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Improvements of curing operations for Portland cement concrete pavement

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HIGHLIGHTS

- ► This study presents the efforts to develop simple compliance testing for application rate and uniformity of curing compound.
- ► This study evaluates the feasibility of implementing compliance testing for curing operations in two paving projects.
- ► Speed control of the curing machine could be the most practical and simplest method for compliance testing.

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ABSTRACT

Curing of concrete has substantial effects on the performance of Portland cement concrete (PCC) pavement. The effectiveness of membrane-forming curing compound depends on the quality of curing materials, time of curing compound application in relation to bleeding and evaporation, and amount and uniformity of curing materials applications. This study presents the efforts to develop simple compliance testing for application rate and uniformity. Compliance testing was based on the speed control of a curing machine utilizing a non-contact Doppler radar speed sensor and wireless data logger system. The findings from trial implementations of this method in PCC paving projects include: (1) speed control of a curing machine could be the most practical and simplest method for compliance testing; (2) Doppler sensor and wireless data logger showed fairly good performance and can be an effective and practical curing compliance testing system; and (3) as wind speed increases, the loss of curing compound tends to increase nearly proportionally.

1. Introduction

It is well known that proper curing is essential to long-lasting and well-performing Portland cement concrete (PCC) pavement [1–5]. Because hydraulic cement requires sufficient moisture in concrete for continued hydration, it is important to have sufficient moisture available for cement hydration. It was reported that in concrete pavement, curing-affected zone which is located within 50 mm of the surface is the most susceptible to the effects of poor curing [4,5]. The failure to adequately cure may result in early-age distresses such as plastic shrinkage cracking or spalling or early-age full-depth transverse cracks if saw-cutting is not performed adequately in advance and, in the long run, pavement distresses caused by concrete's decreased durability [3–5].

There are three components that determine the curing effectiveness of liquid membrane-forming curing compound which is most frequently used in curing operation of concrete pavement as a final curing measure [4,5]. They are: (1) the quality of the curing compound materials; (2) timing of curing compound application in relation to bleeding and evaporation; and (3) the amount and uniformity of the curing compound applications. Most state Department of Transportation (DOT) administers quality monitoring programs for curing compounds. For example, in the Texas Department of Transportation (TxDOT), the quality of the curing compound is stipulated in the Departmental Material Specification (DMS)-4650 [6]. TxDOT requires that all concrete liquid membrane-forming curing compounds be pre-qualified in accordance with the requirements of DMS-4650 and listed on the material producer list (MPL) before use on TxDOT projects. In the Iowa Department of Transportation, research [7] was undertaken to implement adequate curing techniques by evaluating curing materials and application methods. The timing of the curing compound application is also important because premature application could trap bleeding water and degrade the quality of curing membrane, whereas overly delayed application will cause the concrete surface to dry quickly, resulting in less durable concrete [4]. The optimum

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time to apply curing compound application is when the cumulative evaporation just exceeds cumulative bleeding, although identifying this optimum time of application in the field is quite difficult. The last element required for good curing is the amount and uniformity of the curing compound applications. State DOTs recognize the importance of the timing and the rate of application, and have certain requirements in their specifications [8–19]. Table 1 summarizes the current requirements of the timing and the rate of curing compound applications in the specifications of selected state DOTs in the United States. Table 1 shows that most states require the application of curing compound right after the finishing operation is completed. Illinois, Iowa, Michigan, Texas and Washington require in addition that the curing operation be initiated after the free surface moisture has disappeared.

ACI 308 [4] stipulates that the optimum time of the curing compound applications should be when the cumulative evaporation just exceeds cumulative bleeding. From a theoretical point, the recommendation is quite sound and valid. To identify the state of practice in the timing of curing initiation, field testing [20] was conducted to evaluate bleeding characteristics of the concrete used for slip-form paving. The testing was conducted in accordance with ASTM C232 [21] and very little bleeding water was collected. In TxDOT, the maximum-allowed water-to-cementitious materials ratio for paving concrete is 0.45 [16] and in most projects, a minimum of 25% of cement is replaced by fly ash. It appears that the low water-to-cementitious materials ratio along with the use of fly ash reduces bleeding to an almost negligible level. This implies that the curing should be initiated as soon as possible. Field evaluations were made in two projects to estimate how soon the curing operations are initiated in actual projects. Fig. 1 shows a timeline of the paving operations observed in June 2005 on SH130 construction in Pflugerville, Texas [20]. In Fig. 1, time zero indicates when the paver passed a specific location. It took 25 min for the paving crew to complete initial finishing operations at that location, including bull-floating and straight edge operations. In another 9 min, a carpet drag operation was completed, followed by tining in another minute. Curing compound was applied at that location 9 min after the tining operation was completed. Therefore, 44 min elapsed between paving and applying curing compound. The evaluation conducted in August 2005 of the construction of US287 in Wichita Falls, Texas showed a similar time line. In that project, it took 52 min before curing was applied after the paver formed the concrete surface. Considering the minimal bleeding in paving concrete, the requirement for timing of curing initiation in most state DOTs – immediately after finishing operations are completed – appears to be reasonable.

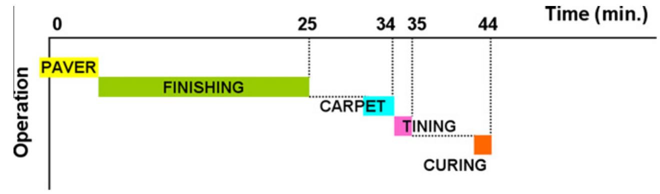

Fig. 1. Timeline of finishing operations on SH130 in Pflugerville, Texas.

Table 1 also shows that most state DOTs require one application at the rate of a maximum of 3.68 m^2/l (150 ft^2/gal). Michigan DOT requires one application for non-grooved surface and two applications for grooved surface. Illinois and Texas DOTs require two applications. TxDOT has the most stringent requirement: double applications with each application rate not to exceed 4.42 m^2/l (180 ft^2/gal) of curing compound, which is equivalent to a maximum 2.21 m^2/l (90 ft^2/gal) of curing compound.

Testing procedures developed in this study provide an easy-to-use method to check the compliance of curing operations in the field. The anticipated benefits of this implementation study are to ensure the quality of curing operations so as to achieve proper concrete properties and to improve the overall performance of PCC pavements. Also, if successful, the new procedures could make it simpler and more effective for SHAs to verify the compliance with specifications.

2. Development of compliance testing procedures

One of the difficulties contractors are faced with in their operations to meet state DOTs specification requirements for curing compound application rate is a lack of convenient means available to provide real-time information on the application rate. If this information is available to the curing cart operator in real time

Table 1
Current requirements for the timing and rate of curing compound application.

State DOT[a]	Timing of curing initiation	Application rate
California	As soon as the finishing process has been completed	Not to exceed 3.68 m^2/l (150 ft^2/gal) [8]
Colorado	Immediately after the finishing operations have been completed	Not to exceed 3.68 m^2/l (150 ft^2/gal) [9]
Georgia	Immediately after finishing the concrete	Not to exceed 3.68 m^2/l (150 ft^2/gal) [10]
Illinois	After the concrete has been finished and immediately after the water sheen has disappeared	Two applications at least 1 min apart; each at the rate of not less than 6.14 m^2/l (250 ft^2/gal) [11]
Iowa	After finishing operations have been completed, and as soon as free water has appreciably disappeared, but not later than 30 min after finishing	3.31 m^2/l (135 ft^2/gal) [12]
Minnesota	Immediately after the last texturing operations	3.68 m^2/l (150 ft^2/gal) [13]
Michigan	Do not delay curing to accomplish texturing. After texturing operations have been completed and after the free water has left the surface	One coat on non-grooved, two coats on grooved. Second coat: after the first coat has dried sufficiently but do not exceed 2 h between coats. Each application rate of 5.52 m^2/l (225 ft^2/gal) [14]
New York	Cure the entire pavement immediately after texturing	3.68 m^2/l (150 ft^2/gal) [15]
Texas	After texturing and immediately after the free surface moisture has disappeared. Apply the first coat within 10 min after completing texturing operations. Apply the second coat within 30 min after completing texturing operations	Two applications: each not to exceed 4.42 m^2/l (180 ft^2/gal) [16]
Virginia	Immediately following the texturing operations	2.45–3.68 m^2/l (100–150 ft^2/gal) on textured surfaces, the rate shall be as close to 2.45 m^2/l (100 ft^2/gal) as possible [17]
Washington	Immediately after the concrete has been finished and after any bleed water that has collected on the surface has disappeared, or at a time designated by the Engineer	3.68 m^2/l (150 ft^2/gal) [18]
Wisconsin	Immediately after the finishing of the surface and before the set of the concrete has taken place	3.68 m^2/l (150 ft^2/gal) [19]

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