HOT WEATHER CONCRETING

Dr. Muhammad Yousaf

Detrimental hot weather conditions include:

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

Effect of Temperature on the Concrete

- The heat generated from the hydration of cement causes a rise in temperature of concrete. If this rise occures uniformly throughout a given concrete element without any external restraint, the element would expand until the maximum temperature has been reached. The concrete will then cool down with uniform contraction as it loses heat to the ambient atmosphere. This uniform expansion and contraction will result in no thermal stresses within the concrete element.
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Effect of Temperature on the Concrete

- According to Neville (1997), restraint exists in all but the smallest of concrete members. These thermal restraints result in external and internal cracking of the concrete. Figure 2.1 shows an example of temperature change,which causes external cracking of large concrete mass. The critical 20^{o}C (35^{o}F) temperature difference occurs during cooling (FitzGibbon, 1976).

Effect of Temperature on the Concrete

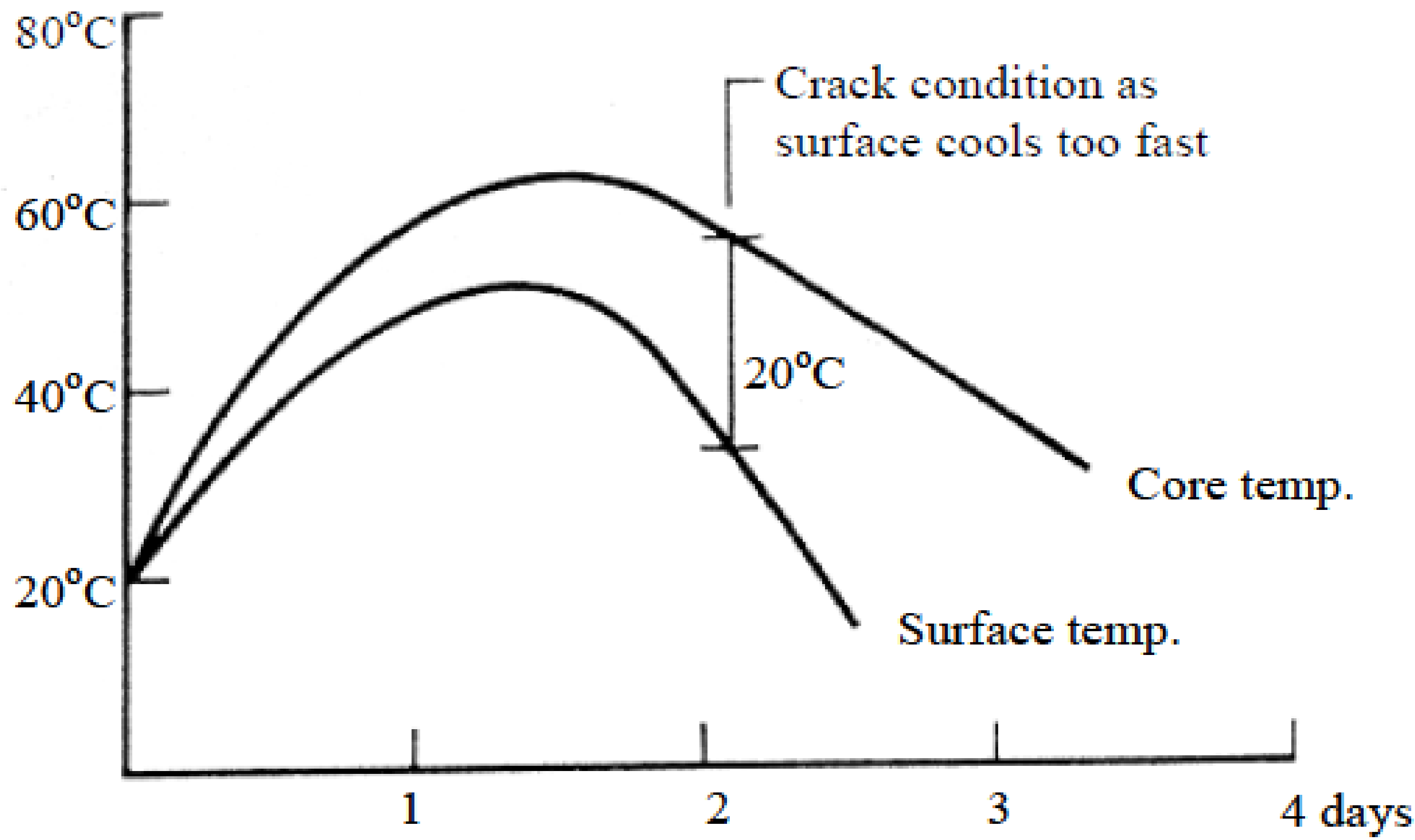


Figure 2.1 External thermal cracking

Effect of Temperature on the Concrete

- In massive concrete structures, internal restraint occurs from the inability of the heat to dissipate quickly from the core of the member due to the low thermal diffusivity of the concrete. A temperature differential is set up between the core of the concrete and the surface due to the accumulation of the heat from the hydration process. The unequal thermal expansion in the various parts of the concrete member results in stresses, compressive in one part and tensile in the other. Cracking of the surface results when the tensile stresses at the surface of the element due to the expansion of the core exceed the tensile strength of the concrete.

Effect of Temperature on the Concrete cracking

- According to FitzGibbon (1976), the cracking strain of concrete is reached when an internal thermal differential of 20oC (36oF) is exceeded. Figure 2.2 shows a pattern of temperature change, which causes internal cracking of a large concrete mass. The critical 20oC (36oF) temperature is reached during heating but cracks open only when the interior has cooled through a greater temperature range than the exterior. Cracking due to thermal behavior may cause loss of structural integrity and monolithic action or may cause extreme seepage and shorten the service life of the concrete structure.

Effect of Temperature on the Concrete cracks

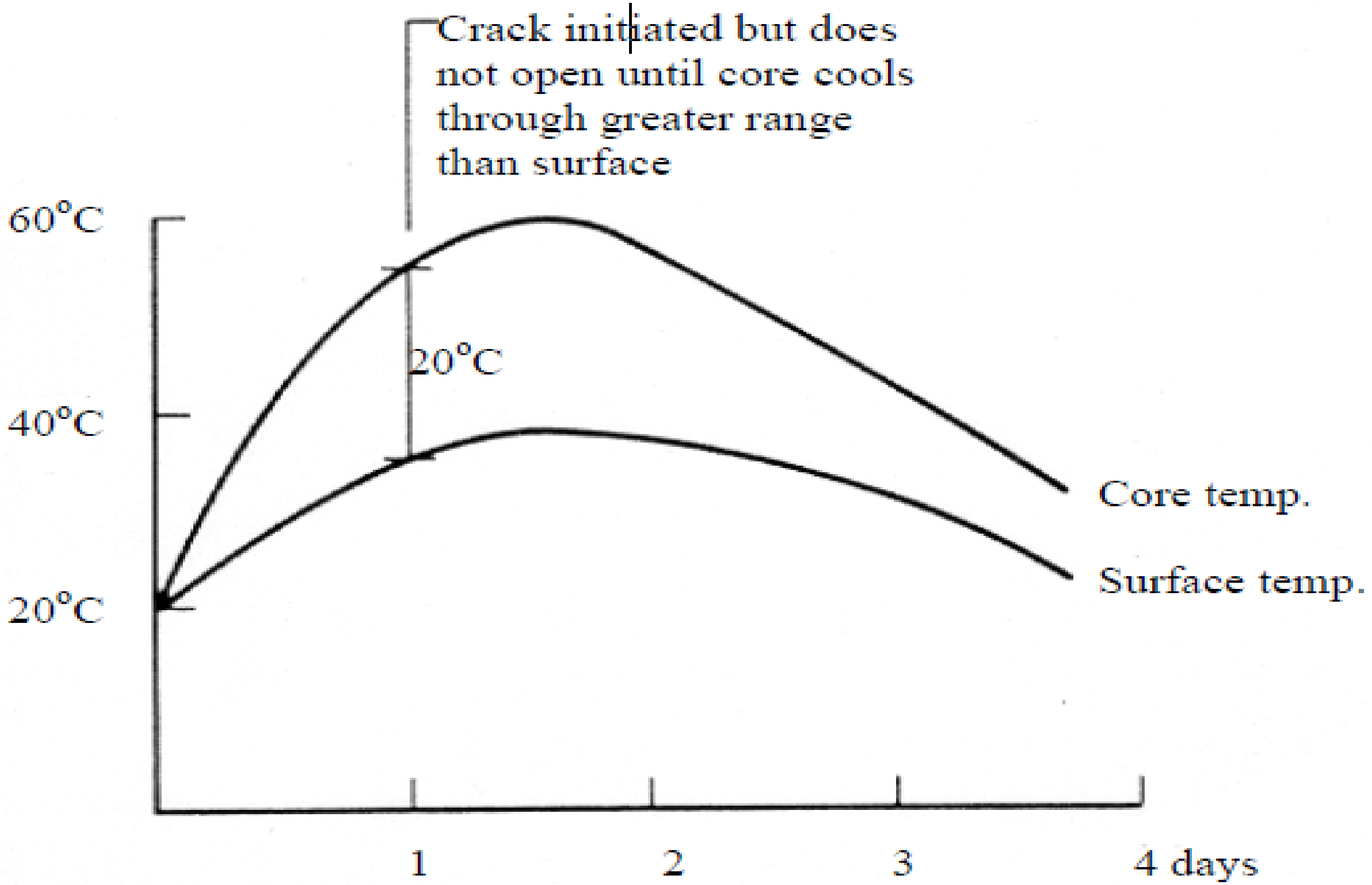


Figure 2.2 Internal thermal cracking

Measures to reduce Temperature

Various measure are undertaken to reduce the temperature rise in large concrete pours. Notable among these measures include:

Careful and sensible

- The prudent selection of a low-heat-generating cement system including pozzolans;
- The reduction of the cementitious content;
- The careful production control of aggregate gradations and the use of large-size aggregates in efficient mixes with low cement contents;

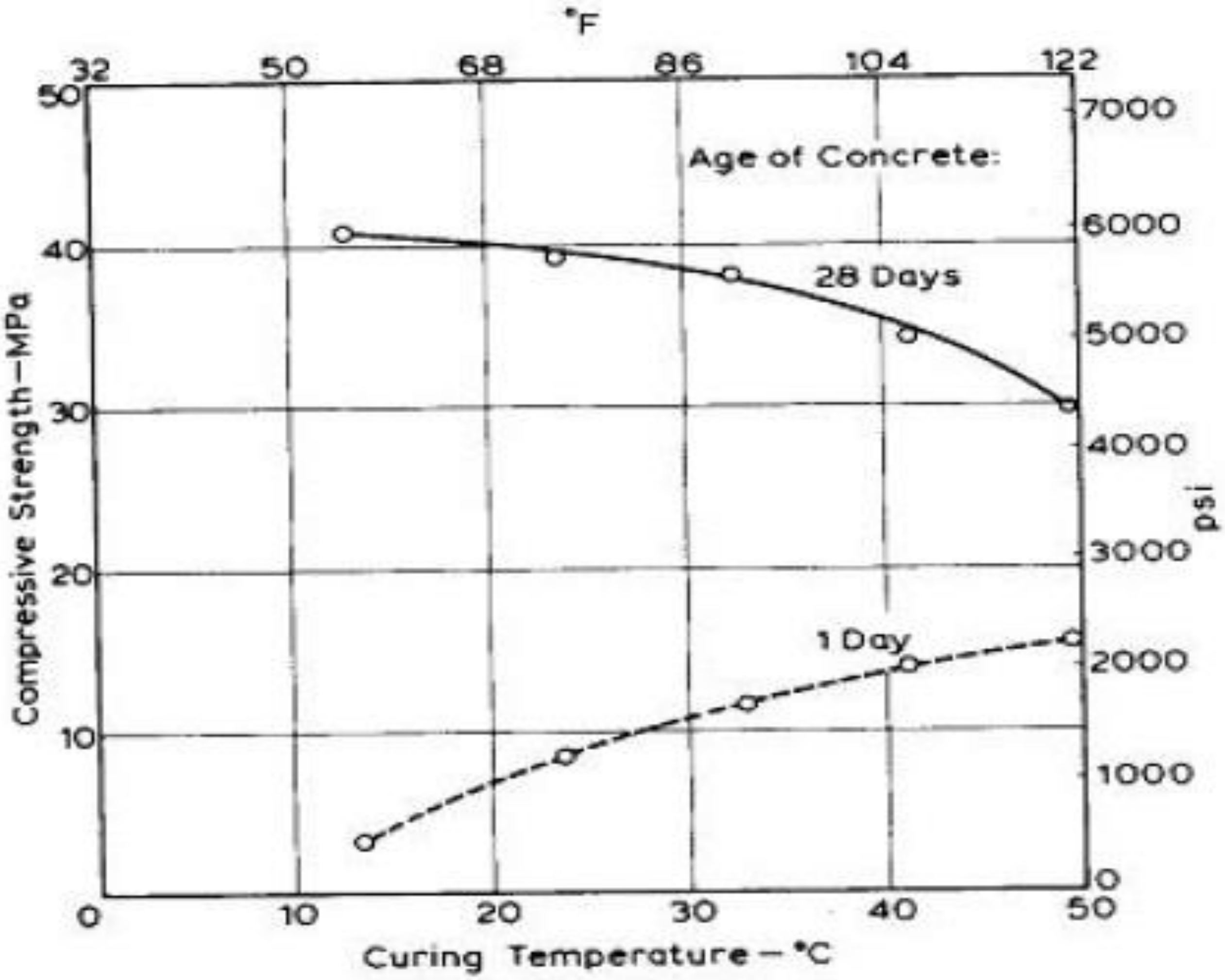
Measures to reduce Temperature

- The precooling of aggregates and mixing water (or the batching of ice in place of mixing water) to make possible a low concrete temperature as placed;
- The use of air-entraining admixtures and chemical admixtures to improve both the fresh and hardened properties of the concrete;
- Coordinating construction schedules with seasonal changes to establish lift heights and placing frequencies;
- The use of special mixing and placing equipment to quickly place cooled concrete with minimum absorption of ambient heat;
- Dissipating heat from the hardened concrete by circulating cold water through embedded piping;
- Insulating surfaces to minimize thermal differentials between the interior and the exterior of the concrete.

Effect of Temperature on the Durability of Concrete

- According to ACI Committee 201, durability of Portland cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration.
- Durable concrete will retain its original form, quality, and serviceability when exposed to its environment. Although designers of concrete structures have been mostly interested in the strength characteristics of concrete, durability issues in concrete technology have been brought to the forefront in recent times as a result of the premature failure of nondurable concrete structures.

Effect of Temperature on the durability of concrete



Effect of curing temperature on concrete strength development

Stages	Effects
Production	• Increased water demand for given workability • Increased difficulty in controlling entrained air content
Transit	• Loss of water by evaporation • Increased rate of loss of workability
Placing, finishing and curing	• Loss of water by evaporation • Increased rate of loss of workability • Increased rate of setting • Increased tendency to plastic shrinkage cracking • Higher peak temperature during hydration leading to increased tendency to cracking
Long-term	• Lower long-term strength • Lower strength • Decreased durability • Variable appearance

Difficulties in Hot Weather

- Increased water demand.
- Accelerated slump loss.
- Increased rate of setting.
- Increased tendency of plastic shrinkage cracking.
- Critical need for prompt early curing.

Hot Weather Concreting

- Certain precautions should be taken in order to reduce the difficulties in hot weather conditions.
- Temperature ranging from 10 to 15˚C is desirable, but such temperatures are not always practical.
- Many specifications require that concrete when placed should have a temperature of less than 29 to 32˚C.

Precautions Depend on

- Type of construction.
- Characteristics of the materials being used.
- The experience of placing and finishing crew Working Staff in dealing with the atmospheric conditions in the site.

Precautions

- Use materials and mix proportions that have a good record in hot weather conditions.
- Cool the concrete or one or more of its ingredients.
- Use a concrete consistency that allows rapid placement and consolidation.
- Reduce the time of transporting, placing, and finishing as possible.
- Schedule concrete placements to avoid extreme weather, such as at night or during favorable weather conditions.
- Consider the methods to limit moisture loss during placing and finishing such as sunshades, wind screens, fogging, and spraying.

Effect of High Concrete Temperature

- 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.

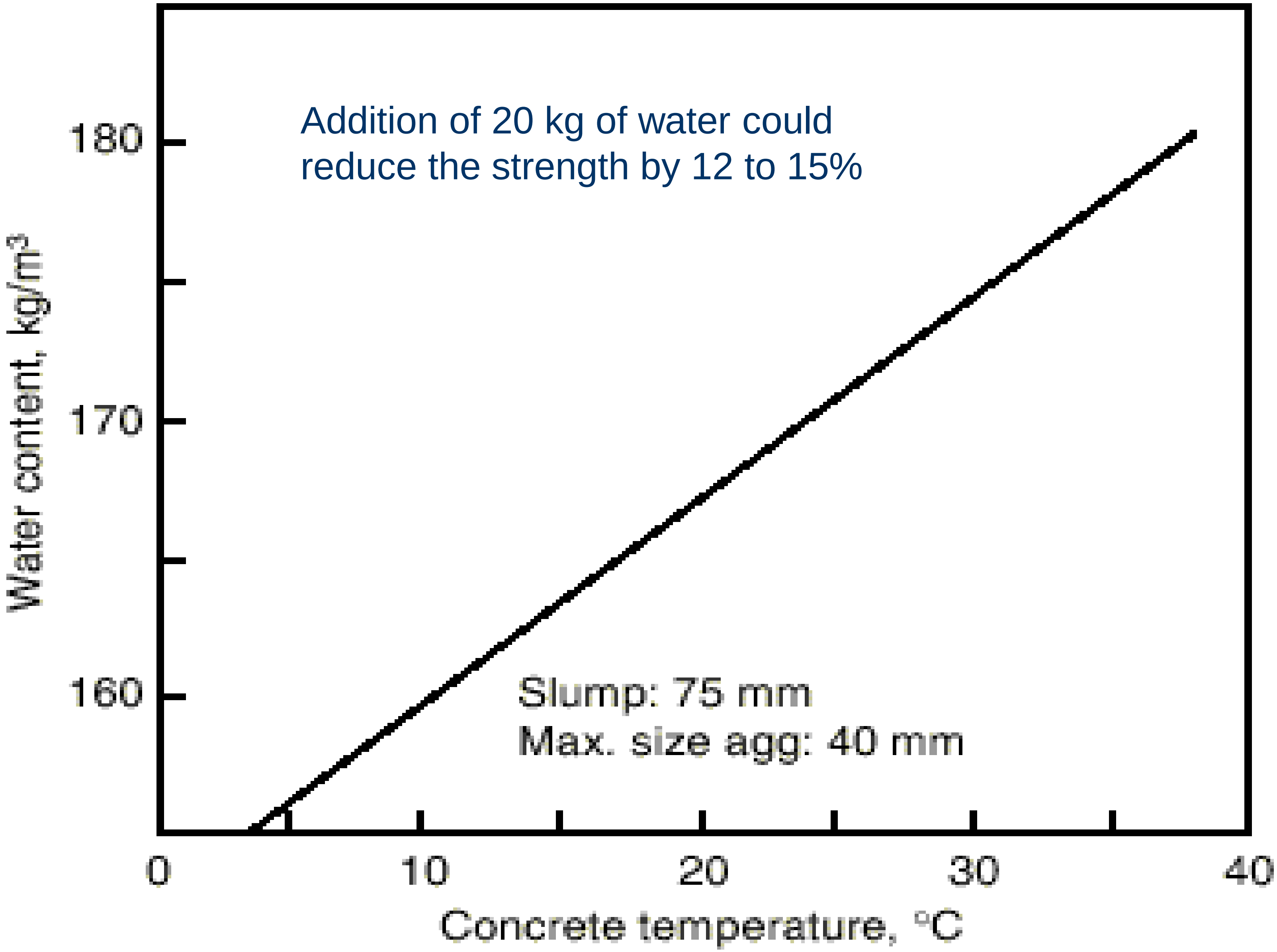


Fig. 13-2. The water requirement of a concrete mixture increases with an increase in concrete temperature (Bureau of Reclamation 1981).

Effect of High Concrete Temperature

- **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 increase in concrete temperature

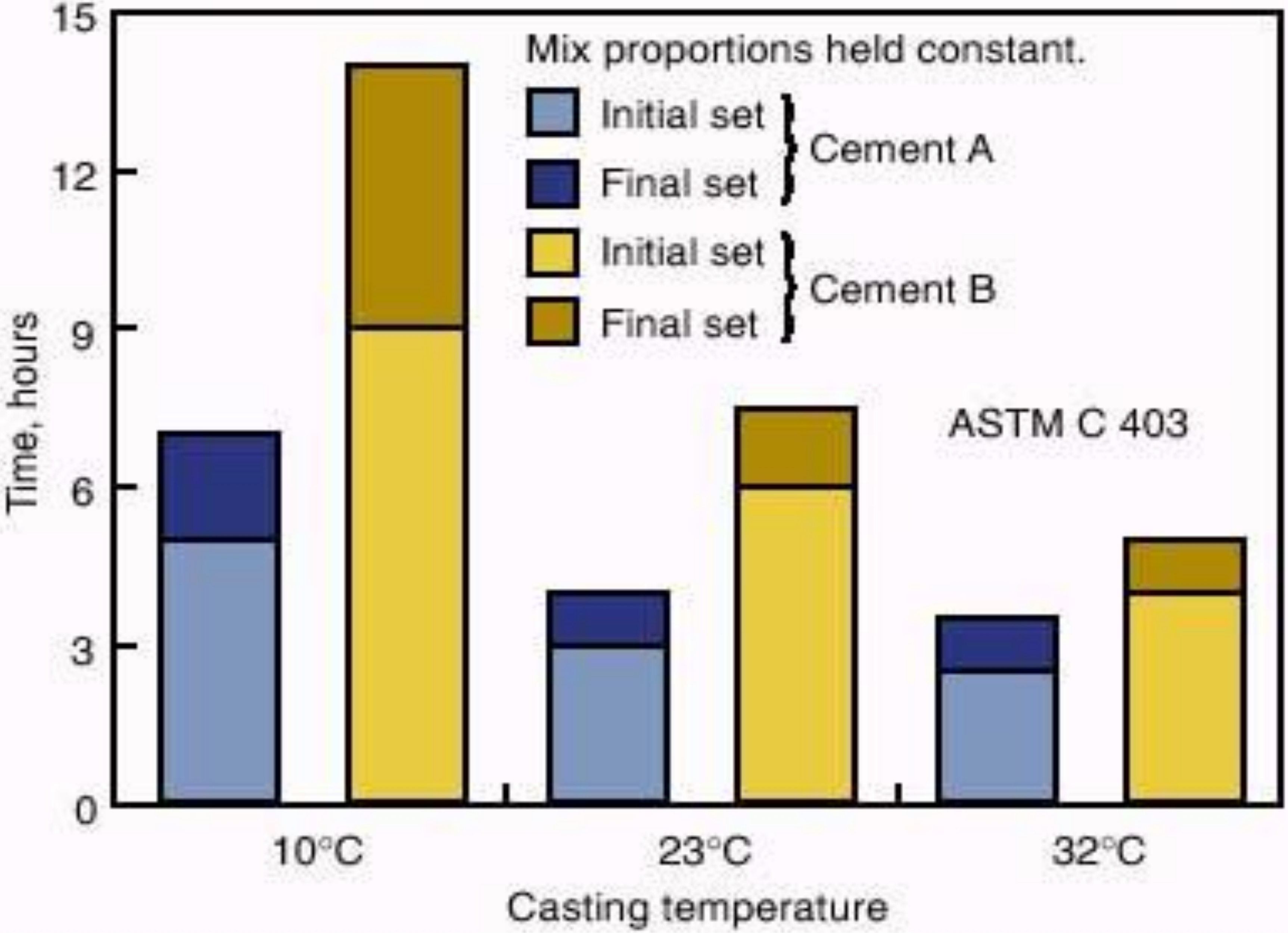


Fig. 13-3. Effect of concrete temperature on setting time (Burg 1996).

Effect of High Concrete Temperature

- 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.
- 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.

Effect of High Concrete Temperature

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

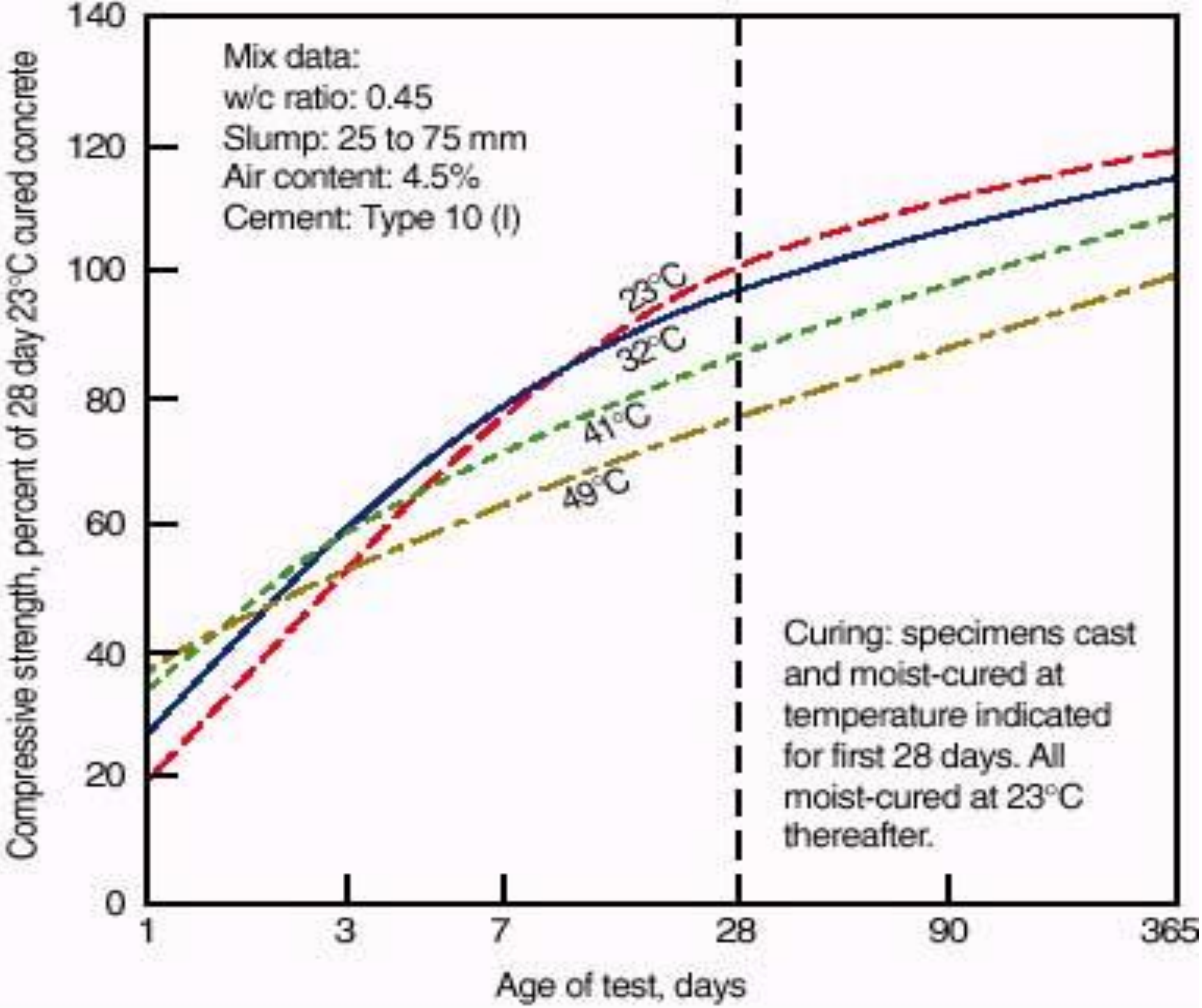


Fig. 13-4. Effect of high concrete temperatures on compressive strength at various ages (Klieger 1958).

Cooling Concrete Materials

- Lower the temperature of concrete materials before mixing.
- The contribution of each material is related to
  - Temperature.
  - Specific heat.
  - Quantity of each material.

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

- Where T = temperature of the freshly mixed concrete, °Celsius
  Ta, Tc, Tw, and Twa = temperature (°Celsius) of aggregates, cementing materials, added mixing water, and free water on aggregates, respectively

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

- where Mi is the mass in kilograms of ice

Table 13-2B. Effect of Ice (44 kg) on Temperature of Concrete

Material	Mass, M, kg	Specific heat kJ/kg • °C	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

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

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

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)

Supplementary Cementitious Materials

- The use of supplementary materials (fly ash, ground granulated blast furnace slag) can help in hot weather conditions.
- These material slow the rate of setting as well as the rate of slump loss.

Preparation Before Placing

- Mixers, chutes, conveyor belts, hoppers, pump lines, and other equipments for handling concrete should be shaded, painted white, or covered with wet burlap to reduce solar heat. coarse jute fabric
- Forms, reinforcing steel, and subgrade should be fogged or sprinkled with cool water just before concrete is placed.
- Restrict placement of concrete to early morning, evening, or night time hours, especially in arid dry climates. This will help in minimizing thermal shrinkage and cracking of thick slabs and pavements.

Transporting, Placing, and Finishing

- Should be done as quickly as practical during hot weather.
- Delays contribute to the loss of slump and increase in concrete temperature.
- Prolonged mixing should be avoided.
- If delays occur, stopping mixer and then agitating can minimize the heat generated by mixing.

Stirring

Transporting, Placing, and Finishing

- Setting of concrete is more rapid in hot weather.
- Extra care must be taken with placement techniques to avoid cold joints.
- Temporary sunshades and windbreaks help to minimize cold joints.

Plastic Shrinkage Cracking

- Associated with hot-weather concreting,
- 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.
- Rapid drying shrinkage creates tensile stresses in the surface that often result in short, irregular cracks.

Plastic Shrinkage Cracking

- Plastic shrinkage cracking increases with:
    1. Low air temperature
    2. High concrete temperature
    3. Low humidity
    4. High wind speed

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

Plastic Shrinkage Cracking

- When the rate of evaporation exceeds 1 kg/m2 per hour, precautionary measures such as windscreens are required around all sides of concrete elements.
- With concrete mixtures containing pozzolans, cracking is possible if the rate of evaporation exceeds 0.5 kg/m2 per hour.
- Concrete containing silica fume is particularly prone to plastic shrinkage because bleeding rates are commonly only 0.25 kg/m2 per hour.

To use this chart:

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.

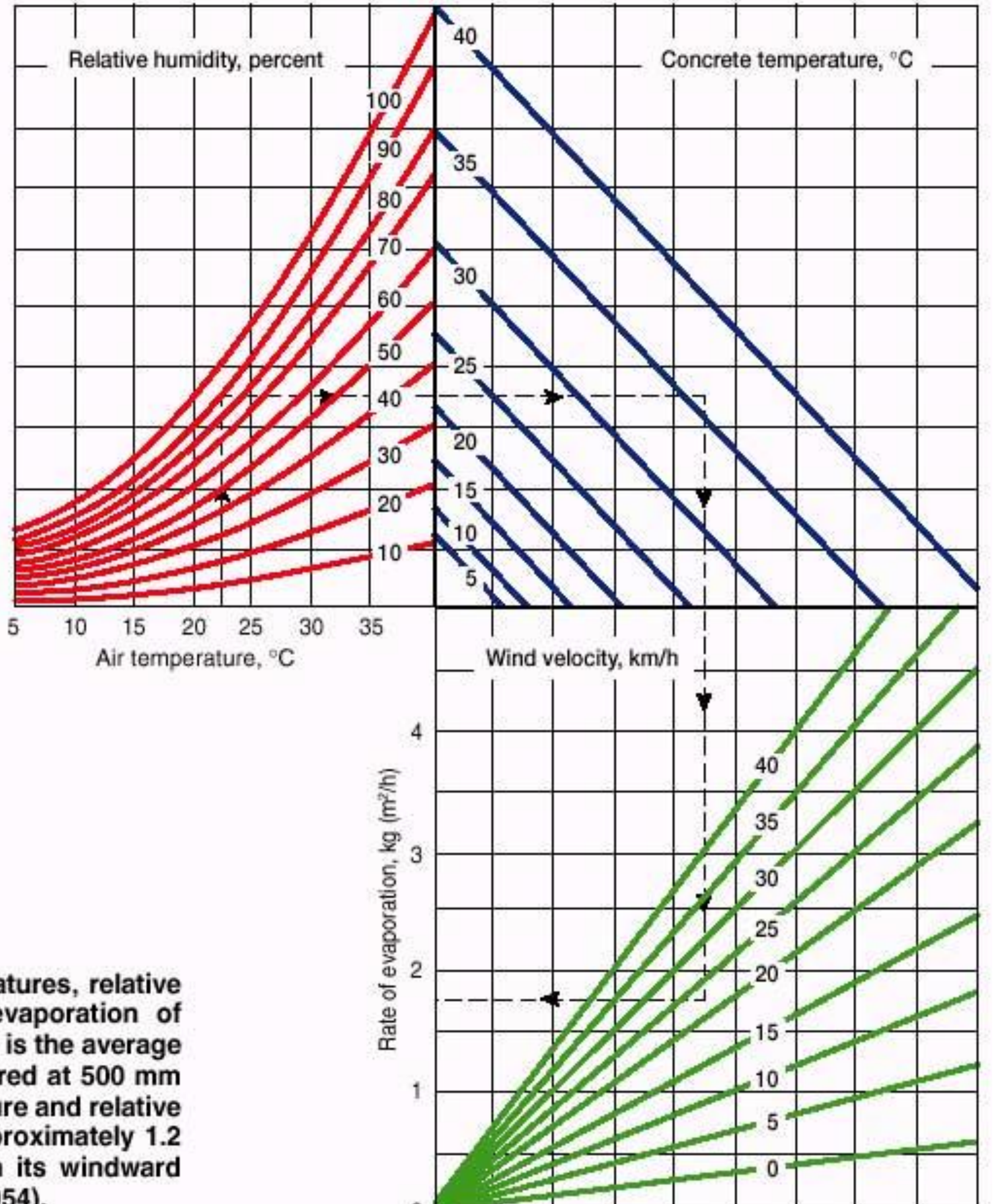


Fig. 13-8. Effect of concrete and air temperatures, relative humidity, and wind velocity on rate of evaporation of surface moisture from concrete. Wind speed is the average horizontal air or wind speed in km/h measured at 500 mm above the evaporating surface. Air temperature and relative humidity should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

Precautions to Minimize Plastic Shrinkage Cracking

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.

Precautions to Minimize Plastic Shrinkage Cracking

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.

Methods to Minimize Plastic Drying Shrinkage

- 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.
- Spray application of temporary moisture-retaining films (usually polymers).
- 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)

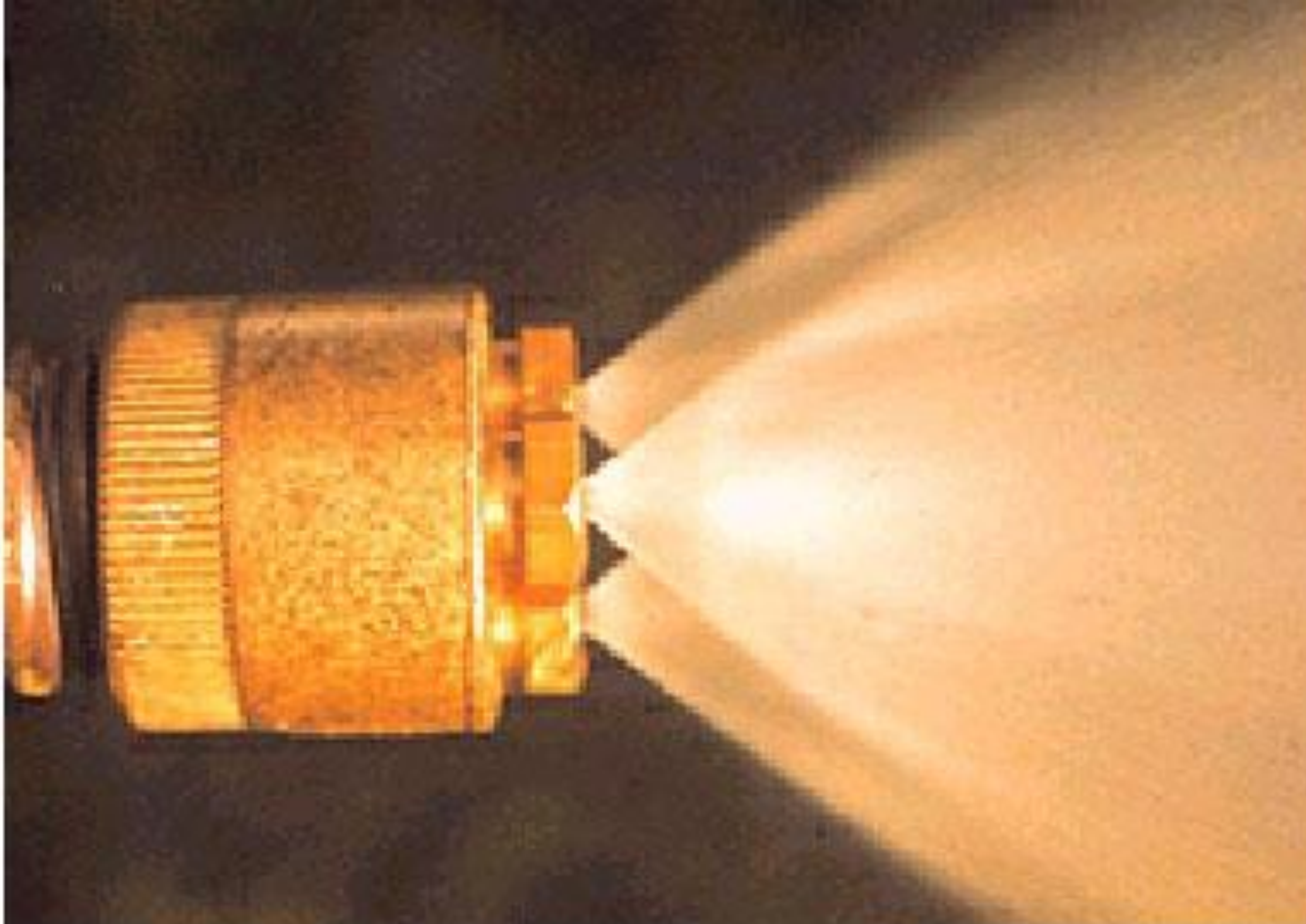


Fig. 13-10. Fog nozzle. (9853)

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)

Curing in Hot Weather

- 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.
- When the air temperature is at or above 27°C, curing during the **basic curing** period should be accomplished by water spray or by using saturated absorptive fabric

Curing in Hot Weather

- For mass concrete, curing should be by water for the basic curing period when the air temperature is at or above 20°C, in order to minimize the temperature rise of the concrete.
- If approved, the application of the curing compound should be preceded by 24 hours of moist curing.
- **Crazing cracks** are very fine and barely visible except when the concrete is drying after the surface has been wet. They do not penetrate much below the surface.

Admixtures

- **A retarding admixtures** can be very helpful in delaying the setting time, despite increased rate of slump loss resulting from their use.
- **A hydration control admixture** can be used to stop cement hydration and setting. As a general rule a 5°C to 9°C temperature rise per 45 kg of Portland cement can be expected from the heat of hydration.