"Moving Advancements into Practice"

MAP Brief Winter 2024

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

Toward Performance-Engineered Curing

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PROJECT TITLE
Toward Performance-Engineered Curing

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Introduction

According to the American Concrete Institute (ACI), curing is "an action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic cement hydration and, if pozzolans are used, pozzolanic reactions to occur so that the potential properties of the mixture may develop" (ACI 2016).

It is important to note that large concrete structural elements have a relatively small amount of exposed surface area for the volume of concrete, and external curing either by ponding or wet burlap is unlikely to influence the strength of the structure significantly (Taylor 2014). In contrast, concrete pavements and flatwork have a much higher exposed surface area for the volume of material, making curing especially important for these types of structures, primarily to ensure that the exposed surface can resist the environment it is exposed to. The zone affected by curing is not defined precisely but is generally considered to be within the outer ¼ to ¾ in. (Rothstein 2017).

While concrete pavements can be cured using ponding, burlap, plastic sheeting, or water-retaining materials, for current construction practices the use of membrane-forming curing compounds is the only practical technique to achieve adequate curing (Wilson and Tennis 2024, Chen and Ley 2022). Figure 1 shows the application of a curing membrane to the top surface and sides of a slipform paving slab.

This MAP brief reviews the current state of membrane-forming curing compounds for concrete pavement, provides recommendations for improving curing, and discusses emerging technologies to allow performance-engineered curing. More information on the mechanisms related to concrete hydration during curing can be found in *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual* (Taylor et al. 2019), and more information on the curing of concrete mixtures can be found in ACI Committee 308 (2016), Taylor (2014), Poole (2006), and Van Dam (2018).

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Figure 1. Curing machine coating both the top surface and sides of a slipform paving slab

State of Testing and Specifications

The standard specification for curing compounds is ASTM C309, which defines three types:

- Type 1: Clear or translucent without dye
- Type 1D: Clear or translucent with fugitive dye
- Type 2: White pigmented

The types are further defined based on the dissolved solids in the compound as either Class A (No Restrictions) or Class B (Resin). A Class B compound is identified using the definition of a resin from ASTM D883: "a solid or pseudosolid organic material, often of high molecular weight, which exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally." ASTM D883 further explains, "In a broad sense, the term [resin] is used to designate any polymer that is a basic material for plastics."

Common curing materials used in highway paving are a wax base meeting Type 2A or a poly-alpha-methyl styrene (PAM) meeting Type 2B.

Three primary criteria are included in ASTM C309 for performance acceptance:

- A water loss of less than 0.55 kg/m² in 72 hours as determined by ASTM C156 on mortar at 200 ft²/gal
- For Type 2 compounds, a reflectance of more than 60% as determined by ASTM E1347
- A drying time of less than 4 hours

NCHRP Synthesis 598: Curing Practice for Concrete Pavements presents a review of membrane-forming curing compound requirements in use by state agencies (Armaghani and Zollinger 2023). Common deviations from ASTM C309 include 24-hour limits for moisture retention, reduced limits at the 72-hour cutoff, increases in reflectance, and state-specific application rates, as shown in Table 1.

In practice, a common technique for determining whether sufficient curing compound has been applied is to compare the pavement's surface to a white sheet of typing paper (MDOT 2020). However, it should not be inferred from this comparison that uniform coverage and proper application rate are equivalent. The pavement shown in Figure 2, for example, clearly exhibits visual differences between two adjacent sections where the application rates were equivalent; the visual difference is due to the settling of solids in the curing compound between applications.

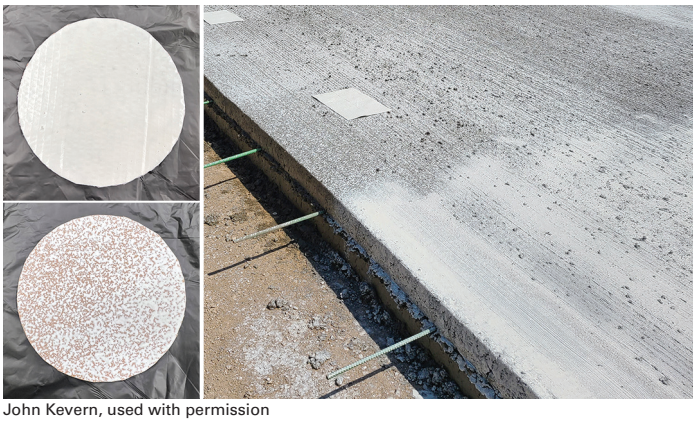

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Figure 2. Variations in curing compound coverage for adjacent pavement sections

The inset shows a uniform application at 400 ft²/gal (top) and a nonuniform application at 200 ft²/gal (bottom). Based solely on appearance, one section would require remediation while the other would be accepted, potentially with neither resulting in adequate curing.

Emerging Testing Technologies

Though a variety of test methods are available for assessing curing application rate, at present most are not being utilized outside of research (Caltrans 2014, Choi and Won 2008). However, four emerging technologies show promise for actively managing curing by assessing concrete performance:

1. Dry bulb and dew point: Relative humidity sensors installed below the cure-affected depth and at the surface can determine the real-time drying gradient (Armaghani and Zollinger 2023).
2. Time domain reflectometry (TDR): TDR measures the relative dielectric constant by comparing the velocity of an electrical signal through a medium to the velocity through air or water (Korhonen et al. 1997). The volumetric water content can be calibrated to the dielectric constant of a particular mixture to determine the state of pore emptying due to hydration and drying (Armaghani and Zollinger 2023).

Table 1. Summary of curing compound requirements from NCHRP Synthesis 598

Agency	24-Hour Limit (kg/m²)	72-Hour Limit (kg/m²)	Application Rate (ft²/gal)
Virginia DOT	0.20	0.30	100 Class B
Mississippi DOT	NA	0.55	120
Iowa DOT	0.20	0.40	135
South Carolina DOT	NA	0.55	100 Class A, 150 Class B
Montana DOT	NA	0.55	150
New York DOT	NA	—	150 in two directional passes
Texas DOT	NA	0.55	180 in two coats
Minnesota DOT	0.15	0.40	200
Delaware DOT	NA	0.55	400 in two applications

3. Ground-penetrating radar (GPR): GPR has been used successfully to determine the quality of curing compound coverage. However, the need for the compound to dry before testing can be performed limits the usefulness of this test for preventing remedial activities. Fortunately, small transmitters and receivers can now be mounted to aerial drones, allowing automated assessment in real time (Joshaghani and Zollinger 2017, 2021).
4. Embedded resistivity: Just as electrical resistivity has become useful for assessing concrete durability, resistance can also be used to assess differences in application rates that cannot be detected visually (Nkongolo et al. 2024).

Steps Toward Active Curing Management

The previous sections have discussed the state of the practice and common challenges related to concrete curing. This section discusses current and emerging activities and technologies to further improve consistency in the use of membrane-forming curing compound.

Current Techniques

Vandenbossche (1999) provides recommendations for curing compound application, including adjusting the nozzle height to ensure a 30% overlap between spray zones and adjusting the cart speed to achieve the desired application rate. Calibration and verification can easily be performed with a wheel indicator and tape measure and by monitoring the volume of liquid in the tank.

Additionally, many specifications contain language regarding stirring and mixing of the curing compound in the tank, which should be followed and enforced.

Next Steps

While most curing carts are simply comprised of a motor for locomotion and a pump for spraying, with the application rate controlled by the speed of the operation, more advanced curing technology is emerging.

A real-time display for monitoring and adjusting curing is available that automatically provides the operator with the correct amount of curing compound for the area covered. Basic inputs to the system include the application rate, pavement width, and spray bar height, as shown in Figure 3. Additional inputs include whether edge sprayers are active and the thickness of the concrete pavement, both of which ensure proper adjustment of the spray bar height.

Figure 4 depicts an operator's display showing the curing machine's current speed and the desired speed required for a particular application rate. A flow meter records the amount of curing compound that goes through the machine over a given period.

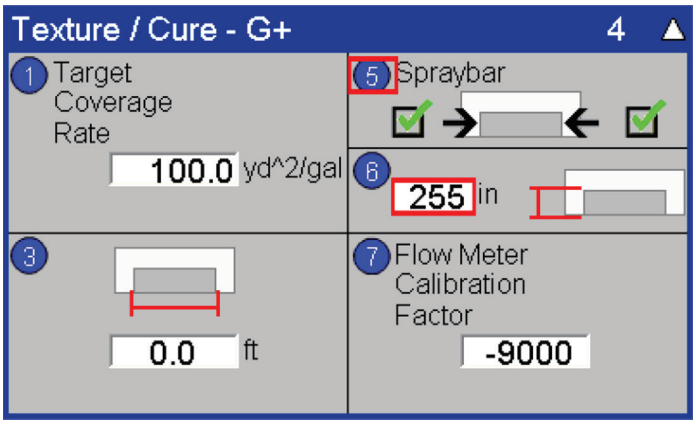

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Figure 3. Curing machine setup screen

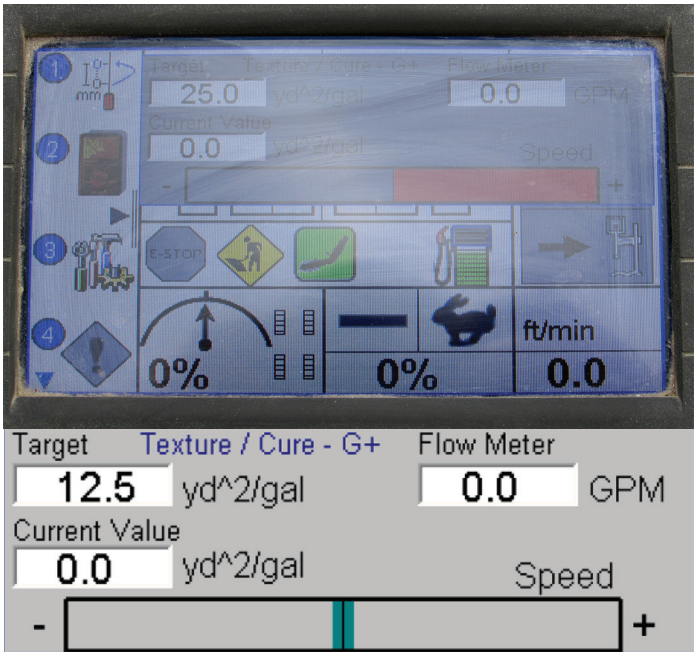

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Figure 4. Operator's display (top) and real-time curing rate screen (bottom)

Additionally, the latest generation of curing machines has three nozzles at each location, which can be rotated in place when one clogs, and a hot water tank to flush the nozzles at the end of a run.

Future

It is conceivable that the evaporative performance of a concrete mixture as a function of the curing compound type and application rate can be assessed during development and incorporated into the initial approval process. Additionally, a fully managed process can be developed that includes the use of on-site weather sensors, weather forecasts, and embedded sensors to determine the optimal timing and application rates of curing compound and the optimal timing of sawing operations.

Closing

Curing habits of the past that were marginally acceptable may no longer be sufficient given the emergence of limestone cements and the increased use of local supplementary cementitious materials. While a limited number of test methods currently exist to assess curing, attention to simple processes can produce significant improvements. Sensors are being developed to evaluate and quantify concrete properties in real time, and the benefits to the industry and the traveling public may be significant.

References

ACI Committee 308. 2016. *Guide to External Curing of Concrete*. ACI 308R-16. American Concrete Institute, Farmington Hills, MI.

Armaghani, J., and D. Zollinger. 2023. *NCHRP Synthesis 598: Curing Practices for Concrete Pavements*. National Cooperative Highway Research Program, Washington, DC. https://doi.org/10.17226/26943.

Caltrans. 2014. *Method of Test for the Application Rate of Concrete Curing Compound In the Field*. California Test 535. California Department of Transportation, Sacramento, CA.

Chen, L., and M. T. Ley. 2022. *Use of a Novel Controlled Release Surface Curing Agent for Bridge Decks Phase 2*. Oklahoma Department of Transportation, Oklahoma City, OK.

Choi, S., and M. Won. 2008. *Identification of Compliance Testing Method for Curing Effectiveness*. Report 0-5106-2. Texas Department of Transportation, Austin, TX.

Joshaghani, A., and D. G. Zollinger. 2017. Concrete pavement curing evaluation with nondestructive tests. *Construction and Building Materials*, Vol. 154, pp. 1250–1262.

Joshaghani, A., and D. G. Zollinger. 2021. Evaluating the quality of curing applications on concrete pavements with ground-penetrating radar. *Transportation Research Record*, Vol. 2675, No. 8.

Korhonen, C. J., V. C. Janoo, and C. M. Berini. 1997. *Time-Domain Reflectometry of Water Content in Portland Cement Concrete*. Special Report 97-27. U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH.

MDOT. 2020. *Standard and Supplemental Specification for Road and Bridge Construction*. V1.2. Montana Department of Transportation, Helena, MT.

Nkongolo, E. B., D. King, P. Taylor, and J. T. Kevern. 2024. Preliminary investigation into using resistance techniques to assess concrete curing. *Transportation Research Record*. In Press.

Poole, T. S. 2006. *Guide for Curing of Portland Cement Concrete Pavements*. FHWA-HRT-05-038. Turner-Fairbank Highway Research Center, McLean, VA.

Rothstein, D. 2017. The how's and why's of concrete curing. *For Construction Pros*. https://www.forconstructionpros.com/concrete/equipment-products/technology-services/article/12169059/twining-inc-the-hows-and-whys-of-concrete-curing.

Taylor, P. 2014. *Curing Concrete*. 1st Edition. CRC Press, Boca Raton, FL.

Taylor, P., T. Van Dam, L. Sutter, and G. Fick. 2019. *Integrated Materials and Construction Practices for Concrete Pavement: A State-of-the-Practice Manual*. National Concrete Pavement Technology Center, Ames, IA. https://intrans.iastate.edu/uploads/2019/05/IMCP_manual.pdf.

Van Dam, T. 2018. *Tech Brief: Curing Concrete Paving Mixtures*. FHWA-HIF 18-015. Federal Highway Administration, Washington, DC.

Vandenbossche, J. M. 1999. *A Review of the Curing Compounds and Application Techniques Used by the Minnesota Department of Transportation for Concrete Pavements*. Final Report 2001-06. Minnesota Department of Transportation, St. Paul, MN.

Wilson, M., and P. D. Tennis. 2024. *Design and Control of Concrete Mixtures*. 17th Edition. Portland Cement Association, Washington, DC.