



# Curing Concrete



**4**

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## Concrete Curing

Curing is the maintenance of a satisfactory moisture content and temperature in concrete for a period of time immediately following placing and finishing so that the desired properties may develop (Fig. 12-1). The need for adequate curing of concrete cannot be overemphasized. Curing has a strong influence on the properties of hardened concrete; proper curing will increase durability, strength, watertightness, abrasion resistance, volume stability, and resistance to freezing and thawing and deicers. Exposed slab surfaces are especially sensitive to curing as strength development and freeze-thaw resistance of the top surface of a slab can be reduced significantly when curing is defective.

When portland cement is mixed with water, a chemical reaction called hydration takes place. The extent to which this reaction is completed influences the strength and durability of the concrete. Freshly mixed concrete normally contains more water than is required for hydration of the cement; however, excessive loss of water by evaporation can delay or prevent adequate hydration. The surface is particularly susceptible to insufficient hydration because it dries first. If temperatures are favorable, hydration is relatively rapid the first few days after concrete is placed; however, it is important for water to be retained in the concrete during this period, that is, for evaporation to be prevented or substantially reduced.



Fig. 12-1. Curing should begin as soon as the concrete stiffens enough to prevent marring or erosion of the surface. Burlap sprayed with water is an effective method for moist curing. (69973)

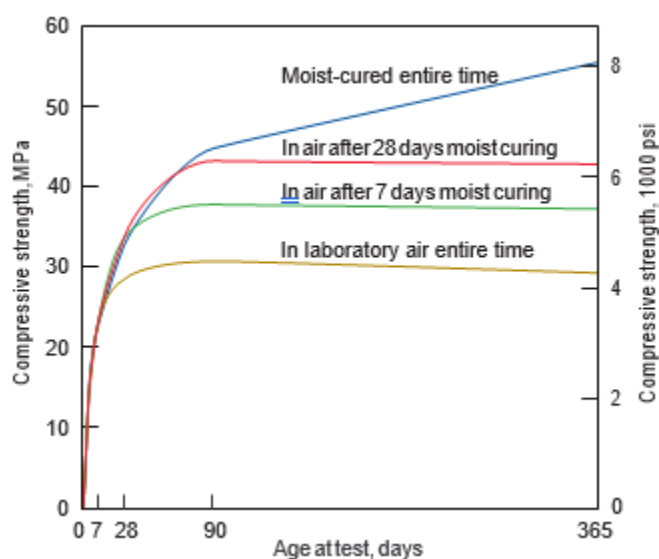


Fig. 12-2. Effect of moist curing time on strength gain of concrete (Gonnerman and Shuman 1928).

With proper curing, concrete becomes stronger, more impermeable, and more resistant to stress, abrasion, and freezing and thawing. The improvement is rapid at early ages but continues more slowly thereafter for an indefinite period. Fig. 12-2 shows the strength gain of concrete with age for different moist curing periods and Fig. 12-3 shows the relative strength gain of concrete cured at different temperatures.

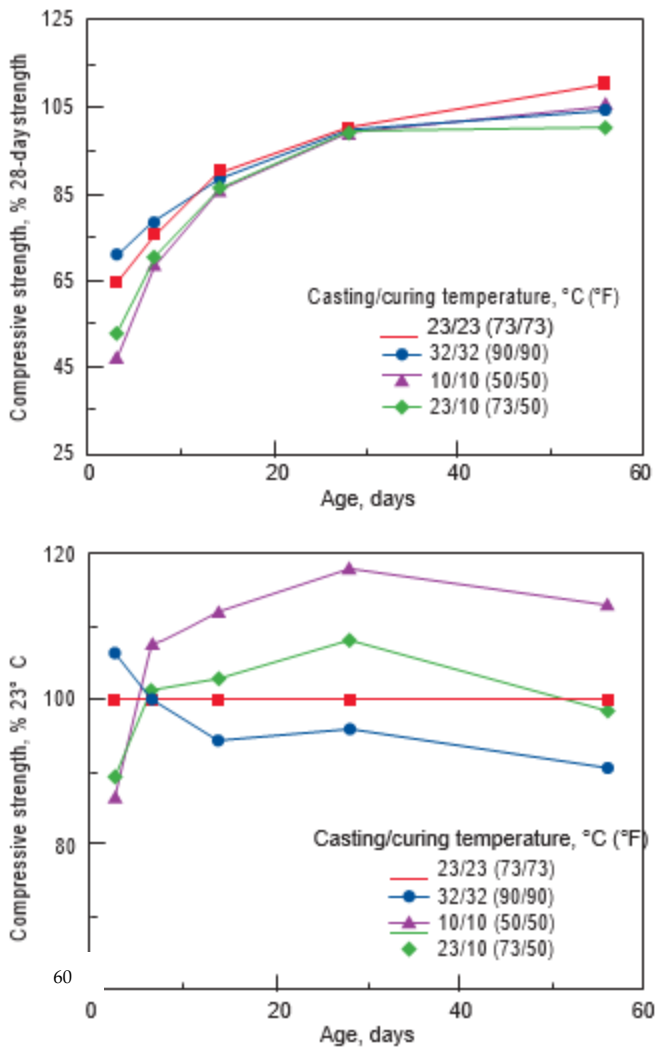


Fig. 12-3. Effect of curing temperature on strength gain (top) relative to 28-day strength and (bottom) relative to the strength of concrete at 23°C (73°F) (Burg 1996).

The most effective method for curing concrete depends on the materials used, method of construction, and the intended use of the hardened concrete. For most jobs, curing generally involves applying curing compounds, or covering the freshly placed and finished concrete with impermeable sheets or wet burlap. In some cases, such as in hot and cold weather, special care using other precautions is needed.

Concrete mixtures with high cement contents and low water-cement ratios (less than 0.40) may require special curing needs. As cement hydrates (chemically combining with water) the internal relative humidity decreases causing the paste to self-desiccate (dry out) if no external water is provided. The paste can self-desiccate to a level where hydration stops. This may influence desired concrete properties, especially if the internal relative humidity drops below 80% within the first seven days. In view of this, membrane-forming curing compounds may not retain enough water in the concrete. Therefore, fogging and wet curing become necessary to maximize hydration (Copeland and Bragg 1955). Fogging during and after placing and finishing also helps minimize plastic

cracking in concretes with very low water-cement ratios (especially around 0.30 or less).

When moist curing is interrupted, the development of strength continues for a short period and then stops after the concrete's internal relative humidity drops to about 80%. However, if moist curing is resumed, strength development will be reactivated, but the original potential strength may not be achieved. Although it can be done in a laboratory, it is difficult to resaturate concrete in the field. Thus, it is best to moist-cure the concrete continuously from the time it is placed and finished until it has gained sufficient strength, impermeability, and durability. Loss of water will also cause the concrete to shrink, thus creating tensile stresses within the concrete. If these stresses develop before the concrete has attained adequate tensile strength, surface cracking can result. All exposed surfaces, including exposed edges and joints, must be protected against moisture evaporation.

Hydration proceeds at a much slower rate when the concrete temperature is low.

Temperatures below 10°C (50°F) are unfavorable for the development of early strength; below 4°C (40°F) the development of early strength is greatly retarded; and at or below freezing temperatures, down to -10°C (14°F), little or no strength develops.

In recent years, a maturity concept has been introduced to evaluate the development of strength when there is variation in the curing temperature of the concrete. Maturity is the product of the age of the concrete and its average curing temperature above a certain base temperature. Refer to Chapter 14 for more information on the maturity concept. It follows that concrete should be protected so that its temperature remains favorable for hydration and moisture is not lost during the early hardening period.

## **CURING METHODS AND MATERIALS**

Concrete can be kept moist (and in some cases at a favorable temperature) by three curing methods:

1. Methods that maintain the presence of mixing water in the concrete during the early hardening period. These include ponding or immersion, spraying or fogging, and saturated wet coverings. These methods afford some cooling through evaporation, which is beneficial in hot weather.
2. Methods that reduce the loss of mixing water from the surface of the concrete. This can be done by covering the concrete with impervious paper or plastic sheets, or by applying membrane-forming curing compounds.
3. Methods that accelerate strength gain by supplying heat and additional moisture to the concrete. This is usually accomplished with live steam, heating coils, or electrically heated forms or pads.

The method or combination of methods chosen depends on factors such as availability of curing materials, size, shape, and age of concrete, production facilities (in place or in a plant), esthetic appearance, and economics. As a result, curing often involves a series of procedures used at a particular time as the concrete ages. For example, fog spraying or plastic covered wet burlap can precede application of a curing compound. The timing of each procedure depends on the degree of hardening of the concrete needed to prevent the particular procedure from damaging the concrete surface (ACI 308 1997).

### **Ponding and Immersion**

On flat surfaces, such as pavements and floors, concrete can be cured by ponding. Earth or sand dikes around the perimeter of the concrete surface can retain a pond of water. Ponding is an ideal method for preventing loss of moisture from the concrete; it is also effective for maintaining a uniform temperature in the concrete. The curing water should not be more than about 11°C (20°F) cooler than the concrete to prevent thermal stresses that could result in cracking. Since ponding requires considerable labor and supervision, the method is generally

used only for small jobs.

The most thorough method of curing with water consists of total immersion of the finished concrete element. This method is commonly used in the laboratory for curing concrete test specimens. Where appearance of the concrete is important, the water used for curing by ponding or immersion must be free of substances that will stain or discolor the concrete. The material used for dikes may also discolor the concrete.

### Fogging and Sprinkling

Fogging (Fig. 12-4) and sprinkling with water are excellent methods of curing when the ambient temperature is well above freezing and the humidity is low. A fine fog mist is frequently applied through a system of nozzles or sprayers to raise the relative humidity of the air over flatwork, thus slowing evaporation from the surface. Fogging is applied to minimize plastic shrinkage cracking until finishing operations are complete. Once the concrete has set sufficiently to prevent water erosion, ordinary lawn sprinklers are effective if good coverage is provided and water runoff is of no concern. Soaker hoses are useful on surfaces that are vertical or nearly so.



Fig. 12-4. Fogging minimizes moisture loss during and after placing and finishing of concrete. (69974)

The cost of sprinkling may be a disadvantage. The method requires an ample water supply and careful supervision. If sprinkling is done at intervals, the concrete must be prevented from drying between applications of water by using burlap or similar materials; otherwise alternate cycles of wetting and drying can cause surface crazing or cracking.

### Wet Coverings

Fabric coverings saturated with water, such as burlap, cotton mats, rugs, or other moisture-retaining fabrics, are commonly used for curing (Fig. 12-5). Treated burlaps that reflect light and are resistant to rot and fire are available. The requirements for burlap are described in the Specification for Burlap Cloths Made from Jute or Kenaf (AASHTO M 182), and those for white



Fig. 12-5. Lawn sprinklers saturating burlap with water keep the concrete continuously moist. Intermittent sprinkling is acceptable if no drying of the concrete surface occurs. (50177)



burlap-polyethylene sheeting are described in ASTM C 171 (AASHTO M 171).

Burlap must be free of any substance that is harmful to concrete or causes discoloration. New burlap should be thoroughly rinsed in water to remove soluble substances and to make the burlap more absorbent.

Wet, moisture-retaining fabric coverings should be placed as soon as the concrete has hardened sufficiently to prevent surface damage. During the waiting period other curing methods are used, such as fogging or the use of membrane forming finishing aids. Care should be taken to cover the entire surface with wet fabric, including the edges of slabs. The coverings should be kept continuously moist so that a film of water remains on the concrete surface throughout the curing period. Use of polyethylene film over wet burlap is a good practice; it will eliminate the need for continuous watering of the covering. Periodically rewetting the fabric under the plastic before it dries out should be sufficient. Alternate cycles of wetting and drying during the early curing period may cause crazing of the surface.

Wet coverings of earth, sand, or sawdust are effective for curing and are often useful on small jobs. Sawdust from most woods is acceptable, but oak and other woods that contain tannic acid should not be used since deterioration of the concrete may occur. A layer about 50 mm (2 in.) thick should be evenly distributed over the previously moistened surface of the concrete and kept continuously wet.

Wet hay or straw can be used to cure flat surfaces. If used, it should be placed in a layer at least 150 mm (6 in.) thick and held down with wire screen, burlap, or tarpaulins to prevent its being blown off by wind.

A major disadvantage of moist earth, sand, sawdust, hay, or straw coverings is the possibility of discoloring the concrete.

### **Impervious Paper**

Impervious paper for curing concrete consists of two sheets of kraft paper cemented together by a bituminous adhesive with fiber reinforcement. Such paper, conforming to ASTM C 171 (AASHTO M 171), is an efficient means of curing horizontal surfaces and structural concrete of relatively simple shapes. An important advantage of this method is that periodic additions of water are not required. Curing with impervious paper enhances the hydration of cement by preventing loss of moisture from the concrete (Fig. 12-6).



Fig.12-6. Impervious curing paper is an efficient means of curing horizontal surfaces. (69994)



As soon as the concrete has hardened sufficiently to prevent surface damage, it should be thoroughly wetted and the widest paper available applied. Edges of adjacent sheets should be overlapped about 150 mm (6 in.) and tightly sealed with sand, wood planks, pressure-sensitive tape, mastic, or glue. The sheets must be weighted to maintain close contact with the concrete surface during the entire curing period.

Impervious paper can be reused if it effectively retains moisture. Tears and holes can easily be repaired with curing-paper patches. When the condition of the paper is questionable, additional use can be obtained by using it in double thickness.

In addition to curing, impervious paper provides some protection to the concrete against damage from subsequent construction activity as well as protection from the direct sun. It should be light in color and nonstaining to the concrete. Paper with a white upper surface is preferable for curing exterior concrete during hot weather.

### Plastic Sheets

Plastic sheet materials, such as polyethylene film, can be used to cure concrete (Fig. 12-7). Polyethylene film is a lightweight, effective moisture retarder and is easily applied to complex as well as simple shapes. Its application is the same as described for impervious paper.

Curing with polyethylene film (or impervious paper) can cause patchy discoloration, especially if the concrete contains calcium chloride and has been finished by hard-steel troweling. This discoloration is more pronounced when the film becomes wrinkled, but it is difficult and time consuming on a large project to place sheet materials without wrinkles. Flooding the surface under the covering may prevent discoloration, but other means of curing should be used when uniform color is important.

Polyethylene film should conform to ASTM C 171 (AASHTO M 171), which specifies a 0.10-mm (4-mil) thickness for curing concrete, but lists only clear and white opaque film. However, black film is available and is satisfactory under some conditions. White film should be used for curing exterior concrete during hot weather to reflect the sun's rays. Black film can be used during cool weather or for interior locations. Clear film has little effect on heat absorption.

ASTM C 171 (AASHTO M 171) also includes a sheet material consisting of burlap impregnated



Fig. 12-7. Polyethylene film is an effective moisture barrier for curing concrete and easily applied to complex as well as simple shapes. To minimize discoloration, the film should be kept as flat as possible on the concrete surface. (70014)

on one side with white opaque polyethylene film. Combinations of polyethylene film bonded to an absorbent fabric such as burlap help retain moisture on the concrete surface.

Polyethylene film may also be placed over wet burlap or other wet covering materials to retain the water in the wet covering material. This procedure eliminates the labor-intensive need for continuous watering of wet covering materials.

### Membrane-Forming Curing Compounds

Liquid membrane-forming compounds consisting of waxes, resins, chlorinated rubber, and other materials can be used to retard or reduce evaporation of moisture from concrete. They are the most practical and most widely used method for curing not only freshly placed concrete but also for extending curing of concrete after removal of forms or after initial moist curing. However, the most effective methods of curing concrete are wet coverings or water spraying that keeps the concrete continually damp. Curing compounds should be able to maintain the relative humidity of the concrete surface above 80% for seven days to sustain cement hydration.

Membrane-forming curing compounds are of two general types: clear, or translucent; and white pigmented. Clear or translucent compounds may contain a fugitive dye that makes it easier to check visually for complete coverage of the concrete surface when the compound is applied. The dye fades away soon after application. On hot, sunny days, use of white-pigmented compounds are recommended; they reduce solar-heat gain, thus reducing the concrete temperature. Pigmented compounds should be kept agitated in the container to prevent pigment from settling out.

Curing compounds should be applied by hand-operated or power-driven spray equipment immediately after final finishing of the concrete (Fig. 12-8). The concrete surface should be damp when the coating is applied. On dry, windy days, or during periods when adverse weather conditions could result in plastic shrinkage cracking, application of a curing compound immediately after final finishing and before all free water on the surface has evaporated will help prevent the formation of cracks. Power-driven spray equipment is recommended for uniform application of curing compounds on large paving projects. Spray nozzles and windshields on such equipment should be arranged to prevent wind-blown loss of curing compound.



Fig. 12-8. Liquid membrane-forming curing compounds should be applied with uniform and adequate coverage over the entire surface and edges for effective, extended curing of concrete. (69975)

Normally only one smooth, even coat is applied at a typical rate of 3 to 4 m<sup>2</sup> per liter (150 to 200 sq ft per gallon); but products may vary, so manufacturer's recommended application rates should be followed. If two coats are necessary to ensure complete coverage, for effective protection the second coat should be applied at right angles to the first. Complete coverage of the surface must be attained because even small pinholes in the membrane will increase the evaporation of moisture from the concrete.

Curing compounds might prevent bonding between hardened concrete and a freshly placed concrete overlay. And, most curing compounds are not compatible with adhesives used with floor covering materials. Consequently, they should either be tested for compatibility, or not used when bonding of overlying materials is necessary. For example, a curing compound should not be applied to the base slab of a two-course floor. Similarly, some curing compounds may affect the adhesion of paint to concrete floors. Curing compound manufacturers should be consulted to determine if their product is suitable for the intended application.

Curing compounds should be uniform and easy to maintain in a thoroughly mixed solution. They should not sag, run off peaks, or collect in grooves. They should form a tough film to withstand early construction traffic without damage, be nonyellowing, and have good moisture-retention properties.

Caution is necessary when using curing compounds containing solvents of high volatility in confined spaces or near sensitive occupied spaces such as hospitals because evaporating volatiles may cause respiratory problems. Applicable local environmental laws concerning volatile organic compound (VOC) emissions should be followed.

Curing compounds should conform to ASTM C 309 (AASHTO M 148). A method for determining the efficiency of curing compounds, waterproof paper, and plastic sheets is described in ASTM C 156 (AASHTO T 155). ASTM C 1151, discontinued in 2000, also evaluates the effectiveness of curing compounds. Curing compounds with sealing properties are specified under ASTM C 1315.

### **Internal Moist Curing**

Internal moist curing refers to methods of providing moisture from within the concrete as opposed to outside the concrete. This water should not effect the initial water to cement ratio of the fresh concrete. Lightweight (low-density) fine aggregate or absorbent polymer particles with an ability to retain a significant amount of water may provide additional moisture for concretes prone to self desiccation. When more complete hydration is needed for concretes with low water to cement ratios (around 0.30 or less), 60 kg/m<sup>3</sup> to 180 kg/m<sup>3</sup> (100 lb/yd<sup>3</sup> to 300 lb/yd<sup>3</sup>) of saturated lightweight fine aggregate can provide additional moisture to extend hydration, resulting in increased strength and durability. All of the fine aggregate in a mixture can be replaced with saturated lightweight fine aggregate to maximize internal moist curing. Internal moist curing must be accompanied by external curing

methods.

### Forms Left in Place

Forms provide satisfactory protection against loss of moisture if the top exposed concrete surfaces are kept wet. A soaker hose is excellent for this. The forms should be left on the concrete as long as practical.

Wood forms left in place should be kept moist by sprinkling, especially during hot, dry weather. If this cannot be done, they should be removed as soon as practical and another curing method started without delay. Color variations may occur from formwork and uneven water curing of walls.

### Steam Curing

Steam curing is advantageous where early strength gain in concrete is important or where additional heat is required to accomplish hydration, as in cold weather.

Two methods of steam curing are used: live steam at atmospheric pressure (for enclosed cast-in-place structures and large precast concrete units) and high-pressure steam in autoclaves (for small manufactured units). Only live steam at atmospheric pressure will be discussed here.

A typical steam-curing cycle consists of (1) an initial delay prior to steaming, (2) a period for increasing the temperature, (3) a period for holding the maximum temperature constant, and (4) a period for decreasing the temperature. A typical atmospheric steam-curing cycle is shown in Fig. 12-9.

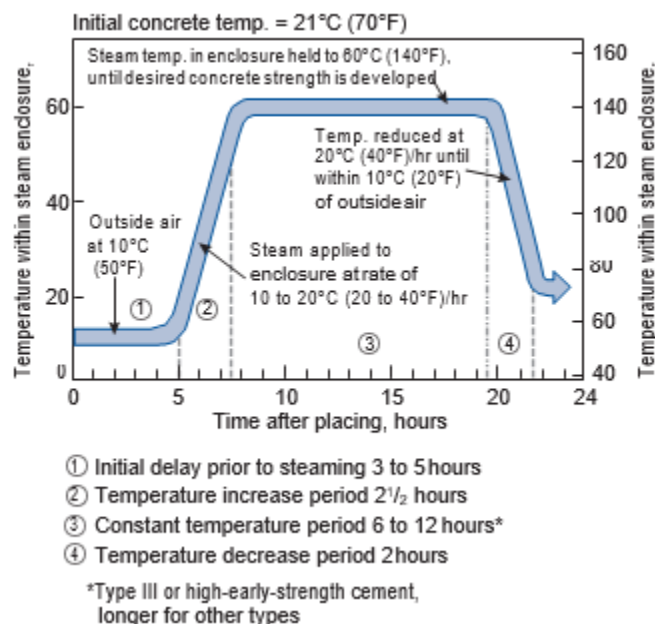


Fig. 12-9. A typical atmospheric steam-curing cycle.

Steam curing at atmospheric pressure is generally done in an enclosure to minimize moisture and heat losses. Tarpaulins are frequently used to form the enclosure. Application of steam to the enclosure should be delayed until initial set occurs or delayed at least 3 hours after final placement of concrete to allow for some hardening of the concrete. However, a 3- to 5- hour delay period prior to steaming will achieve maximum early strength, as shown in Fig. 12-10.

Steam temperature in the enclosure should be kept at about 60°C (140°F) until the desired concrete strength has developed. Strength will not increase significantly if the maximum steam

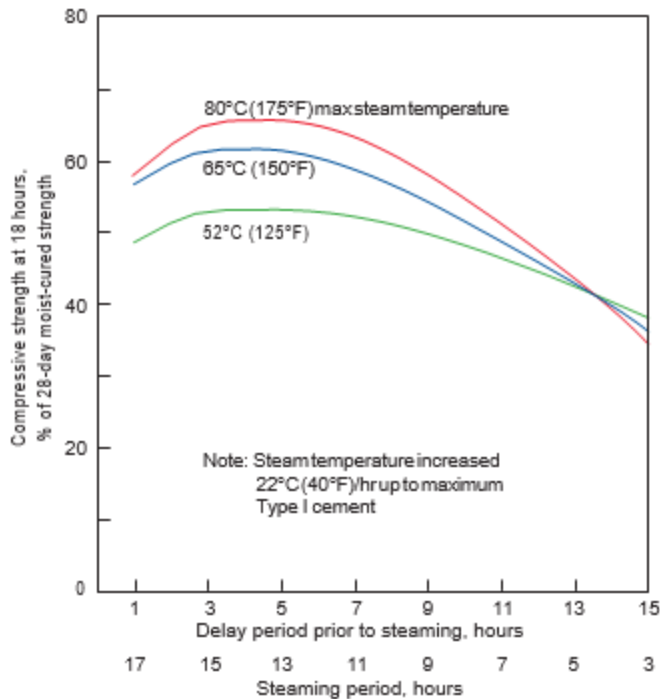


Fig. 12-10. Relationship between strength at 18 hours and delay period prior to steaming. In each case, the delay period plus the steaming period totaled 18 hours (Hanson 1963).

temperature is raised from 60°C to 70°C (140°F to 160°F). Steam-curing temperatures above 70°C (160°F) should be avoided; they are uneconomical and may result in damage. It is recommended that the internal temperature of concrete not exceed 70°C (160°F) to avoid heat induced delayed expansion and undue reduction in ultimate strength. Use of concrete temperatures above 70°C (160°F) should be demonstrated to be safe by test or historic field data.

Concrete temperatures are commonly monitored at the exposed ends of the concrete element. Monitoring air temperatures alone is not sufficient because the heat of hydration may cause the internal temperature of the concrete to exceed 70°C (160°F).

Besides early strength gain, there are

other advantages of curing concrete at temperatures of around 60°C (140°F); for example, there is reduced drying shrinkage and creep as compared to concrete cured at 23°C (73°F) for 28 days (Klieger 1960 and Tepponen and Eriksson 1987).

Excessive rates of heating and cooling should be avoided to prevent damaging volume changes. Temperatures in the enclosure surrounding the concrete should not be increased or decreased more than 22°C to 33°C (40°F to 60°F) per hour depending on the size and shape of the concrete element.

The curing temperature in the enclosure should be held until the concrete has reached the desired strength. The time required will depend on the concrete mixture and steam temperature in the enclosure (ACI Committee 517 1992).

### Insulating Blankets or Covers

Layers of dry, porous material such as straw or hay can be used to provide insulation against freezing of concrete when temperatures fall below 0°C (32°F).

Formwork can be economically insulated with commercial blanket or batt insulation that has a tough moisture-proof covering. Suitable insulating blankets are manufactured of fiberglass, sponge rubber, cellulose fibers, mineral wool, vinyl foam, and open-cell polyurethane foam. When insulated formwork is used, care should be taken to ensure that concrete temperatures

do not become excessive.

Framed enclosures of canvas tarpaulins, reinforced polyethylene film, or other materials can be placed around the structure and heated by space heaters or steam. Portable hydronic heaters are used to thaw subgrades as well as heat concrete without the use of an enclosure

Curing concrete in cold weather should follow the recommendations in Chapter 14 and ACI 306 (1997), Cold- Weather Concreting. Recommendations for curing concrete in hot weather can be found in Chapter 13 and ACI 305, Hot-Weather Concreting.

### **Electrical, Oil, Microwave, and Infrared Curing**

Electrical, hot oil, microwave and infrared curing methods have been available for accelerated and normal curing of concrete for many years. Electrical curing methods include a variety of techniques: (1) use of the concrete itself as the electrical conductor, (2) use of reinforcing steel as the heating element, (3) use of a special wire as the heating element, (4) electric blankets, and (5) the use of electrically heated steel forms (presently the most popular method). Electrical heating is especially useful in cold- weather concreting. Hot oil may be circulated through steel forms to heat the concrete. Infrared rays and microwave have had limited use in accelerated curing of concrete. Concrete that is cured by infrared methods is usually under a covering or enclosed in steel forms. Electrical, oil, and infrared curing methods are used primarily in the precast concrete industry.

## **CURING PERIOD AND TEMPERATURE**

The period of time that concrete should be protected from freezing, abnormally high temperatures, and against loss of moisture depends upon a number of factors: the type of cementing materials used; mixture proportions; required strength, size and shape of the concrete member; ambient weather; and future exposure conditions. The curing period may be 3 weeks or longer for lean concrete mixtures used in massive structures such as dams; conversely, it may be only a few days for rich mixes, especially if Type III or HE cement is used. Steam-curing periods are normally much shorter, ranging from a few hours to 3 days; but generally 24-hour cycles are used. Since all the desirable properties of concrete are improved by curing, the curing period should be as long as necessary.

For concrete slabs on ground (floors, pavements, canal linings, parking lots, driveways, sidewalks) and for structural concrete (cast-in-place walls, columns, slabs, beams, small footings, piers, retaining walls, bridge decks), the length of the curing period for ambient temperatures above 5°C (40°F) should be a minimum of 7 days; additional time may be needed to attain 70% of the specified compressive or flexural strength. When the daily mean ambient temperature is 5°C (40°F) or lower, ACI Committee 306 recommendations for curing should be followed to prevent damage by freezing.



A higher curing temperature provides earlier strength gain in concrete than a lower temperature but it may decrease 28-day strength as shown in Fig. 12-11. If strength tests are made to establish the time when curing can cease or forms can be removed, representative concrete test cylinders or beams should be fabricated in the field, kept adjacent to the structure or pavement they represent, and cured by the same methods. Equipment is available that can monitor internal concrete temperatures and match that temperature in the concrete cylinder curing box; this is the most accurate means of representing in-place concrete strengths. Cores, cast-in-place removable cylinders, and nondestructive testing methods may also be used to determine the strength of a concrete member.

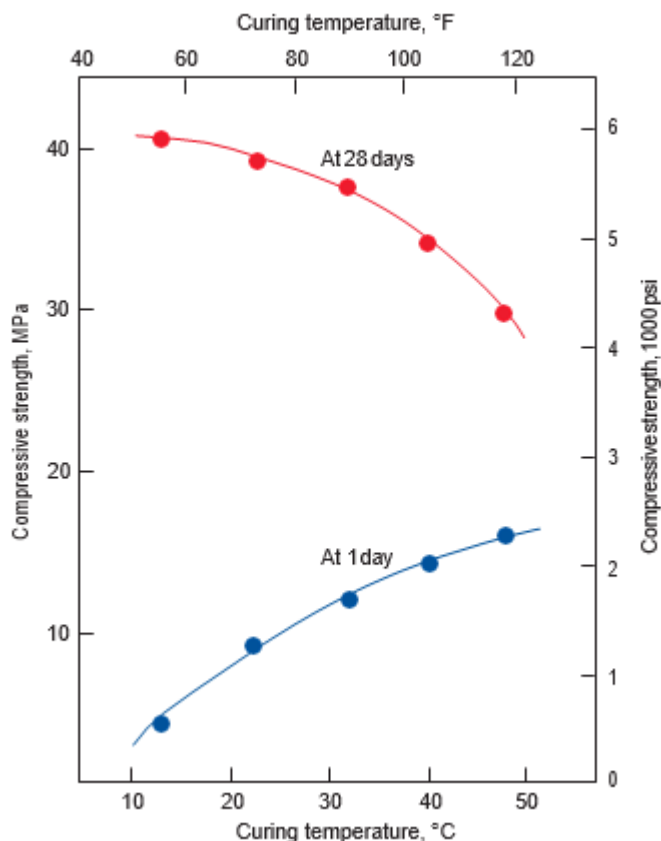


Fig. 12-11. One-day strength increases with increasing curing temperature, but 28-day strength decreases with increasing curing temperature (Verbeck and Helmuth 1968).

Since the rate of hydration is influenced by cement type and the presence of supplementary cementing materials, the curing period should be prolonged for concretes made with cementing materials possessing slow-strength-gain characteristics. For mass concrete (large piers, locks, abutments, dams, heavy footings, and massive columns and transfer girders) in which no pozzolan is used as part of the cementitious material, curing of unreinforced sections should continue for at least 2 weeks. If the mass concrete contains a pozzolan, minimum curing time for unreinforced sections should be extended to 3 weeks. Heavily-reinforced mass concrete sections should be cured for a minimum of 7 days.

During cold weather, additional heat is often required to maintain favorable curing temperatures of 10°C to 20°C (50°F to 70°F). Vented gas or oil-fired heaters, heating coils, portable hydronic heaters, or live steam can be used to supply the required heat. In all cases, care must be taken to avoid loss of moisture from the concrete. Exposure of fresh concrete to heater or engine exhaust gases must be avoided as this can result in surface deterioration and dusting (rapid carbonation).

High-early-strength concrete can be used in cold weather to speed-up setting time and strength development. This can reduce the curing period, but a minimum temperature of 10°C (50°F) must be maintained.



For adequate deicer scale resistance of concrete, the minimum curing period generally corresponds to the time required to develop the design strength of the concrete at the surface. A period of air-drying after curing will enhance resistance to scaling. This drying period should be at least 1 month of relatively dry weather before the application of deicing salts.

## **SEALING COMPOUNDS**

Sealing compounds (sealers) are liquids applied to the surface of hardened concrete to reduce the penetration of liquids or gases such as water, deicing solutions, and carbon dioxide that cause freeze-thaw damage, corrosion of reinforcing steel, and acid attack. In addition, sealing compounds used on interior floor slabs reduce dusting and the absorption of spills while making the surface easier to clean.

Sealing compounds differ in purpose from curing compounds; they should not be confused as being the same. The primary purpose of a curing compound is to retard the loss of water from newly placed concrete and it is applied immediately after finishing. Surface sealing compounds on the other hand retard the penetration of harmful substances into hardened concrete and are typically not applied until the concrete is 28 days old. Surface sealers are generally classified as either film-forming or penetrating.

Sealing exterior concrete is an optional procedure generally performed to help protect concrete from freeze-thaw damage and chloride penetration from deicers. Curing is not optional when using a sealer; curing is necessary to produce properties needed for concrete to perform adequately for its intended purpose. Satisfactory performance of exterior concrete still primarily depends on an adequate air-void system, sufficient strength, and the use of proper placing, finishing and curing techniques. However, not all concrete placed meets those criteria; surface sealers can help improve the durability of these concretes.

Film-forming sealing compounds remain mostly on the surface with only a slight amount of the material penetrating the concrete. The relatively large molecular structure of these compounds limits their ability to penetrate the surface. Thinning them with solvents will not improve their penetrating capability. These materials not only reduce the penetration of water, they also protect against mild chemicals; furthermore, they prevent the absorption of grease and oil as well as reduce dusting under pedestrian traffic.

Surface sealers consist of acrylic resins, chlorinated rubber, urethanes, epoxies, and alpha methyl styrene. The effectiveness of film-forming sealers depends on the continuity of the layer formed. Abrasive grit and heavy traffic can damage the layer requiring the reapplication of the material. Consult manufacturers' application recommendations because some of these materials are intended for interior use only and may yellow and deteriorate under exposure to ultraviolet light.

The penetrating sealer that has been used most extensively for many years is a mixture of 50

percent boiled linseed oil and 50 percent mineral spirits (AASHTO M 233). Although this mixture is an effective sealer, it has two main disadvantages: it darkens the concrete, and periodic reapplication is necessary for long-term protection.

A new generation of water-repellent penetrating sealers have a very small molecular size that allows penetration and saturation of the concrete as deep as 3 mm (1/8 in.). The two most common are silane and siloxane, compounds which are derived from the silicone family. These sealers allow the concrete to breathe, thus preventing a buildup of vapor pressure between the concrete and sealer that can occur with some film-forming materials. Because the sealer is embedded within the concrete, making it more durable to abrasive forces or ultraviolet deterioration, it can provide longer lasting protection than film-forming sealers. However, periodic retreatment is recommended. In northern states and coastal areas silanes and siloxanes are popular for protecting bridge decks and other exterior structures from corrosion of reinforcing steel caused by chloride infiltration from deicing chemicals or sea spray (Fig 12-12).

Application of any sealer should only be done on concrete that is clean and allowed to dry for at least 24 hours at temperatures above 16°C (60°F). At least 28 days should be allowed to elapse before applying sealers to new concrete. Penetrating sealers cannot fill surface voids if they are filled with water. Some surface preparation may be necessary if the concrete is old and dirty. Concrete placed in the late fall should not be sealed until spring because the sealer may cause the concrete to retain water that may exacerbate freeze-thaw damage.

The precautions outlined earlier regarding volatile solvents in curing compounds also apply to sealing compounds. The effectiveness of water-based surface sealers is still being determined. The scale resistance provided by concrete sealers should be evaluated based on criteria established in ASTM C 672. For more information on surface sealing compounds, see AASHTO M 224, ACI Committee 330 and ACI Committee 362.



Fig12-12. Penetrating sealers help protect reinforcing steel in bridge decks from corrosion due to chloride infiltration without reducing surface friction. (69976)

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## Concrete Curing: TIPS

## PART 1 – SHRINKAGE CRACKING

A commonly known concern in concrete curing is maintaining the moisture level in fresh concrete. This article is organized in two parts. Part 1 provides information on common concrete curing problems. Part 2 provides information on concrete curing application.

### Plastic Shrinkage Cracking

Two common problems found in concrete installation are plastic shrinkage cracking and dry shrinkage cracking.

Plastic shrinkage cracks occur when the evaporation of moisture at the surface of the concrete is greater than the availability of rising bleed water to replenish the surface moisture. If the concrete has not achieved enough tensile strength when this occurs, the volume change (shrinkage) at the surface will cause cracking.

Because most of today's concrete uses a low water-to-cement ratio and supplementary cementitious materials (SCMs), the amount of bleed water and the rate of bleeding are often lower than in the past. This places the concrete at greater risk of plastic shrinkage cracking. Proper curing can often, but not always, prevent plastic shrinkage cracking by delaying the evaporation of bleed water.

### Identifying Plastic Shrinkage Cracks

Plastic shrinkage cracking occurs when the concrete is in the plastic state, which is within the first 24 hours after the cement begins to hydrate. In addition, plastic shrinkage cracks are usually spaced 1 to 3 feet apart, are generally parallel to one another, do not generally extend to the free end of the concrete element, and can be of considerable depth<sup>1</sup>.

Figure 1



*Figure 1. Example of plastic shrinkage cracking. Note, the closely spaced, parallel cracking*



*Figure 2. Deep Plastic Shrinkage Crack (below mid-depth)*

shows an example of plastic shrinkage cracks on the surface of a pavement. Figure 2 demonstrates the depth these types of cracks can reach.

#### Preventing Plastic Shrinkage Cracking

To prevent plastic shrinkage cracking, all concrete operations should be matched to the conditions in which the concrete is being placed. Use the following approaches to help minimize or control this cracking.

- Possible Concrete Changes (if allowed by specification and approved by the engineer)
  1. Reduce the SCM content.
  2. Accelerate the setting time and early tensile strength.
  3. Beware of admixture/cement interactions that could cause a delayed set (especially in sulfate-resistant concretes).
  4. Use synthetic fibers.
- Possible Construction Changes
  1. Do not place the concrete in adverse conditions.
  2. Erect wind screens or use a water fog mist. (NOTE: A water fog mist is NOT the same as adding finish water.)
  3. Provide additional personnel to accelerate the finishing and curing operations.
  4. Properly use evaporation retardants\*, especially when finishing operations are lagging behind.
  5. After the curing compound application, provide a water cure.



*\*Use of Evaporation Retardants.* Evaporation retardants are a relatively new tool to properly cure concrete. Evaporation retardants are NOT substitutes for curing compounds! Their purpose is to prevent surface water evaporation until the curing compound can be applied.

Evaporation retardants are composed essentially of water, with a mono-molecular film to slow evaporation. Should the film be disturbed, for example by finishing operations, the effectiveness of the evaporation retardant has been erased, rendering it the same as if plain water had been sprayed on the surface.

Evaporation retardants, used properly, can “buy some time” during the period after finishing and before application of the curing membrane is applied (refer to Items 360 and 420 for time limits). They are not a substitute for curing compounds.



*Figure 3. Drying Shrinkage Cracking.*

Curing compound requirements are described in DMS-4650, Hydraulic Cement Concrete Curing Materials and Evaporation Retardants, with approved suppliers listed on the Material Producer List (MPL) for “Concrete Evaporation Retardants.”

## **Drying Shrinkage Cracking**

### **Identifying Drying Shrinkage Cracking**

Concrete is usually mixed with more water than is needed to adequately hydrate the cement. The remaining water, known as water of convenience, evaporates, causing the concrete to shrink. Restraint to shrinkage, provided by the subgrade, reinforcement, or another part of the structure causes tensile stresses to develop in the hardened concrete. In many situations, drying shrinkage cracking is inevitable (see Figure 3). Therefore, contraction (control) joints are routinely placed in concrete to predetermine the location

of drying shrinkage cracks.<sup>2</sup>

### Preventing Drying Shrinkage Cracking

It is often very difficult to completely eliminate drying shrinkage cracking, but the following approaches may help to minimize or control this cracking.

- Possible Concrete Changes (if allowed by specification and approved by the engineer)
  1. Reduce the total water in the mix, either through the use of chemical admixtures, better combined aggregate gradation, or SCMs such as Class F fly ash.
  2. Reduce the amount of paste (cement + water) in the mix.
  3. Minimize poorly graded fine aggregates.
- Possible Design and Construction Changes
  1. Design adequate and appropriate contraction and construction joints.
  2. Employ a design that minimizes restraint of the concrete, such as the use of a bond breaker.
  3. Saw contraction joints to the proper depth and as soon as possible.
  4. Provide good curing to allow the concrete to gain sufficient tensile strength before significant shrinking forces develop.

### Reduce Cracking Through Curing

For more information on ways to reduce both types of shrinkage through concrete curing, read Part 2, Application.

## PART 2 – APPLICATION

This part of the article provides information on the important elements related to the proper application of concrete curing. Proper concrete curing can minimize plastic shrinkage cracking and dry shrinkage cracking.

### Curing Methods

There are three curing methods recognized in the 2004 TxDOT Standard Specifications:

1. *Form curing* - Form curing allows the concrete to cure by preventing mix water evaporation. Because the concrete is in direct contact with the forms, this direct contact acts as a moisture loss barrier.
2. *Water curing* - Water curing, such as wet mats or using water spray or wet sand curing, is generally considered to be the best curing practice; it allows for the most complete hydration (reaction of mix water with the cement).
3. *Membrane curing* - Membrane curing compound is used as a moisture-loss barrier for non-formed concrete in cases when water cure is not feasible due to time or other practical considerations.

Item 420, Concrete Structures, describes these methods. Either the governing specification or the plans will indicate which method to use for every concrete item.

Concrete curing is an essential stage of the concrete process. Curing compound, properly applied, can be effective in acting as a temporary (interim) curing method for a bridge deck until the concrete can support the weight of the personnel placing the mat and the weight of the wet mat itself. For concrete pavements, sidewalks and curbs, properly applied curing compound is the only protection to prevent the loss of moisture from the fresh concrete.

In either case, timing, application rate and material quality are important.

### Timing the Application of Curing Compounds

In the 2004 TxDOT Standard Specifications, Item 420, Concrete Structures, emphasizes the need to apply curing compound as quickly as possible. This item states:

“... apply interim cure ... as soon as possible after application of the evaporation retardant and after the water sheen has disappeared, but no more than 45 min. after application of the evaporation retardant.”

Item 360, Concrete Pavements, describes similar time constraints:

“Apply the first coat within 10 min. after completing texturing operations. Apply

the second coat within 30 min. after completing texturing operations.”

Do not allow the concrete surface to dry out! Keep in mind the use of supplementary cementitious materials (SCMs) and the low water-to-cement ratios in most of the concrete (used by TxDOT) usually produces very little bleed water. Allow the puddles of bleed water to dry or be absorbed with a towel before applying the curing compound. Then apply the curing compound as soon as possible.

### Application Rates for Curing Compounds

The standard application rate is 180 sq. ft./gal./coat. It is not easy to determine if the application rate is being achieved unless there is extremely accurate accounting of the quantity of compound used and the surface area to which it is being applied. However, there is one commonly used guideline: If any grey concrete can be seen through the fresh curing membrane, there is not enough curing compound! The membrane works only if there is a solid barrier between the concrete and the environment; voids allow water to evaporate. Two evenly placed coats are more effective than one heavy coat.

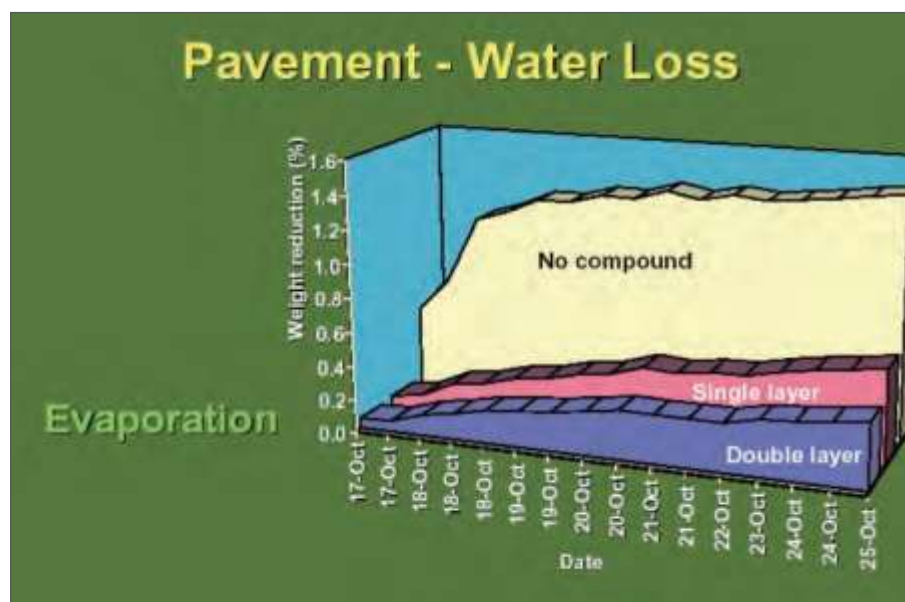


Figure 4. Concrete Moisture Loss vs. Curing Application (ref: CTR R.S. 0-5106).

Figure 4 shows typical benefits of curing compound application, measured by the Center for Transportation Research (CTR) researchers as part of Research Study (R.S.) 0-5106 – Evaluation of Curing Membranes Effectiveness to Reduce Evaporation.

### Curing Material Specifications

Can the curing compound be thinned to keep the nozzles from clogging? No. NEVER

use this method to prevent nozzle clogging.

### Approved Materials

The Construction Division - Materials and Pavements Section (CST-M&P) is responsible for assuring curing compound requirements, described in DMS-4650 Hydraulic Cement Concrete Curing Materials and Evaporation Retardants, are met by the suppliers listed on the Material Producer List (MPL) for Concrete Curing Compound (Liquid Membrane-Forming).

To guarantee the material has been approved by CST-M&P:

- Inspectors should look for a TxDOT approval stamp, the laboratory number and the date for required retesting (found on the container and shipment papers).
- Verify that the product has been tested by matching the lab number on the container with the test report for the product issued by the CST-M&P. (NOTE: Check dates as well.)

Contact the Materials and Pavements Section, Traffic Materials Branch to address discrepancies or perform additional sampling.

### Materials Not Pre-tested

For materials that are not pre-tested (materials are not required to be from an MPL source), sample by project for each batch or shipment and send the sample to the Materials and Pavements Section, Traffic Materials Branch for testing. Materials should be tested and approved prior to use.

### Field Sampling of Questionable Materials

If you suspect the curing compound does not meet specifications, obtain a sample from the sprayer (a clean 4 × 8 cylinder mold, sealed, is a good sample container) and test for:

- gallon weight
- % solids and
- viscosity.

The Materials and Pavements Section, Traffic Materials Branch can perform these tests or any laboratory with a reliable scale (readable to 0.0001g) and an oven can perform the % solids tests.

Anecdotal observations indicate the chances of thinned curing compound are greater when the curing compound is sprayed by hand with a small compressor or when the curing compound is transferred from the manufacturer's tank to a secondary spray tank.

## Preparing for Adverse Conditions

Some conditions are extremely adverse to concrete curing. Under these extreme conditions, even the best and most timely curing compound application will not prevent plastic shrinkage cracks. Factors that can contribute to this undesirable condition are:

- high wind
- low relative humidity
- slow tensile strength gain of the concrete (caused by low concrete and ambient temperatures, SCMs, admixture interactions and poor mixture design selection)
- high concrete temperature and
- high ambient temperature.

One concrete mix is not appropriate for every condition. Careful consideration should be given when weather conditions fluctuate, especially cold fronts during dry and/or windy periods seen in many parts of the state from late February through April.

There are tools to help determine if conditions exist for plastic shrinkage cracks to occur. For example, the nomograph in the Portland Cement Association's Design and Control of Concrete Mixtures and computer programs such as HIPERPAV™ can be used. Both tools along with documentation on how to use them are available upon request through the Concrete Laboratory. Contact names and numbers for the Concrete Laboratory are listed under "Contact Information."

An effective curing regimen can prevent plastic shrinkage cracks in most conditions and can minimize drying shrinkage cracks. Although curing is one of the last steps in concrete work TxDOT performs, obtaining proper curing is one of the most important tasks a TxDOT concrete inspector performs to ensure long-term concrete performance.

## References

<sup>1</sup> Neville, A.M. Properties of Concrete. 4th Edition. Prentice Hall. 1995. Pgs. 423-424.

<sup>2</sup> Portland Cement Association, Frequently Asked Questions,  
<http://www.cement.org/cement-concrete-basics/faqs>

## Contact Information

If you have any questions regarding the content of this article, including how to find programs and information about concrete and concrete curing, please contact the Rigid Pavements Laboratory of the Construction Division – Materials and Pavements Section (CST-M&P)

For questions regarding concrete curing compound approval or testing, please contact the Traffic Materials Laboratory of CSTM&P