

Curing Impact and Methods of Application

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Contents

Background.....	1
Introduction.....	1
CURING METHODS AND MATERIALS.....	4
1. Methods that maintain the presence of mixing water in the concrete during the early hardening period.	4
• Ponding and Immersion:.....	4
• Fogging and Sprinkling:.....	5
• Wet Coverings:	6
2. Methods that reduce the loss of mixing water from the surface of the concrete.....	8
• Impervious Paper:	8
• Plastic Sheets:.....	9
• Membrane-Forming Curing Compounds:	10
3. Methods that accelerate strength	13
• Internal Moist Curing:.....	13
• Forms Left in Place:	14
• Steam Curing	14
• Insulating Blankets or Covers.....	14
• Electrical, Oil, Microwave, and Infrared Curing.....	15
CURING PERIOD AND TEMPERATURE	16
SEALING COMPOUNDS	18
REFERENCES.....	22

Background

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. 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, water tightness, 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.

Introduction

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.

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. 1) shows the strength gain of concrete with age for different moist curing periods and (Fig. 2) shows the relative strength gain of concrete cured at different temperatures.

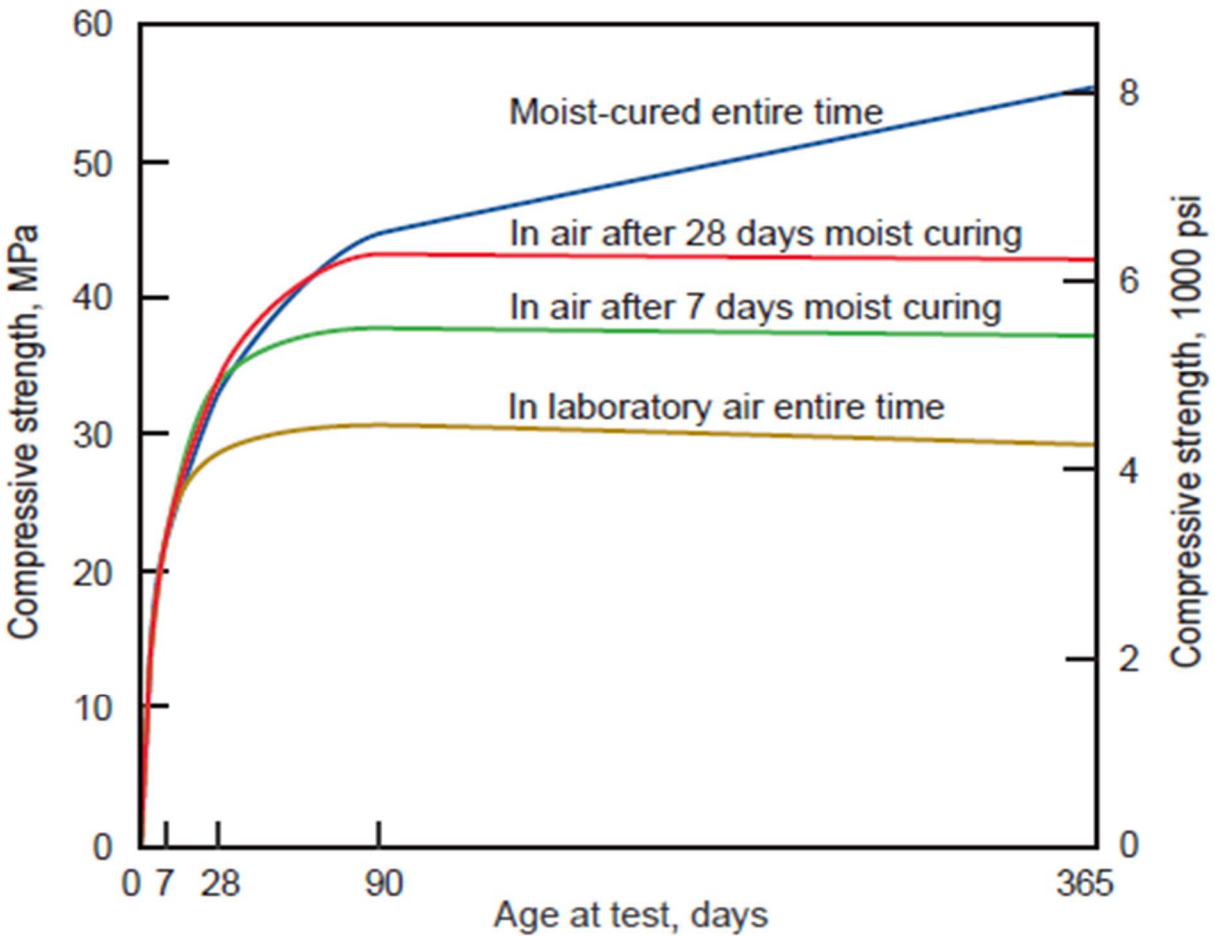


Figure 1: Effect of moist curing time on strength gain of concrete.

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.

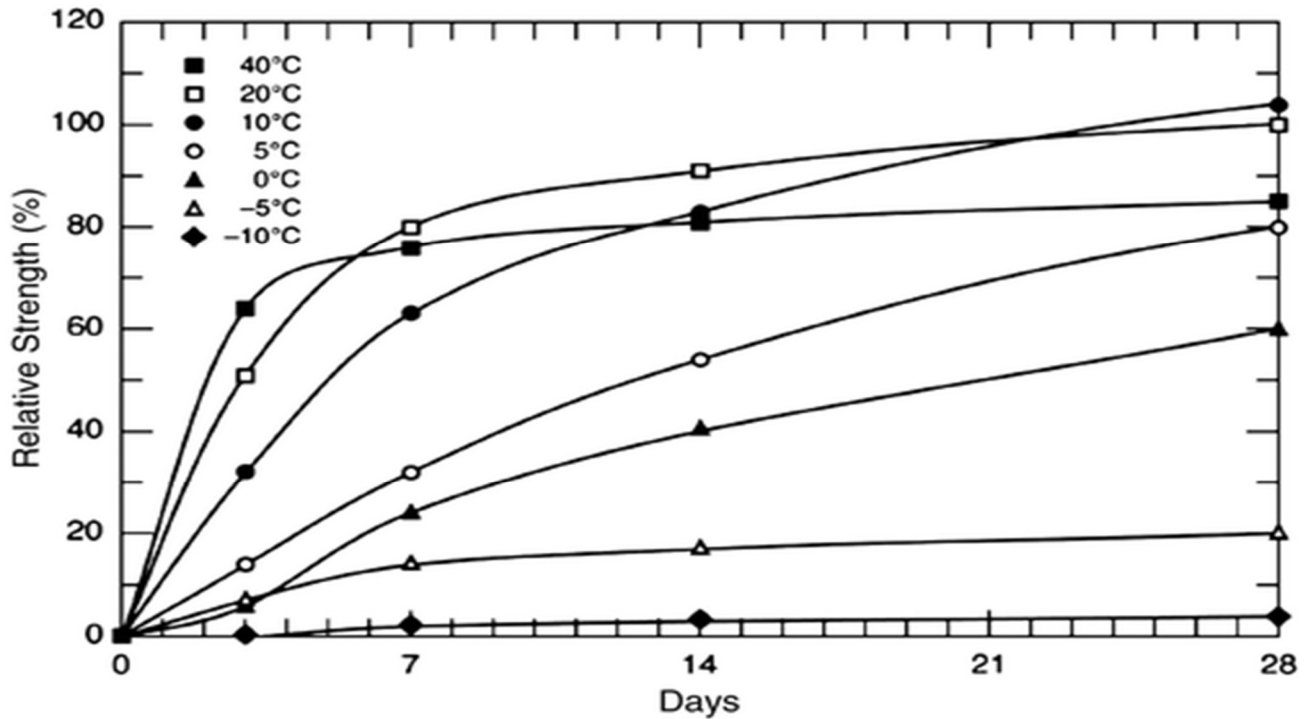


Figure 2: Relative strength gain of concrete cured at different temperatures.

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. Membrane-forming curing compounds may not retain enough water in the concrete. Therefore, fogging and wet curing become necessary to maximize hydration. 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 resumed, the strength development will be reactivated but the original potential strength may not be achieved. 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. 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.
 - **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. 3) 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 flat-work, 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. 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.



Figure 3: Fogging

- **Wet Coverings:** Fabric coverings saturated with water, such as burlap, cotton mats, rugs, or other moisture-retaining fabrics, are commonly used for curing (Fig. 4). Treated burlaps that reflect light and are resistant to rot and fire are available. 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.



Figure 4: Wet Covering, Lawn sprinklers saturating burlap with water keep the concrete continuously moist.

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.

- **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. 5). 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 no staining to the concrete. Paper with a white upper surface is preferred for curing exterior concrete during hot weather.



Figure 5: Impervious curing paper for horizontal surfaces.

- **Plastic Sheets:** Plastic sheet materials, such as polyethylene film, can be used to cure concrete (Fig. 6). 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.



Figure 6: Polyethylene film is an effective moisture barrier for curing concrete and easily applied to complex as well as simple shapes.

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.

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 is 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. 7). 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. Normally only one smooth, even coat is applied at a typical rate of 3 to 4 m² 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 no yellowing, 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.



Figure 7: 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.

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.

- **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 affect 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/m³ to 180 kg/m³ 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: a) live steam at atmospheric pressure (for enclosed cast-in-place structures and large precast concrete units), and 2) high-pressure steam in autoclaves (for small manufactured units).
- **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 poly- urethane 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 ACI 306 (1997), *Cold-Weather Concreting*. Recommendations for curing concrete in hot weather can be found in 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.

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).

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. 8). 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.

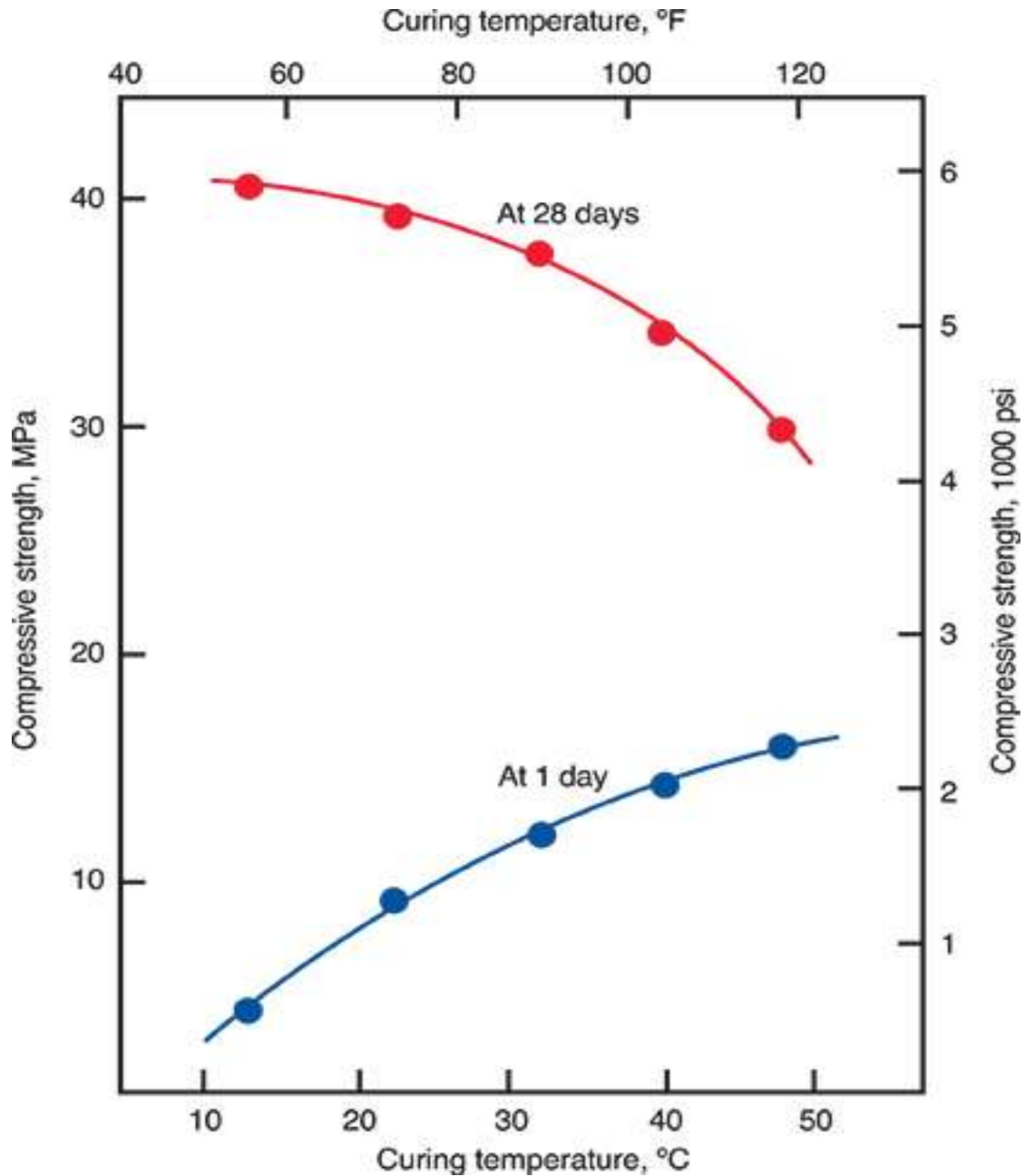


Figure 8: One-day strength increases with increasing curing temperature, but 28-day strength decreases with increasing curing temperature

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 cementations 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 lin- seed 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 has 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 breath, 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. 9).



Figure 9: Penetrating sealers help protect reinforcing steel in bridge decks from corrosion due to chloride infiltration without reducing surface friction.

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