

Hot-Weather Concreting

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Abstract: In practice, concrete is mixed at a wide range of temperatures and also remains in service at different temperatures. There are some special problems involved in concreting in hot weather, arising both from a higher temperature of the concrete and, in many cases, from an increased rate of evaporation from the fresh mix. These problems concern the mixing, placing and curing of the concrete. Hot-weather concreting is not so much an unusual or a specialized process; rather, it requires taking certain recognized measures to minimize or control the effect of high ambient temperature, high temperature of the concrete, low relative humidity, high wind velocity, and high solar radiation. What is required on each construction project where any one or more of the above conditions exist is to develop appropriate techniques and procedures and to follow them rigorously.

Introduction

Laboratory testing of concrete is usually performed at a controlled temperature, normally constant. In practice, however, concrete is mixed at a wide range of temperatures and also remains in service at different temperatures. Indeed, the actual range of temperatures has widened considerably with much modern construction taking place in countries which have a hot climate.

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Effects of Hot Weather Conditions

Because high temperatures increase the speed of hydration of cement and setting of concrete, a good planning is needed for placing the concrete at high temperatures.

The most unsuitable conditions for pouring of concrete are hot, sunny, windy and dry (having low relative humidity) weather. The increase in temperature of weather increases the rate of evaporation, e.g. an increase of 10 °C in temperature increases the evaporation about 2 times. If the concrete has a higher temperature than the weather the evaporation becomes more rapidly. When the humidity in the air decreases the evaporation becomes easy and fast. As the relative humidity decreases from 90 % to 5 %, it is seen that evaporation increases about 5 times. In the sunny days, when the wind velocity increases from 0 to 20 km/h the evaporation increases about 4 times (Baradan, 1998).

A high ambient temperature causes a higher water demand of the concrete and increases the temperature of the fresh concrete. This results in an increased rate of loss of slump and in a more rapid hydration, which leads to accelerated setting and to a lower long-term strength of concrete. Furthermore, rapid evaporation may cause plastic shrinkage cracking and crazing, and subsequent cooling of the hardened concrete can introduce tensile stresses. It is generally believed that plastic shrinkage cracking is likely to occur when the rate of evaporation exceeds the rate at which the bleeding water rises to the surface, but it has been observed that cracks also form under a layer of water and merely become apparent on drying.

Plastic shrinkage cracks can be very deep, ranging in width between 0,1 and 3 mm, and can be short as long as 1 m. (Neville, 1997).

Influence of Early Temperature on Strength of Concrete

A rise in the curing temperature speeds up the chemical reactions of hydration and thus affects beneficially the early strength of concrete without any ill-effects on the later strength. Higher temperature during and following the initial contact between cement and water reduces the length of the dormant period so that the overall structure of the hydrated cement paste becomes established very early.

Although a higher temperature during placing and setting increases the very early strength, it may adversely affect the strength from about 7 days onwards. The explanation is that a rapid initial hydration appears to form products of a poor physical structure, probably more porous, so that a proportion of the pores will always remain unfilled. It follows from the gel/space ratio rule, that this will lead to a lower strength compared with a less porous, though slowly hydrating, cement paste in which a high gel/space ratio will eventually be reached.

The rapid initial rate of hydration at higher temperatures retards the subsequent hydration and produces a non-uniform distribution of the products of hydration within the paste. The reason for this is that, at the high initial rate of hydration, there is insufficient time available for the diffusion of the products of hydration away from the cement particle and for a uniform precipitation in the interstitial space.

In connection with the influence of temperature during the early life of concrete on the overall structure of the hydrated cement paste, it is useful to recall that a low early gain of strength has a beneficial effect on strength also when the hydration is slowed down by the use of retarders. Water-reducing and set-retarding admixtures were found to be beneficial in compensating for the reduction in the long-term strength of admixture-free concrete placed at a high temperature. However their effect arises from water reduction and therefore a lower water/cement ratio. Moreover, the rate of loss of slump is higher when these admixtures are used (Neville, 1997).

Evaporation from Fresh Concrete

The combined effects of air temperature, humidity, concrete temperature and wind velocity as they influence rate of evaporation of water from freshly placed and unprotected concrete is presented in Figure 1. This information is based on data taken from a free water surface. As an example, with air temperature at 26°C, a relative humidity at 50%, a concrete temperature of 30°C and a wind velocity of 20 km/hr, the rate of evaporation would be 1.2 kg/m² hr.

Importantly, plastic shrinkage cracking more commonly occurs when the rate of evaporation exceeds 0.5 kg/m² hr. When the evaporation rate exceeds 1.0 kg/m²hr, precautionary measures to prevent plastic shrinkage are mandatory.

The hydration is greatly reduced when the relative humidity within the capillary pores drops below 80 per cent. Hydration at a maximum rate can proceed only under conditions of saturation. For hydration to continue, the relative humidity inside the concrete has to be maintained at a minimum of 80 per cent. If the relative humidity of the ambient air is at least that high, there will be little movement of water between the concrete and the ambient air, and no active curing is needed to ensure continuing hydration. The preceding statement is valid only if no other factors intervene, e.g. there is no wind, there is no difference in temperature between the concrete and the air, and if the concrete is not exposed to solar radiation. In practice, therefore, active curing is unnecessary only in a very humid climate with a steady temperature.

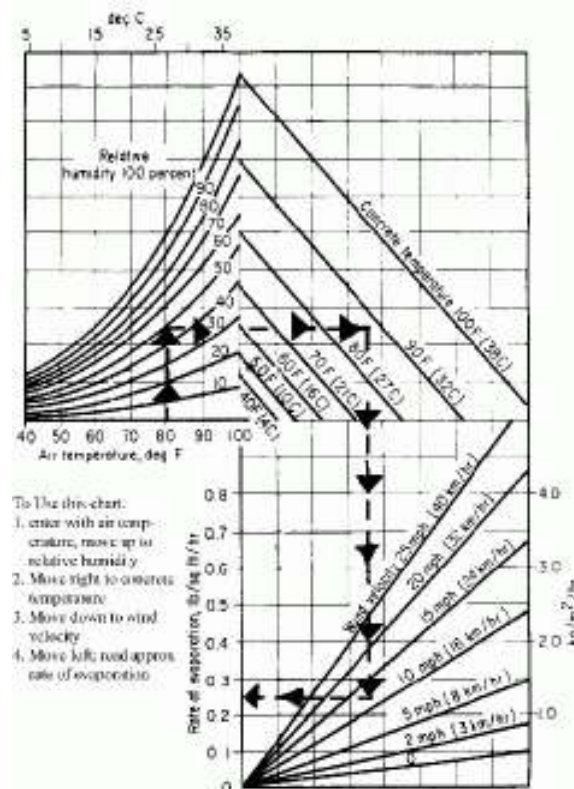


Figure 1: Influence of air temperature, relative humidity, concrete temperature and wind velocity on rate of evaporation

Prevention of the loss of water from the concrete is of importance not only because the loss adversely affects the development of strength, but also because it leads to plastic shrinkage, increased permeability, and reduced resistance to abrasion.

For hydration of cement to continue, it is sufficient to prevent the loss of moisture from the concrete. This is true only if the water/cement ratio of the concrete is sufficiently high for the quantity of the mix water to be adequate for hydration to continue.

The minimum periods of curing for external exposure are given in Table 1.

Rate of gain of strength of concrete		2)apid	R	3)edium	M	4)low	S
Temperature of concrete, °C		5	10	15	5	10	15
Ambient conditions during curing [rh = relative humidity in per cent]	No sun, rh ≥ 80	2	2	1	3	3	2
	Medium sun or medium wind or rh ≥ 50	4	3	2	6	4	3
	Strong sun or high wind or rh < 50	4	3	2	8	6	5

Table 1: Minimum curing times (in days) due to rate of gain of strength of concrete, temperature of concrete and ambient conditions during curing (Neville, 1997).

Curing Concrete Systems

In order to obtain good concrete, the placing of an appropriate mix must be followed by curing in a suitable environment during the early stages of hardening. Curing is the name given to procedures used for promoting the hydration of cement, and consists of a control of temperature and of the moisture movement from and into the concrete (Neville, 1997). Curing is the protection of fresh concrete from evaporation and temperature extremes which might adversely affect cement hydration.

To provide these conditions on site, the concrete must be protected from the harmful influences of wind, sun, low humidity and variable weather whilst hardening. A temperature of about 23°C is considered ideal for hydration to achieve strength and durability characteristics, however, it is known that such conditions will rarely be consistently achieved on site. Curing techniques for concrete fall into two groups:- those designed to prevent loss of water (such as the application of impermeable membranes), and those that supply moisture throughout the early stages of the hydration process (such as ponding or the application of wet sand).(3)

The influence of curing on concrete compressive strength development is demonstrated in Figure 2. Lack of curing can significantly reduce concrete strengths when compared with designed values.(3)

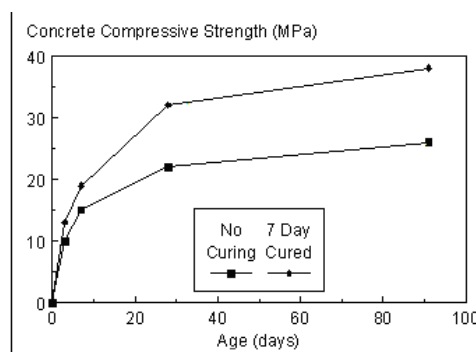


Figure 2: Influence of curing on concrete compressive strength development

Curing Concrete at High Ambient Temperatures

The dangers of placing and curing concrete at temperatures in excess of 30°C are to be noted as such conditions lead to high evaporation rates. The maximum temperature for field hardening allowed under AS1012 Part 18 for concrete specimens taken in the Standard Temperature Zone is 33°C. In the Standard Tropical Zone, the maximum allowable temperature is 35°C. (3)

Water Retaining Materials

Chemical or liquid membranes are commonly used for curing on site largely because of convenience (Figure 3). They can be applied by hand or power sprays. Membrane compounds form a vapor seal on the surface of the concrete when dry. Water in concrete is therefore sealed in and good curing conditions can be established.

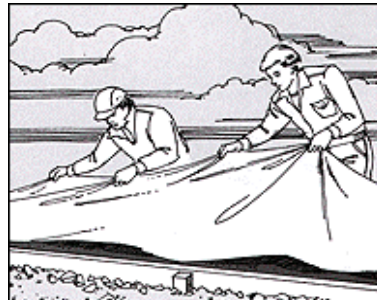


Chemical or liquid membranes reduce evaporation by sealing the concrete.

Figure 3: Using chemical or liquid membranes

Mechanical Barriers

The use of waterproof building papers or plastic film (polyethylene sheeting) will prevent the evaporation of moisture from concrete (Figure 4). Pigmented polyethylene sheeting provides a good curing medium as it is impervious to moisture, light in weight, and can be re-used. Plastic sheeting also has the advantage of flexibility. It is easy to drape over complex shapes, and the progress of curing and condition of the concrete can be checked easily at any time. Any material used as a mechanical barrier to evaporation should cover the concrete as soon as the placing of it does not cause surface damage.

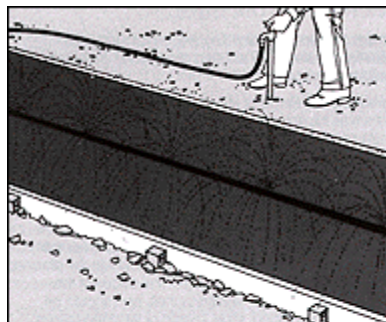


Mechanical barriers should be placed over concrete as soon as the surface is set

Figure 4: Using mechanical barriers

Water Addition Curing

Theoretically, flooding, ponding or mist spraying (Figure 5) is better than the retention methods for achieving curing described above. However, such methods are not always practical under field conditions. On roads, pavements or floors, the method of flooding or ponding is simple. A small dam of earth or other water retaining material can be placed around the perimeter of the surface and the enclosed area is kept flooded with water. Care should be exercised to prevent large temperature differentials between the concrete mass and curing environment so as to avoid potential cracking due to temperature gradients within the concrete. This can result in thermal shock cracking.(3)

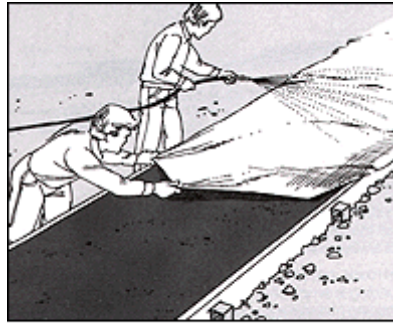


Flooding with water is effective but can be impractical on some sites.

Figure 5: Using water addition curing

Absorptive Covers

An absorptive medium such as sand, or canvas will hold water on the concrete surface during curing (Figure 6). Any such media must be kept damp constantly during the curing period, for if drying is permitted, the media itself will absorb moisture from the concrete. Alternate drying out and wetting of the cover may also cause cracking. The use of sawdust as a cover is not advisable for it has, on occasion, retarded the hardening of concrete through the action of sugars in the sap present in the sawdust.(3)



Water can be retained longer by using an absorptive cover

Figure 6: Using absorptive covers

Summary

To sum up the advantages of careful control of moisture and temperature in curing:

1. The strength of concrete increases with age if curing conditions are favorable. Compressive strength of properly cured concrete is 80 to 100 per cent greater than the strength of concrete which has not been cured at all.
2. Properly cured concrete surfaces wear well.
3. Drying shrinkage cracking is reduced.
4. Greater watertightness in constructions is assured.

Points to keep in mind when curing :

1. Start curing operations as soon as possible after concrete has been placed.
2. For proper curing concrete needs moisture.
3. Continuity in curing is a must. Alternate wetting and drying promotes the development of cracks.
4. If during curing concrete is allowed to dry out (as may happen in hot weather) the hydration reaction rate significantly reduces at the stage when the concrete loses its moisture.
5. The ideal curing temperature is about 23°C.
6. Cure concrete for at least 7 days.

The problems of inadequate curing need to be highlighted. If enough water evaporates from the concrete before it has attained sufficient strength, there will not be sufficient water remaining in the concrete to fully hydrate the binder and so achieve design performance. This will lead to design performance requirements not being achieved on site.

Precautions Recommended for Concreting in Hot Weather

- Placing the concrete in the coolest part of the day : preferably at a time such that the ambient temperature will rise following the setting of the concrete, that is, after midnight or in the early hours of the morning.
- Pre-cooling one or more of the ingredients of the mix :
 - Cooling mixing water. The mixing water should be get from a cooler source. The water reservoirs and the pipelines should be white, and should be placed away from sun radiation and under the ground if possible. Mix water can be chilled partially by crushed or flaked ice. All the ice must melt prior to the end of the mixing operation.
 - Cooling aggregates: The aggregate masses should be kept in the shade. Coarse aggregate can be cooled by spraying with chilled water or by inundation. Another method is to use evaporative cooling by blowing preferably chilled air through moist aggregate. Fine aggregate can also be cooled by air.
 - If possible, cement can also be used cool.

- Using low heat cement types.
- Keeping the cement content as low as possible: so that the heat of hydration does not unduly aggravate the effects of high ambient temperature.
- Keeping all equipment used in concreting in the shade and painting them white if possible.
- Cooling the places of contact of concrete: the formwork, the steel reinforcement, and the ground can be cooled by spraying cold water just prior to the placing of concrete.
- Making the placing of concrete as soon as possible: placing of concrete should be previously planned. Delays in concreting lower the workability and increase the temperature of the concrete.
- Using set-retarders: in general, they prolong the time during which concrete can be transported, placed, and compacted (workability time). Since they have water-reducing effect, they reduce the cement content without changing the w/c ratio, and prevent shrinkage cracks.
- Sufficient and successful curing: the fresh concrete should be kept wet for preventing the fast evaporation. The concrete should be protected from the effects of direct sunlight and wind.

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