

Investigation into Pavement Curing Materials, Application Techniques, and Assessment Methods

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ABSTRACT

Different types of curing compounds were applied to lab and field concrete at different times after casting. Two application methods, single and double layer applications, were employed. Concrete properties, such as electrical conductivity, moisture content, sorptivity, degree of hydration, strength, and permeability were evaluated, and the results were employed for assessment of the curing effectiveness. The investigation indicated that properties of the concrete in the near-surface-area of a pavement without any curing compound were considerably different from those of the internal concrete. Proper curing can significantly increase the moisture content and reduce the sorptivity of the concrete in the near-surface-area, thus providing the pavement with uniform concrete properties throughout depth. For given concrete materials and mix proportion, water retention ability of a curing material can be estimated by monitoring conductivity of the surface concrete. Sorptivity test for lab specimens appeared a good assessment method for curing effectiveness, and the measurement captured the subtle changes caused by different curing materials and application techniques. These research results established a baseline for rational assessment of curing compound effectiveness in both lab and field concrete.

Key words: curing compound—electrical conductivity—hydration—pavement—sorptivity

INTRODUCTION

A variety of curing methods and materials are available for concrete pavements, including water spray or fog, wet burlap sheets, plastic sheets, insulating blankets, and liquid-membrane-forming compounds. Burlap or insulating blankets are considered ideal for retaining heat and moisture, but their application is labor intensive and time consuming. In contrast, liquid membrane-forming curing compounds can provide a similar insulation and be applied much more easily. Control of heat and moisture loss by application of a curing compound, especially in hot or cold weather conditions, has aided contractors in enhancing concrete quality, permitting early open of pavements to traffic and extending the available construction season. Curing compounds are economical, easy to apply, and maintenance free (1).

Concrete practice has indicated that the performances of curing compounds are closely related to the characteristics of the curing materials, application methods (single- or double-layer spray), and application time (2). However, limited research has been done to investigate the effectiveness of different curing compounds and their application techniques. No reliable standard testing method is available to evaluate the effectiveness of curing, especially of the field concrete curing.

RESEARCH OBJECTIVES AND SCOPE

The present investigation was conducted to explore testing methods for measuring the effectiveness in the lab and field as well as to evaluate effectiveness of curing compounds and application techniques for concrete pavements.

The investigation contained two parts: lab study and field application. Three curing compounds with different efficiency indexes were selected and applied to lab and field concrete at different times after casting. Two application methods, single and double layer applications, were employed. Electrical conductivity, moisture content, sorptivity, degree of hydration, strength, maturity, and permeability tests were performed to evaluate the curing effectiveness and concrete properties in the lab and field studies. Some of the results are presented in the following sections. More detailed results can be obtained in separated documents (3,4).

LAB EXPERIMENT

Curing Materials

The curing compounds used are listed in Table 1, where C95.9 and C89.0 are water-based compounds, while C98.1 is a resin-based curing compound. The Efficiency Indexes of the curing compounds were tested according to the test method: Iowa 901-D (5).

TABLE 1. Typical Properties of Selected Curing Compounds

Compound	Color	ASTM Specification	Efficiency Index	Solids Content (%)
C98.1	White	Type 2 Class B	98.1	43.5
C95.9	White	Type 2 Class A	95.9	29.2
C89.0	White	Type 2 Class A	89.0	17.1

Curing Methods

Three reference curing conditions (without curing compound) were selected to simulate the worst, the best, and hot weather curing conditions of field concrete, and they are: air curing (Reference 1: T=77 °F, and R.H.= 38%), wet curing (Reference 2: covered with burlap and stored in a fog room, T=73 °F, and R.H.≥ 95%), and oven curing (Reference 3: T=100 °F at daytime and 77 °F at night time, and R.H.= 35%), respectively. Three cases were also designed for specimens with different applications of the curing compounds, and they are as follows:

Case 1 (Air Curing + Single-Layer Curing Compound, or Air-SL): In this case, a selected curing compound was sprayed on specimens at 15, 30, and 60 minutes after casting. The specimens were cured in the air (T=77 °F, and R.H. = 38%) before and after application of curing compound until testing.

Case 2 (Oven Curing + Single-Layer Curing Compound, or Oven-SL): In this case, a selected curing compound was sprayed on specimens at 15, 30, and 60 minutes after casting. The specimens were cured in the oven (as described in Reference 3) before and after application of curing compound until testing.

Case 3 (Oven Curing + Double-Layer Curing Compound, or Oven-DL): In this case, two layers of a curing compound were applied onto the surface of the specimens. The first layer was sprayed at 15, 30, and 60 minutes after casting. The second layer of the same curing compound was sprayed 5 minutes after the first application of the curing compound. Samples were cured in the oven (as described as Reference 3 curing condition) before and after application of curing compound until testing.

Specimens

Two types of mortar specimens were prepared: one was 2"x2"x4" prisms and the other was 10" (length) x 5" (width) x 4" (depth) slabs. The mortar was made of Type I cement and river sand with fineness modulus of 2.94. The sand to cement ratio was 2.75, and w/c was 0.42.

The prism specimens were used for moisture content and sorptivity tests. The slab specimens were used for temperature monitoring, conductivity tests, and three 2"-cores were drilled from the slabs for compression tests. Small cement paste slabs, 10" (length) x 5" (width) x 4" (depth), were prepared for testing degree of cement hydration tests. The paste has the same cement as that used for mortar with a w/c of 0.28. At the 15, 30, and 60 minutes after casting of the specimens, selected curing compounds were uniformly sprayed on the surface of the specimens until the prescribed rate (3.3 m²/liter) was reached.

Test Methods

Moisture Content: Moisture content was measured from a set of three mortar prisms. In the tests, a mortar prism was fractured along designed notches that divided the prism into three equal pieces: top, middle, and bottom. Each piece was weighed initially (W_i) and then put in an oven at a 105°C for 48 hours to obtain a constant weight (W). The moisture content (MC) is given by $MC = [(W_i - W)/W]*100$.

Electrical Conductivity: After a mortar slab was cast, a pair of copper plates, 0.75" (height) x 2" (width) x 0.125" (thickness) and 3" apart, were vertically inserted into the sample, approximately dividing the sample equally in length. Solomat MPM 2000 conductivity meter was used to measure the resistivity between the two copper plates.

Sorptivity: Sorptivity of mortar prisms was measured at 3 days. The prisms were cut evenly into three pieces. The lateral surfaces of each piece were sealed with five-minute epoxy, and the top surface was covered with plastic. After weighed, the bottom surface of the samples was immersed into tap water, with

a maximum immersed depth of 3 mm. The samples were then weighed again after 5, 10, 20, 30, 60 minutes, and 6 hours of immersion. The test was finished when the slope of mass gain per unit area versus square root of testing time was constant. This constant slope is the sorptivity coefficient.

Degree of Hydration: A 2” diameter core was taken from a paste sample. Three 0.5” thick pieces were cut from the top, middle, and bottom of the core. Each piece was crushed and sieved with a #16 sieve. The samples were heated at 105°C for 18 hours and weighed (W_{105}). They were then heated at 1000°C for another hour and weighed again (W_{1000}). The degree of cement hydration (α) is expressed as: $\alpha = [(W_{105} - W_{1000}) / (0.24 * W_{1000})] * 100\%$. (6)

Test Results

Moisture Content

Curing compound is considered as materials that can form a coating on the surface of newly placed concrete and prevent a quick loss of moisture in the concrete. Table 2 presents one-day moisture content of mortar specimens tested.

TABLE 2. One-day Moisture Content of Mortar Specimens (%)

Layer	(a) Reference Specimens			(b) Case 2: Oven-SL, Measured at Top Layer			
	Oven Curing	Air Curing	Wet Curing	Spray Time	C89.0	C95.9	C98.1
Top	4.77	6.26	8.31	15 min	7.35	7.35	7.26
Middle	5.73	7.04	8.31	30 min	7.20	7.29	7.24
Bottom	5.74	6.88	8.00	60 min	6.96	6.82	6.92

As shown in Table 2(a), for reference specimens (without any curing compound), the top-layer, the one-day moisture content of the mortar slab was 4.77 percent for the oven-cured specimen, 6.26 percent for the air-cured specimen, and 8.31 percent for wet-cured specimen. At hot weather (oven curing) condition, the difference in moisture contents between top- and middle-layer of the mortar (5.73 percent) was approximate 17 percent. At mild weather (air curing) condition, the difference in moisture contents between top- and middle-layer of the mortar reduced to 11 percent. Wet curing provided the mortar with uniform moisture content through depth. The slightly low moisture content in the bottom-layer mortar was found in all specimens, and it might be attributed by aggregate settlement and bleeding water rise in the mortar.

Table 2(b) indicates that for specimens sprayed with a single-layer curing compound at a hot weather condition (oven curing), regardless the type of a curing compound, the one-day moisture content in the top-layer of the mortar slabs was approximate 7.3 percent, compared with 4.77 percent in the reference slab without curing compound. With curing compound, the top-layer moisture content in the slabs was very close to the middle layer moisture content of the slab although it was still lower than the moisture content of the wet cured specimens. As the spraying time of a curing compound was delayed, the moisture content of the top-layer mortar slightly reduced.

Electrical Conductivity

As cement hydration progresses and free water is lost, the numbers and/or mobility of ions in the concrete pore solutions are changed. This in turn causes a change in the electrical conductivity of the concrete (7). For given materials and mix design, the conductivity of concrete depends primarily on the cement hydration process and moisture content in the concrete, which is related to the curing conditions.

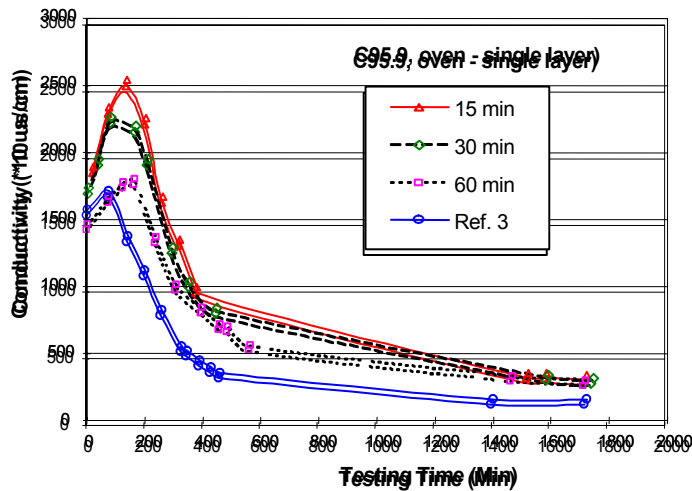


FIGURE 1. Conductivity of Mortar Specimens

Figure 1 illustrates conductivity of mortar specimens with single layer curing compound of C95.9 sprayed at 15, 30, 60 minutes after casting. As shown in the figure, specimen Reference 3, oven cured without curing compound, had the lowest conductivity values, possibly due to fast water loss. When a curing compound was applied, conductivity of the mortar increased with early spray time. It was also observed that wet-cured specimen had the highest conductivity value among all specimens. Specimens with curing compounds all fell within the boundaries formed by Reference 2 (wet curing) and Reference 3 (oven curing). The conductivity of samples sprayed with high efficiency-index curing compounds tended close to that of wet curing specimen (3).

Statistic analysis of the test data has demonstrated a good relationship between conductive and moisture content:

$$\text{Conductivity} = 1/[A-B \log (\text{MC})] \quad (1)$$

Where A and B are constants related to concrete materials and mix design, which are 18.65 and 7.68 respectively based on the present research, and MC is moisture content of the specimens tested. The reliability coefficient of the equation, R^2 , is 0.79, indicating a reasonably reliable relationship. According to this relationship, the electrical conductivity measure can be used to estimate moisture retaining ability of field concrete cured with different materials and application methods.

Sorptivity

Concrete sorptivity is closely related to its pore structure, which in turn influence concrete durability. Absorption test is considered as one of the most reliable methods for assessing curing effects of concrete (8). Poor curing of the concrete may result in high sorptivity, and this effect is more pronounced in the near-surface layer (1–2 inches from the surface) of concrete (9).

Table 3 demonstrates sorptivity values of mortar specimens at different depths, with different curing compound materials, and different application methods. As observed in Table 3(a) and (b), sorptivity of the near surface layer (top layer) of the specimens is generally higher than that of the middle and bottom

layer of the specimens regardless whether or not a curing compound is applied. This may be also attributed to the aggregate settlement. In freshly cast concrete, aggregate settles due to its gravity and bleeding water raises, thus increasing porosity of top-layer concrete. As a result, sorptivity of the top-layer concrete is higher than that of bottom-layer concrete.

TABLE 3. Three-Day Sorptivity of Mortar Specimens ($\text{g/m}^2/\text{min}^{1/2}$)

(a) Reference Specimens				(b) Effect of Curing Materials: Case 2 (oven-SL)			
Layer	Oven Curing	Air Curing	Wet Curing	Layer	C89.0	C95.9	C98.1
Top	4.23	3.64	0.41	Top	0.63	0.44	0.42
Middle	0.98	1.94	0.36	Middle	0.38	0.3	0.33
Bottom	0.15	1.06	0.17	Bottom	0.11	0.13	0.13
(c) Effect of Application Methods (top layer)				(d) Effect of Spray Time (case 2, top layer)			
Case	C89.0	C95.9	C98.1	Spray time (after casting)	C89.0	C95.9	C98.1
Case 1(room-SL)	0.76	0.7	0.6	15 min	0.63	0.44	0.42
Case 2 (oven-SL)	0.63	0.44	0.42	30 min	0.52	0.45	0.46
Case 3 (oven-DL)	0.5	0.34		60 min	0.59	0.56	0.49

At hot weather (oven curing) condition, the sorptivity of the near surface layer mortar without a curing compound is the highest ($4.23 \text{ g/m}^2/\text{min}^{1/2}$) among all specimens tested; while the sorptivity of the specimens with curing compounds are comparable with that of specimen cured at wet condition ($0.41 \text{ g/m}^2/\text{min}^{1/2}$). For the specimens at hot weather (oven curing) condition without curing compound, the difference in the sorptivity values between the top-layer and the middle/bottom-layer mortar is large (over 3 times); while for the specimens with curing compound, the difference is much small (1.3-2 times). These indicate that use of curing compounds is a very effective way to improve concrete microstructure and reduce concrete porosity or permeability. Table 3(b) also suggests that the higher efficient-index curing compound generally provides its mortar specimens with lower sorptivity. Table 3(c) illustrates that sorptivity value reduces approximate 25 percent when double-layer curing compound is applied and compared with single-layer curing compound application. High temperature (oven) curing provides the mortar specimens with lower sorptivity, when compared with room temperature (air) curing. As shown in Table 3(d), sorptivity measurement can also well reveal effect of application time of curing compound on mortar microstructure. At the mild weather condition (air curing), curing compound spraying at 30 minutes after casting is the optimal compared with spraying at 15 or 60 minutes. At hot weather (oven) condition, the research implies that spraying curing compound at 15 minutes after casting is the optimal (3). The optimal time for spraying a curing compound is right after disappearing bleeding water but before drying of the concrete. Sorptivity measurement appears a rational test method for evaluating concrete curing effectiveness among other tests employed in this research.

Degree of Hydration

Table 4 demonstrates degree of cement hydration of paste specimens with depth. Typically, the top layer of a slab specimen (with or without curing compound) has the lowest and the middle layer has the highest degree of hydration. Application of curing compound generally increases degree of cement hydration, especially in the top layer of the specimens. The specimens at hot weather condition (oven) and sprayed with C89.0, C95.9, and C98.1 had degree of hydration of 46.7 percent, 52.3 percent, and 51.6 percent, respectively, compared with 43.6 percent of the oven specimen without curing compound. Application time and double layer spray seemed not having clear effects on degree of hydration of the specimens.

TABLE 4. Three-Day Degree of Hydration of Paste Specimens (%)

(a) Reference Specimens			(b) Case 2: Oven-SL, Spray Time: 15 min.				
Layer	Oven Curing	Air Curing	Wet Curing	Layer	C89.0	C95.9	C98.1
Top	43.62	41.00	47.11	Top	46.72	52.48	51.64
Middle	55.17	47.87	51.68	Middle	55.35	57.48	54.96
Bottom	55.45	46.63	48.47	Bottom	52.05	54.33	51.7

A statistical analysis of all test data was performed to investigate whether there was any relationship among the parameters measured. The analysis indicates that the sorptivity is closely related to MC and degree of hydration (α), and the relationship is as follows:

$$\text{Sorptivity} = 29.11 - 3.56(\text{MC}) - 0.53\alpha + 0.07(\text{MC}) * \alpha \quad (2)$$

The reliability coefficient of Equation (2) is $R^2 = 0.79$, or $|R| = 0.89$. According to this equation, sorptivity of concrete may be estimated from simple tests of cement hydration and moisture content, which is in turn related to conductivity of concrete.

FIELD INVESTIGATION

Description of Test Sections

The field tests were applied on highway US 65 in Polk County. The materials and proportion of the pavement concrete are as follows: limestone : limestone chips : sand : Type I/II cement : Class C fly ash : water = 3:1:(2.43):1:(0.18):(0.47). The test sections included the following:

- 600 linear feet of curing compound C98.1 single application
- 600 linear feet of curing compound C95.5 single application
- 600 linear feet of curing compound C95.5 double application
- 600 linear feet of curing compound C89.0 double application
- 600 linear feet of wet curing
- 20 linear feet with no curing materials applied

All sections were placed in the same day. For analysis purposes the 600-foot sections were subdivided into three 200-foot subsections. Each subsection had a test station; and thus a total of 16 test stations were established for this investigation. Each test station was in the middle length of a subsection and two feet from the edge of the pavement slab.

Data Collection Methods

The data collected included the concrete properties (such as temperature, moisture content, conductivity, and permeability) and the environmental conditions (such as air temperature, wind speed, relative humidity, and cloud condition). The measurements were taken every two hours from the morning to the night (about 8:00 a.m. to 9:00 p.m.), and the gathering of the measurements lasted seven days.

A thermocouple was attached to a wood dowel to monitor the temperature of concrete at the top (1 inch below top surface), mid-depth, and bottom (1 inch above the base) of a pavement slab. A pair of copper plates, 1" (height) x 4" (width) x 1/8" (thickness), were vertically inserted to the top and mid-depth of the

slab to measure the concrete conductivity (4). Three 2” and 4” diameter cores were taken from each subsection for sorptivity and rapid chloride permeability tests. Since sorptivity test data from the field specimens did not show a linear relation of absorbed water with testing time, sorptivity test results are not presented in the paper. The unexpected test data may be caused by non-uniform moisture distribution in the samples.

Field Test Results

Maturity of Field Concrete

Maturity of concrete was calculated from the concrete temperature monitored. Figure 2 illustrates the differences in maturity of pavements cured with different curing compounds and application methods. Each data point represents the average value of three stations cured with the same method.

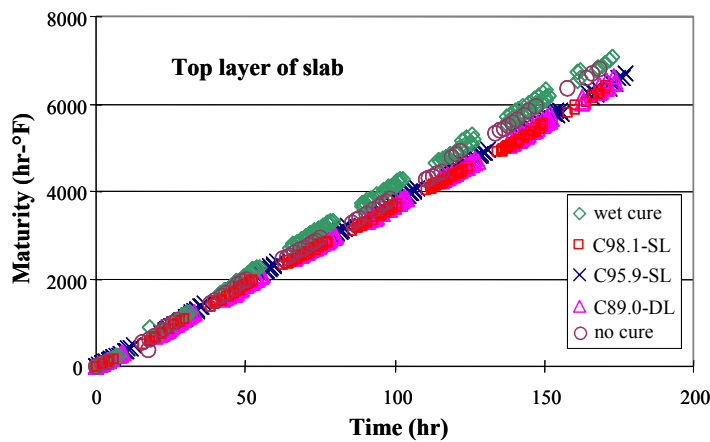
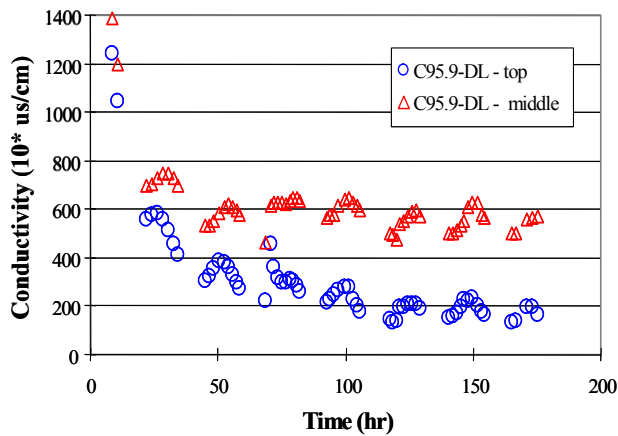


FIGURE 2. Effect of Curing on Maturity of Concrete

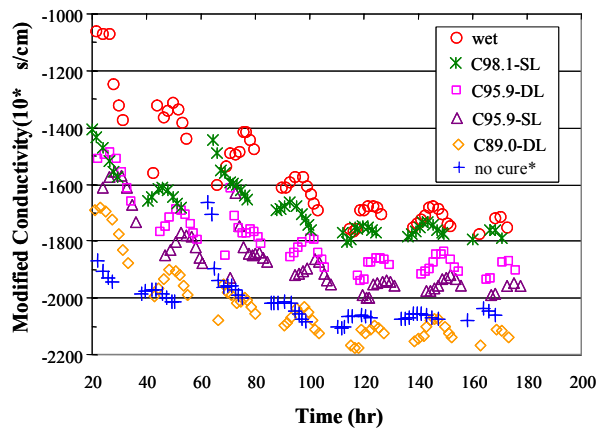
The figure indicates that pavements sprayed with different curing compounds had little differences in their maturity values. The top-layer concrete of the pavement with wet curing or without curing had slightly higher maturity values than the pavements with the curing compounds. The high humidity might contribute to the higher maturity of the wet-cured pavement, while the high heat absorbed by the concrete from Sunlight might contribute to the higher maturity of the pavement with no cure. It was also observed that had less difference existed in the middle- or bottom-layer concrete cured with different methods.

Conductivity of Field Concrete

As mentioned before, for a given material, the electrical conductivity depends primarily on the cement hydration process and the moisture content inside concrete. The lab study on mortar specimens curing at different conditions has shown a good statistical relationship between the electrical conductivity and moisture content. Figure 3 demonstrates some conductivity test results of the field concrete.



(a) Effect of Depth



(b) Effects of Curing Methods (Top)

FIGURE 3. Conductivity of Field Concrete

As observed in Figure 3(a), conductivity of the top-layer concrete sprayed with curing compound C95.9 and double application is much lower than that of the middle-layer concrete. This indicates low moisture content in this top-layer concrete due to its surface moisture loss, and the results are consistent with those of moisture content tests performed at lab. Other conductivity measurement for concrete cured with different curing methods had the same trend. Figure 3(b) demonstrates effects of curing materials and application methods on concrete conductivity. The researchers found that the initial conductivity of field concrete was very sensitive to the weather condition under which paving was performed. To overcome this influence, modified conductivity, the difference between measured conductivity and the initial conductivity of the concrete, was employed. According to Figure 3(b), the wet curing is the best curing method for water retention in concrete, followed by the C98.1-single layer, C95.9-double layer, C95.9-single layer, and C89.0-double layer applications. This trend is consistent with the lab test results.

Permeability of Field Concrete

Permeability of concrete is often considered as the most important factor that influences concrete durability because it controls the entry rate of the moisture flow that may contain aggressive chemicals. In this investigation, the cores were drilled from three selected stations at the seventh day after paving. Rapid chloride permeability tests of the field samples were performed according to AASHTO T277, and the results (average of three tested samples) are presented in Table 5.

TABLE 5. Effects of Curing Methods on Concrete Permeability

Specimen Location	Rapid Chloride Permeability (Coulombs)		
	Wet Curing	C95.9-Double Layer	No Curing
Top	3084	3084	3289
Middle	2448	2214	2288
Bottom	1479	1488	1500

Table 5 indicates that regardless curing conditions, rapid chloride permeability of concrete decreases with depth. The difference in the chloride permeability values among layers might result from different curing condition and/or from the aggregate settlement in the concrete. Note that there is no significant difference in rapid chloride permeability values among the concretes cured with different methods. A better curing method (wet curing or with curing compound) may reduce but not eliminate the difference between top-layer and internal concrete.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be made based on the presented study:

- Regardless whether or not a curing compound is applied, properties of the near-surface-area concrete, such as moisture content, permeability, degree of hydration, and sorptivity, differ from those of the internal concrete. The differences may be caused by surface moisture loss and/or aggregate settlement.
- Application of a curing compound significantly increases moisture content and decreases sorptivity of the near-surface-area concrete, thus reducing the differences in concrete properties between the near-surface-area concrete and internal concrete.
- The non-destructive conductivity test method showed a close relation with moisture content of the concrete in lab study. For given concrete materials and mix proportion, water retention ability of a curing material may be estimated by monitoring conductivity of the near-surface-area concrete. Field conductivity test results showed a similar trend to the lab test results of concrete with different curing materials and application methods. This test method may further modified for future evaluation of curing effectiveness in both laboratory and field tests.
- Of all the test methods applied in lab, the sorptivity test is the most sensitive one to provide a good indication for the subtle changes in the properties related to microstructure of the near-surface-area concrete caused by different curing materials and application procedures. Sorptivity measurements of the near-surface-area concrete have demonstrated a close relation with moisture content and degree of hydration. However, when the method is used for testing field sample, special care of the moisture balance in the samples is needed.
- Maturity measurements in the near-surface-area concrete did not provide good indication for the subtle changes provided by different curing conditions.

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REFERENCES

1. Mather, B. Curing Compound. *Concrete International: Design and Construction*, Vol. 12, No. 2, February 1990, pp. 40–41.
2. Vandebossche, J.M. *A Review of the Curing Compounds and Application Techniques*. Minnesota Department of Transportation, St. Paul, Minnesota, November 1999.
3. Wang, K., J.K. Cable, and G. Zhi. *Investigation into Improved Pavement Curing Materials and Techniques—Part 1 (Phases I and II): Final Report*. Center for Transportation Research and Education, Iowa State University, Ames, Iowa, April 2002.
4. Cable, J.K., K. Wang, and G. Zhi. *Investigation into Improved Pavement Curing Materials and Techniques—Part 2 (Phases III): Final Report*. Center for Transportation Research and Education, Iowa State University, Ames, Iowa, April 2003.
5. Iowa Department of Transportation. *Method of Determining the Efficiency Index of Liquid Membrane Curing Compounds*. Test Method No: Iowa 901-D. Iowa Department of Transportation, Ames, Iowa, May 2002.
6. Mindess, S., and J.F. Young. *Concrete*. Prentice-Hall, Englewood Cliffs, New Jersey, 1981, pp. 101–108.
7. Tamas, F.D. Electrical Conductivity of Cement Pastes. *Cem. Concr. Res.*, No. 12, 1982, p. 115.
8. Bentz, D.P., J.R. Clifton, C.F. Terraris, and E.J. Garboczi. *Transport Properties and Durability of Concrete: Literature Review and Research Plan*. NIST IR 6395. National Institute of Standards and Technology, Gaithersburg, MD, 1999.
9. Gowripalan, N., J.G. Cabrera, A.R. Cusens, and P.J. Wainwright. Effect of Curing on Durability. *Concrete International*, Vol. 12, No. 2, 1990, pp. 47–54.