Tech Brief

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CURING CONCRETE PAVING MIXTURES

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Introduction

Hydraulic cement concrete (HCC) is composed of aggregates that are bound together by a paste made up of hydraulic cement binder and water. All hydraulic cement binders have one thing in common: they gain strength and other engineering properties through an exothermic (heat generating) hydration reaction that occurs when minerals present in the cement (and in any supplementary cementitious materials [SCMs]) chemically react with the mixing water to form hydration products (e.g., calcium silicate hydrate, calcium hydroxide, calcium aluminate, etc.). These hydration products partially occupy the space previously filled with water, binding the cement particles and aggregates together in a rigid matrix that is known as concrete. As hydration progresses, more space becomes occupied and the concrete strengthens and becomes less permeable. The hydration reactions will continue:

- As long as cement particles are available and remain accessible to water.
- As long as water is available to support the hydration reaction.
- As long as the temperature remains high enough to support the hydration reaction.

Mixture proportioning controls the availability and accessibility of cement particles to water, while the latter two items are addressed through curing, which is defined as providing sufficient moisture and suitable temperatures to sustain the hydration reaction until the desired engineering properties (e.g., strength, permeability) of the concrete are achieved. Curing is an important step in all concrete construction, with more extensive discussions on the topic provided by Taylor (2014), Kosmatka and Wilson (2016), and ACI (2016a). Hot and cold weather construction pose special challenges related to curing, and additional information on those topics are also available (ACI 2010; ACI 2016b; Kosmatka and Wilson 2016; FHWA 2018).

This Tech Brief focuses specifically on approaches commonly used for curing cast-in-place concrete pavements. The most common method is the application of membrane-forming curing compounds, although fogging, plastic sheets, wetted materials, and insulated blankets may also be used depending on the type of project and the ambient conditions during and after placement. Also discussed briefly is internal curing using prewetted lightweight aggregate (ACI 2013; Weiss 2016). In the context of this Tech Brief, two curing steps are considered: 1) initial curing applied during or immediately after the concrete is placed under less-than-favorable conditions, and 2) conventional curing applied once the concrete has undergone initial set.

Curing and Evaporation Rate

Curing supports cement hydration by ensuring that sufficient moisture and temperature are maintained until the desired engineering properties of the concrete are achieved. Although all cast-in-place concrete pavement requires curing, certain conditions warrant greater care in the application of curing to avoid early-age plastic shrinkage cracking. These conditions include:

- Use of mixtures with reduced amount and rate of bleeding, which is the appearance of a layer of water at the top or the surface of freshly placed concrete after it has been consolidated and struck off but before it has set (Mindess, Young, and Darwin 2003).
- Use of slow-setting mixtures.
- Placement in highly evaporative environments (see Section 5.2.1.1.1 of ACI [2016a]).

Low-slump concrete mixtures used in slipform paving typically have a relatively low total cementitious materials content (for example, it is not unusual to see mixtures with 500 lb/yd^3 [297 kg/m^3] of total cementitious content or less) and a low water content and may often contain 15 to 25 percent or more replacement of cement with SCMs. Such mixtures will have less total bleeding than conventional concrete mixture as well as a slower rate of bleeding. As such, the amount of bleed water rising to the surface might be insufficient to replenish moisture lost to the atmosphere even under normal evaporation rates. If this occurs and the surface dries out, plastic shrinkage cracking can occur.

High SCM mixtures may also suffer a delay in setting, a situation exacerbated by cooler temperatures (i.e., those below 70 ^{0}F [21 ^{0}C]). This can result in the concrete lying in a plastic state for an extended period of time, which is critical for pavements as they have a large surface area exposed to the atmosphere and thus evaporation may result in drying before the concrete sets. Similar to what was described in the preceding paragraph, such circumstances can result in plastic shrinkage cracking.

Adding further to the risk of plastic shrinkage cracking is the placement of concrete pavements when temperatures, wind velocity, and relative humidity combine to create an environment in which the rate of evaporation exceeds the rate of bleeding. Figure 1 illustrates this concept for three hypothetical mixtures and three evaporation rates.

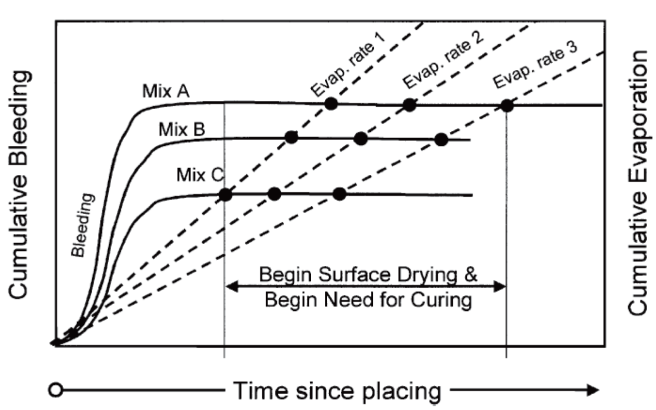


Figure 1. Illustration of the effects of bleeding rate and evaporation rate on need for curing (ACI 2016a).

Authorized reprint from *Guide to External Curing of Concrete*. ACI 308R-16.

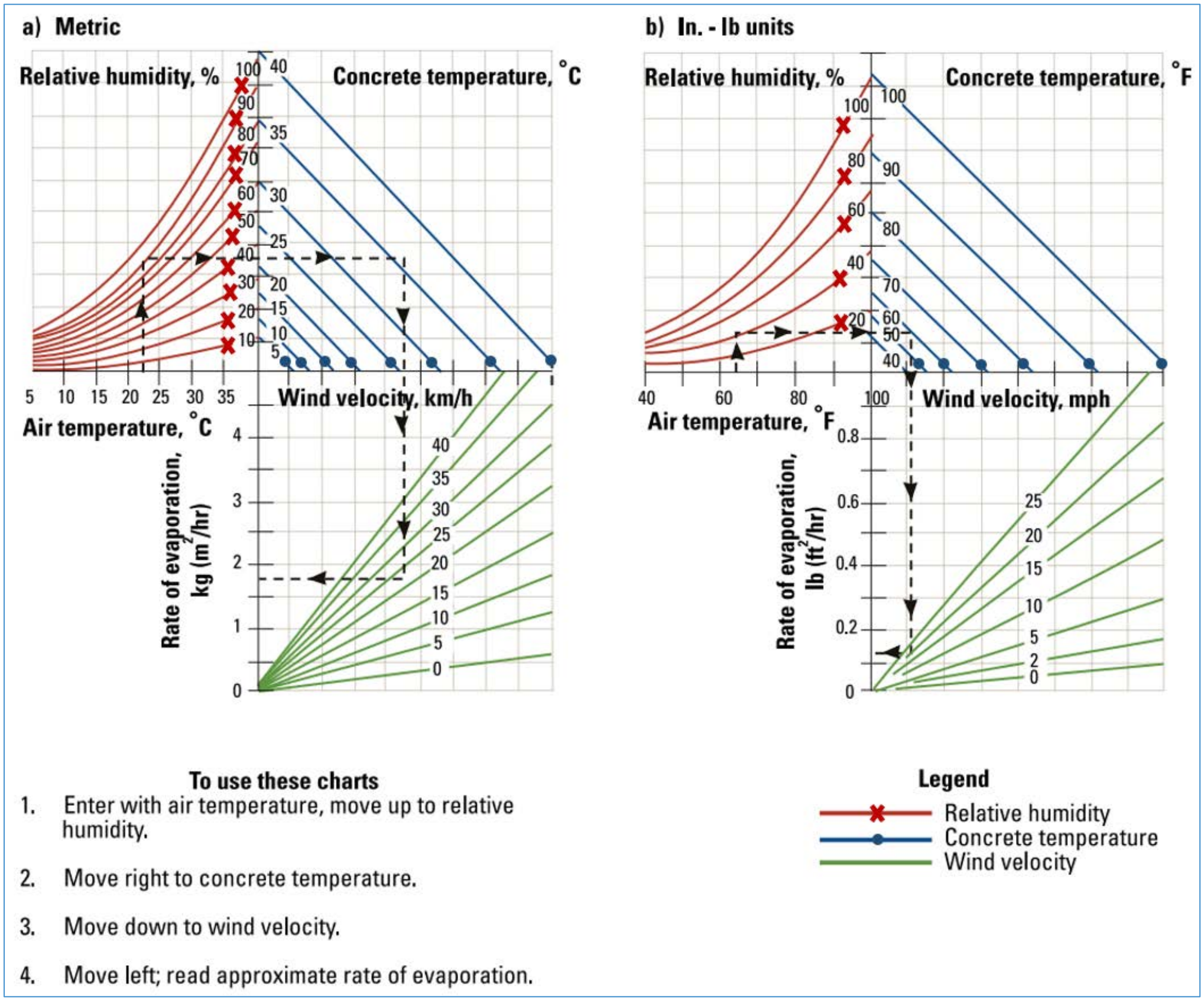
As shown in figure 1, Mix A has a high degree of bleeding compared to Mix C, which has little bleeding. Because of this, Mix C requires that curing be applied much earlier than Mix A, especially under the highly evaporative conditions represented by Evaporative Rate 1. More time is available for curing initiation under the reduced evaporation rate represented by Evaporative Rate 3, although the time is shorter for Mix C than Mix A.

The most common method to estimate evaporation rate is through the use of the Menzel/NRMCA nomograph (see figure 2). This nomograph is available as an application from numerous sources including the ACPA (2017). A common value set for the critical evaporation rate is 0.20 $lb/ft^2/hr$ (0.98 $kg/m^2/hr$) based on work originally reported by Menzel (1954) and Lerch (1957) using data collected to study evaporation of reservoirs. Over the ensuing decades, questions have been raised regarding both the applicability of this nomograph to a fresh concrete surface and the appropriateness of the critical value for modern concrete (ACI 2016a). Nevertheless, the nomograph and the critical evaporation rate are common features in concrete specifications as a way of minimizing the risk of plastic shrinkage cracking. And today, hand-held meters are available that measure relevant environmental conditions and calculate the evaporation rate for use during construction.

Initial Curing

Curing measures should begin when the concrete surface begins to dry as evaporation exceeds bleeding and the surface starts to lose the sheen created by the presence of bleed water. The purpose of initial curing is to prevent the early loss of moisture from the newly placed pavement surface, allowing the concrete to set before the development of plastic shrinkage cracking. The two most common methods to achieve initial curing for pavements is through fogging or through the application of evaporation reducers (Kosmatka and Wilson 2016; ACI 2016a). Fogging, which uses specialized fog nozzles to create a fog blanket, is the most effective way to minimize evaporation and reduce risk of plastic shrinkage cracking as it raises the relative humidity immediately above the slab surface (Kosmatka and Wilson 2016). The specialized fog nozzles are distinctly different from conventional spray nozzles that produce excess water on the slab surface. Fogging should be continued until the application of the conventional method of curing.

Evaporation reducers are solutions of organic chemicals that, when applied in sufficient quantity, form a film on the bleed water surface, thereby reducing the evaporation rate and reducing the risk of plastic shrinkage cracking (ACI 2016a). They are applied by spraying them onto the fresh concrete surface when bleed water is still present and must be applied in strict accordance with the manufacturer's recommendations. They are not to be worked into the surface as finishing aids.



Source: FHWA

Figure 2. The Menzel/NRMCA nomograph for estimating the maximum potential rate of evaporation from a water-covered surface (from Taylor et al. 2007).

Conventional Curing

Conventional curing should begin immediately after finishing is complete. The downward pressure exerted during finishing brings water to the surface and texturing (e.g., brooming or tining) creates a high surface area that in combination increases evaporation and therefore requires moisture control measures (ACI 2016a). It is recognized that the most effective curing methods are wet coverings or water spraying, both of which effectively maintain the concrete in a damp condition (Kosmatka and Wilson 2016). However, this is widely considered impractical for pavements and therefore curing is almost universally accomplished through the application of liquid membrane-forming curing compounds.

Liquid Membrane-Forming Curing Compounds

Liquid membrane-forming curing compounds are composed of waxes, resins, and other materials applied to retard the evaporation of moisture from the pavement surface. They are specified under AASHTO M 148 (ASTM C309) (see tables 1 and 2). AASHTO M 148 curing compounds include Type 1 – clear, Type 1D – clear with fugitive dye, Type 2 – white pigmented, Class A – unrestricted composition (usually used to designate wax-based products), and Class B – resin-based compositions. The water-retention capability of the membrane-forming curing compounds is assessed by AASHTO T 155 (ASTM C156). It is noted that membrane-forming curing compounds that meet the requirements of AASHTO M 148 have a variable capacity to reduce moisture loss, with some moisture loss occurring depending on both how the compound is applied and the ambient conditions (ACI 2016a). Work conducted by Hajibabaee, Moradllo, and Ley (2016) found that a solvent-based curing compound (i.e., poly alpha methylstyrene) was more effective than two water-based curing compounds (i.e., wax-based and resin-based) in providing water-retention, possibly due to better surface wetting that produces fewer imperfections.

Table 1. AASHTO M 148 curing compound classification, color.

Type	Description
1	Clear
1D	Clear with fugitive dye
2	White pigmented

Table 2. AASHTO M 148 curing compound classification, solid composition.

Class	Description
A	Unrestricted composition – often used for wax-based products
B	Resin-based composition

Application: Timing and Rates

As discussed, membrane-forming curing compounds should be applied as soon as finishing is completed, and bleeding has ceased. At this stage, the bleed water has just left the surface and the texturing has increased the surface area resulting in increased evaporation. It can be difficult to determine if bleeding has ceased in highly evaporative environments, particularly for mixtures with low bleeding rates. Under such conditions, an 18-inch (457 mm) square of transparent plastic sheeting placed on the uncured surface can be used to assess bleed water accumulation (ACI 2016a). This is a critical time, as a delay in the application of the curing compound under adverse conditions can result in plastic shrinkage cracking. As noted earlier, modern concrete paving mixtures often have little to no bleeding and thus the curing compound might need to be applied immediately following the finishing operations.

Curing compounds should be applied to all exposed concrete surfaces at a rate equal to or in excess of the manufacturers' recommendations, noting that deep texturing such as an aggressive broom finish or tining will require increased application rates (ACI 2016a). The application must be uniform and complete, and it is recommended that it be applied in two passes sprayed at right angles to one another (Hajibabaee, Moradllo, and Ley 2016). For mainline paving, spray equipment mounted on self-propelled unit should be used with hand spray applications being limited to small placements or irregular areas inaccessible to the self-propelled unit. Different curing compounds require different spraying equipment and nozzles, and each manufacturer's recommendations must be followed for the specific product being used. In addition, it is critical that nozzles and hoses be cleaned and properly maintained in order to achieve uniform application.

For slipform paving, it is critical that all exposed sides of the slabs are treated, including the sides. This is shown in figure 3, which depicts a self-propelled unit with a spray bar applying curing compound to the surface and sides of the slab. If the concrete pavement is placed with fixed forms, the exposed sides of the slab should be coated if the forms are stripped within 7 days of placement. In these cases, the sides should be kept uniformly moist following form removal until the curing compound can be applied to the exposed sides at the same rate as for the pavement top surface. Some agencies also require that curing compound be applied to the joints after they have been sawed. The use of curing compounds with fugitive dye or white pigmented helps ensure that proper coverage has been attained. White-pigmented curing compounds are recommended for use on hot, sunny days as they increase surface reflectivity, which reduces concrete temperature (Kosmatka and Wilson 2016).

Source: FHWA

Figure 3. Spray equipment mounted on self-propelled unit applying curing compound to surface and sides of slipformed concrete pavement (Taylor et al. 2007).

Prior to application, the curing compound should be agitated in accordance with the manufacturer's instructions. Hand or power sprayers with appropriate wands and nozzles with pressure usually in the range of 25 to 100 lb/in^2 (0.2 to 0.7 MPa) are commonly used to apply curing compounds, with power sprayers being recommended for large jobs (ACI 2016a). Again, the manufacturer's recommendations must be followed regarding the equipment specifications for the application of their product.

Limitations

Wax-free curing compounds are recommended for areas that will be subjected to traffic before the desired curing period is over (ACI 2016a). Further, it should be determined if the curing compound will interfere with the bonding of lane striping or other surface treatments. If testing indicates that this may be a problem, the curing compound must be removed from the surface prior to application of the striping or surface treatment.

Membrane-forming curing compounds are only effective if they are applied uniformly, in sufficient quantity, and at the proper time. Poor coverage, such as is shown in figure 4, will result in unacceptable moisture loss. And, as described previously, the curing compounds must be applied to all exposed concrete surfaces, including concrete exposed after form removal.

Figure 4. Inadequate application of membrane-forming curing compound.

Internal Curing

When the water-to-cementitious materials ratio (*w/cm*) of concrete drops below 0.42, there is no longer enough mixing water available to hydrate all the cement (Mindess, Young, and Darwin 2003). Furthermore, the formation of hydration products within the first few days sufficiently fills the capillary pores resulting in "depercolation," which effectively prevents externally applied water from penetrating beyond the near surface zone. Thus, even if water is applied externally to the concrete to support curing, it cannot penetrate beyond the cure affected zone, which is the outer 0.2 to 0.3 inches (4 to 8 mm) (ACI 2013). Thus, by providing an internal source of water, continued hydration can be supported in mixtures with *w/cm* below 0.42.

For paving concrete, this can be accomplished through partial replacement of the fine aggregate with prewetted lightweight fine aggregates, which act as small reservoirs feeding water to hydrating cement as the capillary pores begin to dry out. Additional information on internal curing is available from FHWA (Weiss 2016) and ACI (ACI 2013).

Summary

Proper curing of a newly placed concrete pavement is an essential step to ensure that the concrete as designed, batched, and placed reaches its full potential. Improper curing can result in inadequate hydration and reduced concrete strength and can negatively affect the near-surface concrete properties including increased permeability, decreased wear resistance, and increased risk of plastic shrinkage cracking.

Curing measures should begin when the concrete surface begins to dry as evaporation exceeds bleeding and the surface starts to lose the sheen created by the presence of bleed water. Initial curing, using either fogging or the application of evaporation reducers, can be used to prevent the early loss of moisture from the newly placed pavement surface, allowing the concrete to set before the development of plastic shrinkage cracking. Conventional curing, using either moist curing or membrane-forming curing compounds, should be performed immediately after finishing is complete. Moist curing, where the concrete surface is kept moist for the duration of the curing period, not only prevents surface evaporation but also provides additional moisture to support hydration. Logistically, however, moist curing is difficult to implement on most paving projects and therefore the most common curing method involves the use of membrane-forming curing compounds. The choice of curing compound is often dictated by specifications, but it must be understood that the ability to retain water is highly dependent on the thoroughness of the coverage application, which must be uniform and complete. This often requires a double application, sprayed at right angles, at or in excess of the manufacturer's recommended application rate.

In addition, internal curing provided through partial replacement of the fine aggregate with prewetted lightweight fine aggregate can support addition cement hydration, especially in mixtures with *w/cm* below 0.42 where external curing is less effective and self-desiccation can occur.

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