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Curing

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Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. The October 2015 MAP Brief provides information relevant to Track 8 of the CP Road Map: Concrete Pavement Construction, Reconstruction, and Overlays.

This MAP Brief is available at www.cproadmap.org/publications/MAPbriefOctober2015.pdf.

"Moving Advancements into Practice"

MAP Brief October 2015

Best practices and promising technologies that can be used now to enhance concrete paving

Curing

Definition

Curing is formally defined as "action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration and (if applicable) pozzolanic reactions to occur so that the potential properties of the mixture may develop" (ACI 2013).

In other words, curing involves keeping the concrete wet enough and warm enough for hydration to proceed.

Why curing is important

Concrete experts spend a lot of time talking about curing, but in practice it may be an afterthought in the concrete paving process. We also often get away with it, but when disputes occur, the assessment of adequate curing is subjective. The aim of this document is to describe why curing is desirable, particularly for slabs on grade, and to provide recommendations on how it may be achieved.

Hydration of portland cement based mixtures is a chemical process that requires the presence of cementitious reagents and water to proceed. Allowing a mixture to dry prematurely stops the reaction and the cementitious materials effectively become aggregate particles. This is of greater importance when mixtures contain supplementary cementitious materials that generally hydrate slower than plain cement.

Sufficient hydration is critical to ensuring that the pavement or structure achieves the desired performance goals. Hydration is initially very rapid, but slows over time as shown in figure 1. The longer curing promotes hydration, the greater the performance of the system.

Properties that can be affected by curing include the following:

- Permeability is a property that influences the ability of a system to resist the environment to which it is exposed. Decreasing permeability will almost always extend the life of a system. Permeability is most critical at the surface where the concrete is impacted by the environment, and it is this same zone that is most strongly affected by the quality of curing.
- Strength, which is affected by curing, is a concern for structural loading purposes. However, it should be noted that external curing is largely only effective to a depth of about an inch or less below the surface. This means that while a small test cylinder will show reduced strength due to poor curing, a large column is less likely to be measurably weaker due to poor curing.
- Cracking is increasingly likely with increased shrinkage movements. The

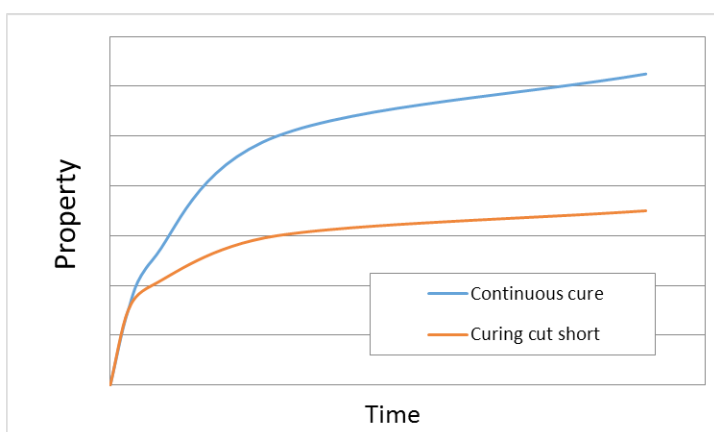

Figure 1. Effect of inadequate curing on concrete properties

amount of shrinkage is directly related to the amount of moisture that is lost due to drying of the system and is most critical in slabs with large surface-to-volume ratios. Delaying the drying will reduce water available to leave the system because it is chemically consumed, and it will also allow the paste to gain increased strength, thus making it better able to resist the stresses induced by the shrinkage.

In summary, curing is critically important to get the most out of the mixture and to ensure that the system is long lived.

How curing is achieved

The following sections describe best practices for curing.

Temperature management

In typical practice, curing mostly involves preventing moisture loss; however, when paving under extreme temperature conditions (very cold or hot), temperature management becomes a very important aspect of curing. The lower the temperature of a mixture the slower the rate of hydration, with reaction rates being about halved with every 18°F reduction in temperature. While freezing of a mixture is only a concern when pore temperatures are well below 32°F, it is desirable to keep a mixture warm to accelerate development of properties and so reduce the risk of thermal and moisture related cracking.

Thermal gradients across an element can also set up significant stresses and promote cracking. Use of warm water in the mixture, plastic sheeting or blankets will all help to hold heat in the slab and promote hydration. It should be noted that hydration will generate heat within the mixture.

On the other hand, the concrete should not be allowed to get too hot. Temperatures above about 160°F may promote formation of delayed ettringite in some cementitious systems, which may cause cracking in the long term. In addition, the higher the temperature in the first stages of hydration, the higher the permeability of the mixture. Use of chilled mixing water and embedded cooling pipes may be needed in large concrete elements. Steam curing of precast systems should be controlled to below about 160°F in the concrete.

Keep it wet

Initial curing is a term applied to activities to prevent moisture loss before the concrete sets and finishing activities are completed. Such efforts may be needed in hot, dry, or windy environments. The aim is to ensure that the evaporation rate is lower than the bleeding rate at the surface of the slab. Activities may include fogging or application of evaporation retarders, primarily to prevent plastic shrinkage cracking. Evaporation retarders applied at controlled rates can be worked back into the surface, but are often abused as finishing aids, which should not be permitted.

Final curing takes places after finishing is complete with the aim of reducing or preventing moisture loss from the concrete for several days. Past or little-used curing methods include the following:

- Flooding a slab (figure 2) was an approach used in the 1920s and 1930s, but is no longer practical with current schedules.
- Covering the slab with plastic sheeting (figure 3) is not uncommon in smaller applications like sidewalks. One caveat is that a buff color may form under the tented folds of the plastic sheeting under hot conditions. Placing the plastic on the surface too early may also disrupt the texture.
- Tenting (figure 4) may be considered if winds are high, but this is a labor intensive activity.

Liquid curing compounds are the most common form of protection used for concrete pavements and are discussed in more detail below.

Figure 2. Flooding of an Iowa roadway (photo courtesy of Mitchell County, Iowa)

Figure 3. Colors formed under plastic sheets in hot weather

Figure 4. A rolling tent structure

Curing compounds

Curing (or liquid membrane-forming) compounds are typically based on waxes and resins emulsified in water or solvent. Emulsified linseed oil cure/sealer compounds are also used for curing some concrete pavements. Pressures to reduce volatile organic compound (VOC) emissions are forcing manufacturers toward water based systems that may be less effective. However, newer products based on poly-alpha-methyl-styrene (PAMS) are proving to be particularly effective. PAMS is a white pigmented curing compound that significantly reduces water loss due to evaporation. PAMS is currently allowed by at least nine state transportation agencies. The Minnesota DOT has been using PAMS-based curing compounds successfully for 15 years. Curing compounds should comply with ASTM C 309, but it should be noted that the precision of this test is low.

Many agencies specify a minimum application rate, typically 15-20 sq yd/gal, but the following should be considered when selecting such limits:

- Increasing roughness or texture of the concrete surface will significantly increase the amount of product required to achieve effective coverage of the whole surface.
- Application rates should be based on the solids content of products, which are likely to vary significantly between products.
- Allowance must be made for wind losses, and wind shields should be provided.
- Like painting, experience and research has shown that two thin coats are more effective than one thick coat.
- Nozzle spacing and height should ensure uniform and sufficient application rates.

Requirements for application of the curing compound include the following:

- The surface must be moist. Waiting until sunset on a hot summer day will ensure that the compound provides little to no benefit.
- Bleeding must have ended, otherwise a water-rich layer may form below the surface accelerating scaling. Bleeding continues until the cement paste has stiffened sufficiently to resist the settlement of the solid particles (typically less than 30 minutes).
- Applying curing compound to a surface that is too wet prevents the product from forming a sealant layer.
- Application must be uniform and conducted by machine. Figure 5 shows a photo of an unacceptable finish.
- Some agencies require that the surface should be compared a sheet of white paper for uniformity. There are no standard approaches to measuring or ensuring adequate application at present. Figure 6 shows a properly cured pavement.
- Traffic should be kept off treated surfaces for the desired curing period in order to prevent compound from being scrubbed off.
- All exposed faces of the slab should have curing compound applied to them.

Figure 5. Inadequate curing compound application

Figure 6. Proper curing compound application

Ideally, curing should be provided for 3–7 days, which is about the degree of protection provided by curing compounds. Therefore, when used as recommended, no extra treatment is required.

Internal curing

Internal curing is a relatively recently adopted approach to providing curing water throughout the depth of a section. This approach was initially aimed at high-performance mixtures that were prone to desiccation, but the literature is indicating that normal bridge and paving mixtures will also benefit.

About 20%–30% of the fine aggregate is replaced with a lightweight fine material (LWFA) that has been wetted for some time before batching. An alternative is to use super absorbent polymers that perform in a similar way. The extra water does not affect w/cm, but can be desorbed from the LWFA or SAP when relative humidity in the paste pores drops below about 95%, and thus promote continued hydration of the system.

The benefit, when compared to surface curing, is that the water is evenly distributed throughout the element, thus reducing differential moisture profiles (and reducing warping). Reported benefits include less shrinkage, better SCM hydration, and improved permeability.

Several states are using the technique as normal practice in bridge decks—pavement applications are more limited at this time. Additional effort is required to store the LWFA and to control its moisture state before batching.

Summary

Curing is a relatively low cost activity that provides benefits well beyond the effort. The fundamentals are simple—keep it wet and keep it warm. The details, however, need to be worked out for each project depending on the weather, materials, and construction constraints.

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