REQUIREMENTS FOR HOT WEATHER

Iowa Standards and Specifications provide that whenever the ambient air temperature exceeds 90° F, hot weather concreting procedures will be used. ACI Standard 305, Hot Weather Concreting, is summarized in this section to provide guidance to field offices so that compliance with these provisions can be assured.

General

Hot weather introduces problems in mixing, placing and curing concrete that can adversely affect the properties and serviceability of the hardened concrete. High temperatures accelerate the hardening of concrete. At higher temperatures, more mixing water is generally required for the same consistency. If the water-cement ratio is not maintained by adding additional cement, strengths will be reduced. Higher water contents also mean greater drying shrinkage. In very hot weather, fresh concrete may be plastic only an hour or less before it hardens.

Hot weather is considered to be any combination of high air temperature, low relative humidy and wind velocity tending to impair the quality of fresh or hardened concrete or otherwise resulting in abnormal properties. It is difficult to define in terms of temperature alone. The climatic factors affecting concrete in hot weather are high air temperature and reduced relative humidity, the effects of which may be considerably more pronounced with increases in wind velocity. The effects of hot weather are most critical during periods of rising temperature, falling relative humidity, or both. They generally occur during the summer season. Precautionary measures required on a calm, humid day will be less strict than those required on a dry, windy day, even if air temperature is identical. In Iowa, hot weather precautions should be considered when the air temperature is above 85° F.

Hot Weather Effects

In the absence of special precautions, undesirable hot weather effects may include:

a. Increased water demand for required consistency
b. Difficulty in control of entrained air
c. Rapid evaporation of mixing water
d. Rapid slump loss making the concrete mix more difficult to work
e. Accelerated set
f. Difficulties with normal handling, finishing, and curing
g. Greater dimensional change on cooling of hardened concrete
h. Increased plastic shrinkage
i. Increased tendency to crack or craze
j. Reduced durability from increased water demand and cracking
k. Reduced strength
l. Variations in the appearance of the concrete surface
m. Reduced bond of concrete to reinforcing steel

n. Increased risk of steel corrosion, from increased permeability and cracking
o. Possible "cold joints"
p. Increased permeability

Production and Delivery

If the proportioning and mixing controls or the delivery schedules are such that concrete arrives for placement in an unsuitable condition, then desirable placing and curing practices are not possible. Control of concrete temperature through the temperature of ingredients can only be done at the point of mixing. For concrete of conventional proportions, a reduction of concrete temperature of 1° F. requires reducing either the cement temperature about 8° F., the water temperature about 4° F. or the aggregate temperature about 2° F. Since the greatest portion of concrete is aggregate, reduction of aggregate temperature brings about the greatest reduction in concrete temperature, thus all practical means should be employed to keep the aggregates as cool as possible. This can be done, for example, by shading the supplies. Sprinkling or fog spraying of coarse aggregate stockpiles is effective in reducing aggregate temperatures by evaporative and direct cooling. Such sprinkling should not be done haphazardly, because it leads to excessive variation in surface moisture and thereby impairs uniformity of slump. The benefits, however, are valuable and warrant close attention.

Cooling of mixing water and/or use of ice is important. The temperature of water is easily lowered and, even though water is used in smaller quantities than other ingredients, the use of cold mixing water will effect a moderate reduction on concrete placing temperature. Tanks and pipelines carrying mixing water should be buried, insulated, shaded or painted white to maintain the water at the lowest practicable temperature.

When ice is used as part of the mixing water, it must be completely melted by the time mixing is completed. Crushed or flaked ice is very effective in reducing concrete temperature. For example, if 75 lb. of ice per cubic yard were used in a concrete mix with a temperature of 90° F., the temperature would drop to about 75° F.

Mixing time should be held to the minimum which will insure adequate concrete quality and uniformity because the concrete is warmed from the work of mixing, from the air, and from the sun. The effect of mixer surfaces exposed to the hot sun should be minimized by painting and keeping the mixer drum white and spraying it with cool water. White surfaces may be 10-15° F. cooler than aluminum and may be as much as 30° F. cooler than black or dark gray. Mixer drums and blades should be checked frequently during hot weather for buildup of cement and mortar which reduce mixer efficiency.

Cement hydration, temperature rise, slump loss, aggregate grinding and loss of air all increase with passage of time; thus, the period between mixing and delivery should be kept to an absolute minimum. With ready-mixed concrete operations, this presents some special problems. Attention should be given to coordinating the dispatching of trucks with the rate of placement to avoid delays in delivery. When elapsed time from batching to placement is so long as to result in significant increases in mixing water demand, or in slump loss, mixing in the trucks should be delayed until only sufficient time remains to accomplish mixing before the concrete is placed.

Laboratory research, as well as field experience, suggests that strength reduction, as well as other detrimental effects of hot weather, is directly proportional to the amount of retempering water added. On arrival at the job site, addition of water should not be allowed other than that required to adjust to the specified slump, within the limits of the specified maximum water-cement ratio.

Preparation Before Placing

Before concrete is placed, certain precautions can be taken during hot weather to help lower the concrete temperature. Mixers, chutes, belts, hoppers, pump lines, and other equipment for handling concrete can be shaded, painted white, or covered with wet burlap to reduce the effect of the sun's heat.

Forms, reinforcing steel, and subgrade should be sprinkled with cool water just prior to placing concrete. Wetting down the area cools the surrounding air and increases its relative humidity. This not only reduces the temperature rise of the concrete but also minimizes evaporation of water from the concrete during placing. For slabs on ground, it is a good practice to dampen the subgrade the evening before concreting. Prior to placing concrete, there should be no standing water or puddles on the subgrade.

When daytime temperatures and drying conditions may be critical, scheduling concrete placement to begin in the late afternoon will materially improve placing conditions. On massive slabs and pavements this has been found to result in much less thermal shrinkage and cracking. Concrete placed during the early morning may attain an undesirably high temperature, particularly during the middle of the day, when the maximum sun radiation and heat of hydration occur. Such concrete could subsequently be exposed to severe thermal stress on cooling.

Curing and Protection

It should be emphasized that in hot weather there is a great need for continuous curing, preferably by water. The need is greatest during the first few hours, and in fact throughout the first day after concrete is placed. All surfaces should be protected from drying, even intermittently, for a curing period of at least seven days after placement, as this contributes to development of pattern cracking. This can be done by use of fog sprays, wet burlap (kept wet) or other means of keeping the concrete continuously moistened.

Finishing of slabs and other exposed surfaces should be started as soon as the condition of the concrete allows and completed without delay. Exposed surfaces should be covered as soon as finishing is completed and kept continuously wet for at least the seven day curing period unless white pigmented curing compound is applied.

The forms should be loosened as soon as it can be done without damage to the concrete and provisions made for the curing water to run down inside them. During form removal, care should be taken to provide wet cover to newly-exposed surfaces to avoid exposure to hot sun and wind. Form tie cone holes can be filled and any necessary repairs made by uncovering a small portion at a time as necessary to carry on this work. These repairs should be completed as soon as possible after the forms are removed so that the repairs and cone hole fillings can cure with the surrounding concrete. Curing compound should not be applied until after cone holes are filled and repairs are made.

Providing proper temperature and moisture conditions for curing of concrete is much more critical in hot weather than under normal temperatures. It is of utmost importance that curing be promptly commenced, ample in coverage, and continued without interruption.

References

1. American Concrete Institute, ACI Standard 305-77, Hot Weather Concreting.
2. Portland Cement Association, Design and Control of Concrete Mixtures, Eleventh Edition.
3. United States Department of Interior, Bureau of Reclamation, Concrete Manual.

REQUIREMENTS FOR COLD WEATHER

Iowa Standards and Specifications provide that whenever the ambient air temperature drops below 40° F. cold weather concreting procedures will be used. ACI Standard 306, Cold Weather Concreting, is summarized in this section to provide guidance to field offices so that compliance with these provisions can be assured.

General

Precautions must be taken when placing concrete during winter months to insure that it will have the strength and durability to function properly. When the minimum daily air temperature is less than 40° F., concrete should be insulated or housed and heated after placement. The temperature of concrete and air adjacent to the concrete should be maintained at not less than 50° F. nor more than 90° F. for the seven day period following placement.

Plans for protecting fresh concrete from cold weather should be made well in advance of freezing temperatures. All needed equipment and materials should be at the work site and ready to use before the concrete is placed. It is too late to begin planning protective measures after the concrete has been placed and its temperature being to approach freezing.

Preparation Before Concreting

Before concreting is started, all ice, snow and frost should be completely removed from the interior of forms and from reinforcing steel and parts to be embedded. The temperature of all surfaces to be in contact with the concrete should be raised as nearly as practical to the temperature of the fresh concrete to be placed. Concrete should never be placed on a frozen subgrade or on one that contains frozen materials.

Prior to placement of concrete, the subgrade may be protected from freezing by covering it with straw and tarpaulins or plastic sheets or other insulating blankets.

Temperature of Concrete as Placed - Heating of Materials

The temperature of concrete leaving the mixer should be no higher than necessary to assure that the concrete after exposure, during transportation and placing, will have a temperature not more than a few degrees higher than the specified minimum. The temperature of the exposed concrete will depend on the atmospheric temperature, but rarely is it necessary for concrete leaving the mixer to be warmer than 65° to 75° F. Current SCS specifications provide that the temperature of the concrete at the time of placing should not be less than 50° F. nor more than 90° F.

Overheating of concrete is objectionable because it may accelerate chemical action, cause excessive loss of slump, and increase the water requirement for a given slump. Moreover, the warmer the concrete, as placed, the greater the drop to ultimate low temperatures, with corresponding increase in thermal shrinkage.

To obtain the required temperatures for freshly mixed concrete in cold weather, it is necessary to heat mixing water or aggregates, or both, depending on severity of the weather. Heating of the mixing water is the most practicable and efficient procedure. Water is not only easy to heat, but each pound of water heated to a given temperature has roughly five times as many available heat units in it as are in a pound of aggregate or cement at the same temperature.

Mixing water should be heated in such a manner and in sufficient quantity that appreciable fluctuations in temperature from batch to batch are avoided. Very hot water should not be allowed to touch the cement because of the danger of causing quick or "flash" set. If hot water and the coldest portion of the aggregate can be brought together in the mixer first so that the temperature of this mixture does not exceed 100° F., the possibility of flash set will be minimized and advantage can be taken of high water temperatures.

If heating of aggregates is used as an alternative method, the aggregates should be heated uniformly and carefully, eliminating all frozen lumps, ice, and snow, and avoiding overheating or excessive drying. Unless temperatures are uniform, noticeable variations in water requirement and slump will occur. Average temperatures should not exceed 150° F., for temperatures much above this may crack the aggregate.

Heating of aggregates is preferably accomplished by steam or hot water in pipes. Heating with steam jets is objectionable because of the resulting variable moisture in the aggregate. Experience has demonstrated that this variable moisture can be exceedingly troublesome. On small jobs, aggregates may be thawed by heating carefully over metal culvert pipes in which fires are maintained. Exposed surfaces of aggregates in stockpiles, bins, etc., should be covered with tarpaulins during heating to obtain a uniform distribution of the heat and avoid frozen crusts.

Table 1 illustrates the effect of the temperature of materials on the temperature of freshly mixed concrete.

Protection

Protection required in cold weather is only that necessary to keep the temperature of the concrete from falling below 50° F. Adequate protection can often be provided by conserving the heat of hydration generated by the hardening concrete.

Heat may be retained in the concrete by use of commercial insulating blanket or bat insulation. The effectiveness of insulation can be determined by placing a thermometer under the insulation in contact with the concrete. If the temperature falls below the minimum required, additional insulating material should be applied. Corners and edges of concrete are most vulnerable to freezing and should be checked to determine effectiveness of the protection.

Forms built for repeated use often can be economically insulated. Commercial blanket or bat insulation used for this purpose should have a tough moistureproof covering to withstand handling abuse and exposure to the weather.

Table 2 gives insulation values for commonly used materials. Tables 3 and 4 show the amount of insulation necessary for good protection for various kinds of work and different weather conditions.

Enclosures for heating may be made of wood, canvas, wall board, plywood, waterproof paper, plastic sheeting or other suitable material. A wood framework covered with tarpaulins or plastic sheets is commonly used. Enclosures should be sturdy and reasonably airtight with sufficient space for circulation of warmed air. Openings for access should be few and preferably should be self-closing; at least they should be easily closed.

Heat may be supplied by live or piped steam, by salamanders or stoves of various types, or by airplane heaters located outside the enclosure. Salamanders and stoves are easily handled and inexpensive and are convenient for small jobs but they have the disadvantages of producing dry heat, of emitting fumes and smoke which often disfigure the work, and of being fire hazards. They often cause fire losses which would more than offset the cost of live steam heating, even on relatively small jobs.

If salamanders or stoves are used, they should be blocked up to avoid damage to the slab on which they are resting and vented to the outside to prevent carbonation damage to the exposed concrete surfaces. Adequate firefighting apparatus should be on the job at all times to insure continuous operation of heating units and protection from fire hazards.

Housing and enclosures should be left in place for the entire seven day curing period except that sections may be temporarily removed as required to permit placing additional forms or concrete, provided they are replaced as soon as the form or concrete is in its final position and the uncovered concrete is not frozen, and provided time lost from the required period of protection is made up at the required temperature before protection is discontinued and removed.

Rapid cooling of the concrete at the end of the heating period should be avoided. Sudden cooling of the concrete surface while the interior is still warm may cause cracking. Cooling should be gradual so the maximum drop in temperature throughout the first 24 hours will not be more than that given in Table 1. Gradual cooling can often be accomplished by simply shutting off the heat and allowing the enclosure to cool to outside air temperature.

Temperature Records

Inspection personnel should keep a record of the date, hour, outside air temperature, temperature of concrete as placed, and weather (calm, windy, clear, cloudy, etc.). The record should include temperatures at several points within the enclosure and on the concrete surface, corners, and edges in sufficient number to show highest and lowest temperatures of the concrete. Thermometers embedded in the concrete surface are ideal, but satisfactory accuracy and greater flexibility of observation can be obtained by placing the thermometer against the concrete under a temporary cover of heavy insulating material until it registers a constant temperature. Maximum and minimum temperature readings in each 24-hour period should be recorded. Data recorded should clearly show the temperature history of each part of the concrete. A copy of the temperature readings should be included in permanent records of the job.

Cold Weather Curing

It is essential that new concrete in all weather be protected from drying out for a curing period of at least seven days after placement so that adequate hydration may be achieved. This requirement normally means that positive measures must be taken to prevent excessive evaporation of moisture from concrete.

Concrete exposed to cold weather is not likely to dry at an undesirable rate. As long as forms remain in place, surfaces adjacent to the forms are adequately cured in cold weather. But unformed surfaces, particularly finished floors, are prone to rapid drying in a heated enclosure. When concrete warmer than 60° F. is exposed to air at 50° F., it is essential that positive measures be undertaken to prevent drying. The preferable technique is the use of steam for both heating and to prevent excessive evaporation. If a curing compound is to be used, it should not be applied until the use of steam has been discontinued. When dry heating is used the concrete should be covered with an approved impervious material or curing compound.

References

1. United States Department of Interior, Bureau of Reclamation, Concrete Manual
2. American Concrete Institute, ACI Standard 306-78, Cold Weather Concreting.
3. Portland Cement Association, Design and Control of Concrete Mixtures, Eleventh Edition.

TABLE 1 -- EFFECT OF TEMPERATURE OF MATERIALS ON TEMPERATURE OF VARIOUS FRESHLY MIXED CONCRETES 1/

Approximate maximum size rock, in.		1-1/2			
Approximate percent sand		35			
Weight of sand for batch, lb.		1100			
Weight of coarse aggregate for batch, lb.		2100			
Weight of water for batch (total) lb.		250			
Weight of cement for batch, lb.		500			
Minimum temperature fresh concrete as placed, Deg. F.		50			
Minimum temperature fresh concrete as mixed for weather 2/ Deg. F.	Above 30 F	55			
	0 to 30 F	60			
	Below 0 F	65			
Minimum temperature of materials to produce indicated temperature of freshly mixed concrete, deg. F	Cement 3/	35	10	10	-10
	Added water	140	140	140	140
	Aggregate water 4/	38	95	50	61
--	Sand	38	95	50	61
--	Coarse aggregate	38	10 5/	50	61
Temperature mixed concrete, deg. F		60	65	65	70
Maximum allowable gradual drop in temperature throughout first 24 hours after end of protection, deg. F		50			

1/ Adapted from ACI Standard 306-78 and USDI-BR Concrete Manual.
2/ For colder weather a greater margin is provided between temperature of concrete as mixed and the required minimum temperature of fresh concrete in place.
3/ Cement temperature has been considered the same as that of average air and of unheated materials.
4/ The amount of free water in the aggregate has been assumed equal to ¼ of the mix water.
5/ Coarse aggregate at temperatures below freezing is assumed to be surface dry and free of ice.

TABLE 2 - INSULATION VALUES OF VARIOUS MATERIALS

Insulating Material	Thermal resistance R for these thicknesses of material* 1-in., deg F/Btu/hr ft^2
Boards and slabs	
Expanded polyurethane (R-11 exp.)	6.25
Expanded polystyrene extruded (R-12 exp.)	5.00
Expanded polystyrene extruded, plain	4.00
Glass fiber, organic bonded	4.00
Expanded polystyrene, molded beads	3.57
Mineral fiber with resin binder	3.45
Mineral fiber board, wet felted	2.94
Sheathing, regular density	2.63
Cellular glass	2.63
Laminated paperboard	2.00
Particle board (low density)	1.85
Plywood	1.25
Blanket	
Mineral fiber, fibrous form processed from rock, slag, or glass	3.23
Loose fill	
Wood fiber, soft woods	3.33
Mineral fiber, (rock, slag, or glass)	2.50
Perlite (expanded)	2.70
Vermiculite (exfoliated)	2.20
Sawdust or shavings	2.22

*Values from *ASHRAE Handbook of Fundamentals*, 1977, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, New York.

TABLE 3 - THERMAL INSULATION PROVIDED FOR CONCRETE WALLS ABOVE GROUND

Concrete placed and surface temperature maintained at 50° F. for 7 days

Wall Thickness, in.	Minimum ambient air temperature, deg F allowable when insulation having these values of thermal resistance R, deg F/Btu/hr ft^2 is used			
	R = 2	R = 4	R = 6	R = 8
Cement Content = 500 lb/yd^3				
6	47	43	38	33
12	42	31	20	9
18	36	19	2	-15
24	30	7	-16	-39
36	18	-15	-46	-79
48	10	-25	-60	--
60	10	-25	--	--
Cement Content = 600 lb/yd^3				
6	46	41	35	29
12	40	28	14	0
18	33	13	-7	-29
24	26	-1	-28	-55
36	12	-27	-66	--
48	4	-40	--	--
60	4	-40	--	--

TABLE 4 - THERMAL INSULATION PROVIDED FOR CONCRETE SLABS PLACED ON THE GROUND

Concrete placed and surface temperature maintained at 50° F. for 7 days on ground at 35° F.

Slab depth, in.	Minimum ambient air temperature, deg F allowable when insulation having these values of thermal resistance R, deg F/Btu/hr ft^2 is used			
	R = 2	R = 4	R = 6	R = 8
Cement Content = 500 lb/yd^3				
4	*	*	*	*
8	*	*	*	*
12	48	44	40	36
18	36	22	8	-6
24	28	6	-16	-38
30	22	-7	-36	-64
36	16	-18	-50	--
Cement Content = 600 lb/yd^3				
4	*	*	*	*
8	*	*	*	*
12	44	38	32	26
18	31	14	-5	-24
24	22	-5	-32	-61
30	14	-19	-67	--
36	7	-30	--	--

* Owing to influence of cold subgrade on thin slabs, insulation alone will not maintain the temperature of concrete at the specified 50° F. minimum after placing in cold weather. In such cases, additional heat is necessary to maintain required temperatures in the concrete by using higher placing temperatures, by preheating the ground, by placing electric resistance wire under the insulation, or by other means, depending on the severity of the prevailing weather.