)	54,560
Ice*	75 (M_i)	1.00	75	32 (T_i)	2,400
			1088		
minus	75 (M_i) x heat of fusion, (144 Btu/lb) =				–10,800
					81,320

Concrete temperature = $\frac{81,320}{1088}$ = 74.7°F

*$32\ M_i - 144\ M_i = -112\ M_i$

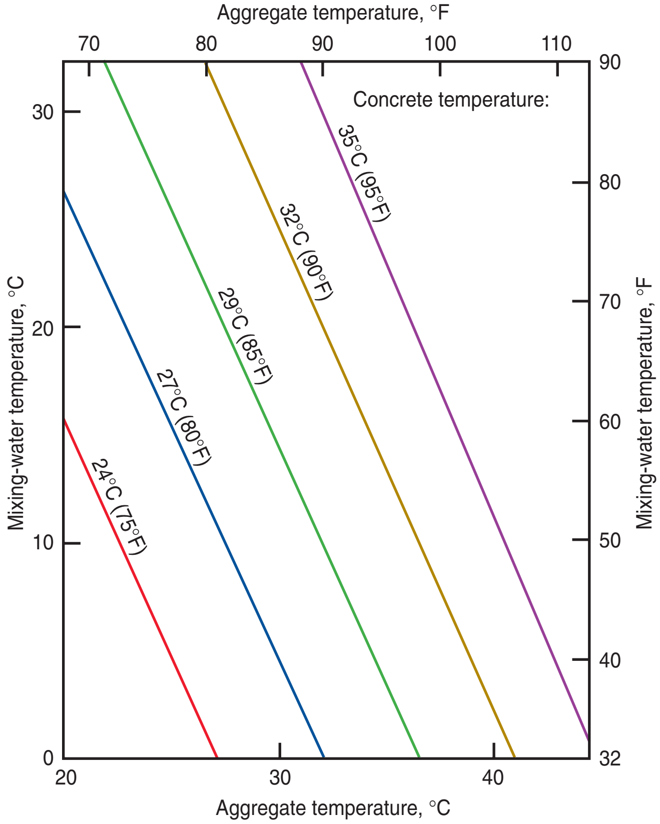


Fig. 13-5. Temperature of freshly mixed concrete as affected by temperature of its ingredients. Although the chart is based on the following mixture, it is reasonably accurate for other typical mixtures:

Aggregate	**1360 kg (3000 lb)**
Moisture in aggregate	**27 kg (60 lb)**
Added mixing water	**109 kg (240 lb)**
Cement at 66°C (150°F)	**256 kg (564 lb)**

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)

kept moist by sprinkling. Do not spray salt water on aggregate stockpiles. Since evaporation is a cooling process, sprinkling provides effective cooling, especially when the relative humidity is low.

Sprinkling of coarse aggregates should be adjusted to avoid producing excessive variations in the surface moisture content and thereby causing a loss of slump uniformity. Refrigeration is another method of cooling materials. Aggregates can be immersed in cold-water tanks, or cooled air can be circulated through storage bins. Vacuum cooling can reduce aggregate temperatures to as low as 1°C (34°F).

Cement temperature has only a minor effect on the temperature of the freshly mixed concrete because of cement's low specific heat and the relatively small amount of cement in a concrete mixture. A cement temperature change of 5°C (9°F) generally will change the concrete temperature by only 0.5°C (1°F). Because cement loses heat slowly during storage, it may still be warm when delivered. (This heat is produced in grinding the cement clinker during manufacture.) Since the temperature of cement does affect the temperature of the fresh concrete to some extent, some specifications place a limit on its temperature at the time of use. This limit varies from 66°C to 82°C (150°F to 180°F) (ACI Committee 305). However, it is preferable to specify a maximum temperature for freshly mixed concrete rather than place a temperature limit on individual ingredients (Lerch 1955).

SUPPLEMENTARY CEMENTITIOUS MATERIALS

Many concrete producers consider the use of supplementary cementitious materials to be essential in hot weather conditions. The materials of choice are fly ash and other pozzolans (ASTM C 618 or AASHTO M 295) and ground granulated blast-furnace slag (ASTM C 989 or AASHTO M 302). These materials generally slow both the rate of setting as well as the rate of slump loss. However, some caution regarding finishing is needed; because the rate of bleeding can be slower than the rate of evaporation, plastic shrinkage cracking or crazing may result. This is discussed in greater detail under "Plastic Shrinkage Cracking" below.

PREPARATION BEFORE CONCRETING

Before concrete is placed, certain precautions should be taken during hot weather to maintain or reduce concrete temperature. Mixers, chutes, conveyor belts, hoppers, pump lines, and other equipment for handling concrete should be shaded, painted white, or covered with wet burlap to reduce solar heat.

Forms, reinforcing steel, and subgrade should be fogged or sprinkled with cool water just before the concrete is placed. Fogging the area during placing and finishing operations not only cools the contact surfaces and surrounding air but also increases its relative humidity. This reduces the temperature rise of the concrete and minimizes the rate of evaporation of water from the concrete after placement. For slabs on ground, it is a good practice to moisten the subgrade the evening before concreting. There should be no standing water or puddles on forms or subgrade at the time concrete is placed.

During extremely hot periods, improved results can be obtained by restricting concrete placement to early morning, evening, or nighttime hours, especially in arid climates. This practice has resulted in less thermal shrinkage and cracking of thick slabs and pavements.

TRANSPORTING, PLACING, FINISHING

Transporting and placing concrete should be done as quickly as practical during hot weather. Delays contribute to loss of slump and an increase in concrete temperature. Sufficient labor and equipment must be available at the jobsite to handle and place concrete immediately upon delivery.

Prolonged mixing, even at agitating speed, should be avoided. If delays occur, stopping the mixer and then agitating intermittently can minimize the heat generated by mixing. ASTM C 94 (AASHTO M 157) requires that discharge of concrete be completed within 1½ hours or before the drum has revolved 300 times, whichever occurs first. During hot weather the time limit can be reasonably reduced to 1 hour or even 45 minutes. If specific time limitations on the completion of discharge of the concrete are desired, they should be included in the project specifications. It is also reasonable to obtain test data from a trial batch simulating the time, mixing, and anticipated concrete temperature to document, if necessary, a reduction in the time limit.

Since the setting of concrete is more rapid in hot weather, extra care must be taken with placement techniques to avoid cold joints. For placement of walls, shallower layers can be specified to assure enough time for consolidation with the previous lift. Temporary sunshades and windbreaks help to minimize cold joints.

Floating of slabs should be done promptly after the water sheen disappears from the surface or when the concrete can support the weight of a finisher with no more than a 5-mm (¼-in.) indentation. Finishing on dry and windy days requires extra care. Rapid drying of the concrete at the surface may cause plastic shrinkage cracking.

PLASTIC SHRINKAGE CRACKING

Plastic shrinkage cracks sometimes occur in the surface of freshly mixed concrete soon after it has been placed, while it is being finished or shortly thereafter (Fig. 13-7). These cracks which appear mostly on horizontal surfaces can be substantially eliminated if preventive measures are taken.

Plastic shrinkage cracking is usually associated with hot-weather concreting; however, 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 travel to the surface during the bleeding process. This creates rapid drying shrinkage and tensile stresses in the surface that often result in short, irregular cracks. The following conditions, singly or collectively, increase evaporation of surface moisture and increase the possibility of plastic shrinkage cracking:

1. Low air temperature
2. High concrete temperature
3. Low humidity
4. High wind speed

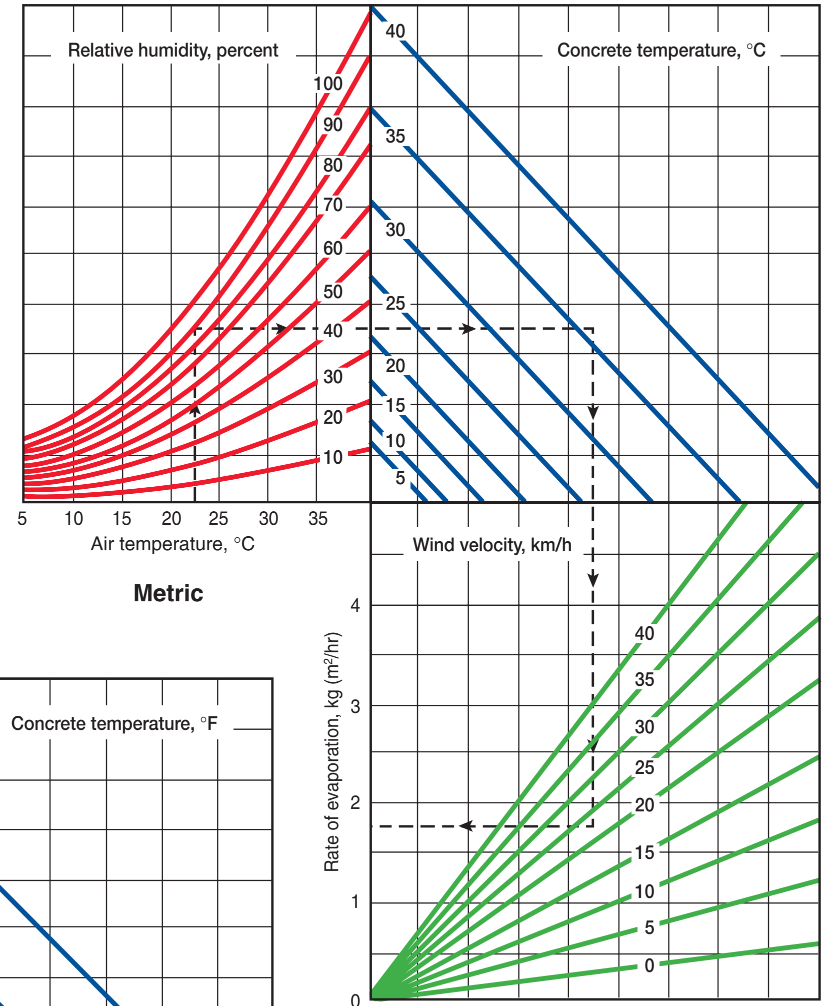
The crack length is generally 50 to 1000 mm (a few inches to 3 ft) in length and they are usually spaced in an irregular pattern from 50 to 700 mm (a few inches to 2 ft) apart. Fig. 13-8 is useful for determining when precautionary measures should be taken. There is no way to predict with certainty when plastic shrinkage cracking will occur.

When the rate of evaporation exceeds 1 kg/m² (0.2 lb/ft²) per hour, precautionary measures such as windscreens are almost mandatory. With some concrete mixtures, such as those containing pozzolans, cracking is possible if the rate of evaporation exceeds 0.5 kg/m² (0.1 lb/ft²) per hour. Concrete containing silica fume is particularly prone to plastic shrinkage because bleeding rates are commonly only 0.25 kg/m² (0.05 lb/ft²) per hour. Therefore, protection from premature drying is essential at lower evaporation rates. At some point in the process of setting, bleeding goes to zero and the surface begins to dry at evaporation rates much lower than the typically specified 1.0 kg/m² (0.2 lb/ft²) per hour; in such cases, further protection becomes necessary regardless of the type of concrete mixture.

Fig. 13-7. Typical plastic shrinkage cracks. (1311)

To use these charts:

1. Enter with air temperature, move *up* to relative humidity.
2. Move *right* to concrete temperature.
3. Move *down* to wind velocity.
4. Move *left:* read approximate rate of evaporation.



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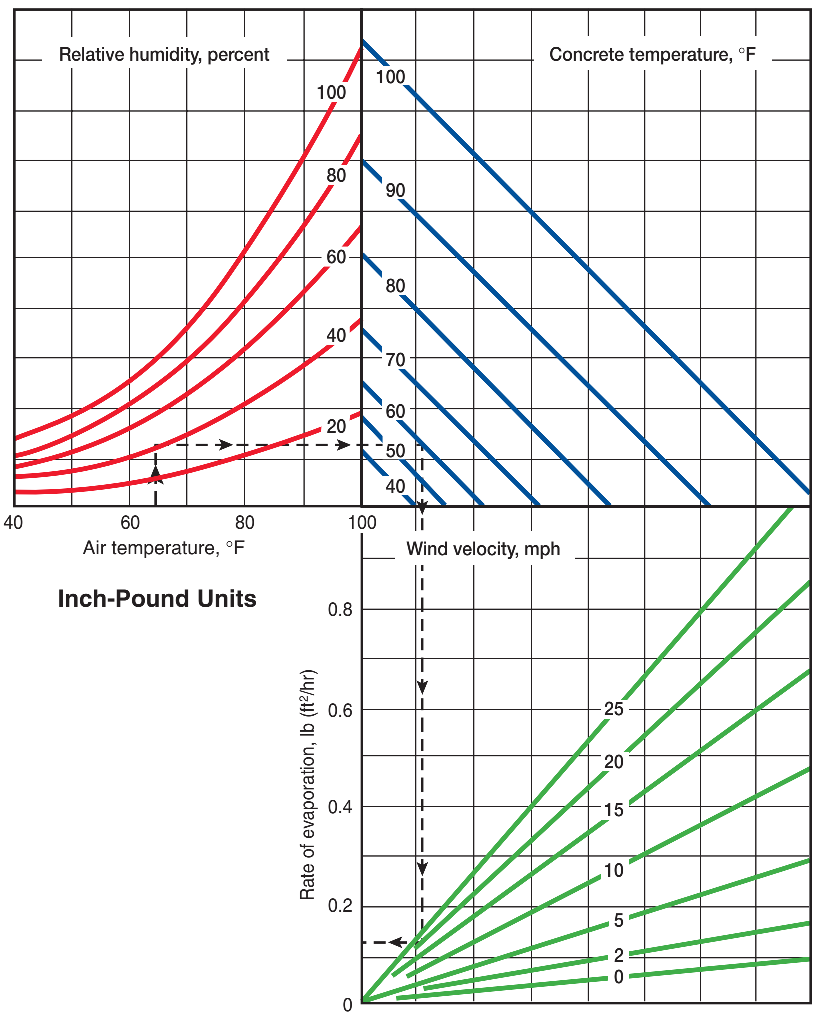

Inch-Pound Units

One or more of the precautions listed below can minimize the occurrence of plastic shrinkage cracking. They should be considered while planning for hot-weather concrete construction or while dealing with the problem after construction has started. They are listed in the order in which they should be done during construction.

1. Moisten concrete aggregates that are dry and absorptive.
2. Keep the concrete temperature low by cooling aggregates and mixing water.
3. Dampen the subgrade (Fig. 13-9) and fog forms prior to placing concrete.
4. Erect temporary windbreaks to reduce wind velocity over the concrete surface.
5. Erect temporary sunshades to reduce concrete surface temperatures.

Fig. 13-8. Effect of concrete and air temperatures, relative humidity, and wind velocity on rate of evaporation of surface moisture from concrete. Wind speed is the average horizontal air or wind speed in km/h (mph) measured at 500 mm (20 in.) above the evaporating surface. Air temperature and relative humidity should be measured at a level approximately 1.2 to 1.8 m (4 to 6 ft) above the evaporating surface and on the windward side shielded from the sun's rays (Menzel 1954).

6. Protect the concrete with temporary coverings, such as polyethylene sheeting, during any appreciable delay between placing and finishing.
7. 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.
8. Add plastic fibers to the concrete mixture to help reduce plastic shrinkage crack formation.

Fogging the concrete before and after final finishing is the most effective way to minimize evaporation and reduce plastic shrinkage cracking. Use of a fog spray will raise the relative humidity of the ambient air over the slab, thus reducing evaporation from the concrete. Fog nozzles atomize water using air pressure (Figs. 13-10 and 13-11) to create a fog blanket. They should not be confused with garden-hose nozzles, which leave an excess amount of water on the slab. Fogging should be continued until a suitable curing material such as a curing compound, wet burlap, or curing paper can be applied.

Other methods to prevent the rapid loss of moisture from the concrete surface include:

- Spray application of temporary moisture-retaining films (usually polymers); these compounds can be applied immediately after screeding to reduce water evaporation before final finishing operations and curing commence. These materials are floated and troweled into the surface during finishing and should have no adverse effect on the concrete or inhibit the adhesion of membrane-curing compounds.
- Reduction of time between placing and the start of curing by eliminating delays during construction.

Fig. 13-9. Dampening the subgrade, yet keeping it free of standing water will lessen drying of the concrete and reduce problems from hot weather conditions. (69955)

If plastic shrinkage cracks should appear during finishing, striking each side of the crack with a float and refinishing can close the cracks. However, the cracking may reoccur unless the causes are corrected.

CURING AND PROTECTION

Curing and protection are more critical in hot weather than in temperate periods. Retaining forms in place cannot be considered a satisfactory substitute for curing in hot weather; they should be loosened as soon as practical without damage to the concrete. Water should then be applied at the top exposed concrete surfaces—for example,

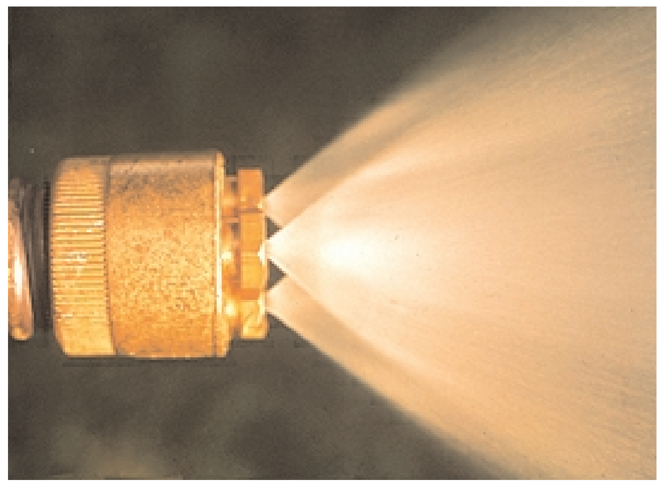

Fig. 13-10. Fog nozzle. (9853)

Fig. 13-11. Fogging cools the air and raises the relative humidity above flatwork to lessen rapid evaporation from the concrete surface, thus reducing cracking and improving surface durability. (69956)

with a soil-soaker hose—and allowed to run down inside the forms. On hardened concrete and on flat concrete surfaces in particular, curing water should not be more than about 11°C (20°F) cooler than the concrete. This will minimize cracking caused by thermal stresses due to temperature differentials between the concrete and curing water.

The need for moist curing 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 continue for at least 24 hours. In hot weather, continuous moist curing for the entire curing period is preferred. However, if moist curing cannot be continued beyond 24 hours, while the surfaces are still damp, the concrete should be protected from drying with curing paper, heat-reflecting plastic sheets, or membrane-forming curing compounds.

White-pigmented curing compounds can be used on horizontal surfaces. Application of a curing compound during hot weather should be preceded by 24 hours of moist curing. If this is not practical, the compound should be applied immediately after final finishing. The concrete surfaces should be moist.

Moist-cured surfaces should dry out slowly after the curing period to reduce the possibility of surface crazing and cracking. Crazing, a network pattern of fine cracks that do not penetrate much below the surface, is caused by minor surface shrinkage. Crazing cracks are very fine and barely visible except when the concrete is drying after the surface has been wet. The cracks encompass small concrete areas less than 50 mm (2 in.) in dimension, forming a chicken-wire like pattern.

ADMIXTURES

For unusual cases in hot weather and where careful inspection is maintained, a retarding admixture may be beneficial in delaying the setting time, despite the somewhat increased rate of slump loss resulting from their use. A hydration control admixture can be used to stop cement hydration and setting. Hydration is resumed, when desired, with the addition of a special accelerator (reactivator).

Retarding admixtures should conform to the requirements of ASTM C 494 (AASHTO M 194) Type B. Admixtures should be tested with job materials under job conditions before construction begins; this will determine their compatibility with the basic concrete ingredients and their ability under the particular conditions to produce the desired results.

HEAT OF HYDRATION

Heat generated during cement hydration raises the temperature of concrete to a greater or lesser extent depending on the size of the concrete placement, its surrounding environment, and the amount of cement in the concrete. As a general rule a 5°C to 9°C (10°F to 15°F) temperature rise per 45 kg (100 lb) of portland cement can be expected from the heat of hydration (ACI Committee 211 1997). There may be instances in hot-weather-concrete work and massive concrete placements when measures must be taken to cope with the generation of heat from cement hydration and attendant thermal volume changes to control cracking (see Chapters 15 and 18).

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