CENTER FOR
PORTLAND CEMENT CONCRETE
PAVEMENT TECHNOLOGY

Investigation into Improved Pavement Curing Materials and Techniques: Part 2 (Phase III)

Final Report
March 2003

Iowa Department of Transportation

Department of Civil and Construction Engineering
IOWA STATE UNIVERSITY

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16. Abstract

Appropriate curing is important for concrete to obtain the designed properties. This research was conducted to evaluate the curing effects of different curing materials and methods on pavement properties. At present the sprayed curing compound is a common used method for pavement and other concrete structure construction. Three curing compounds were selected for testing. Two different application rates were employed for the white-pigmented liquid curing compounds. The concrete properties of temperature, moisture content, conductivity, and permeability were examined at several test locations.

It was found, in this project, that the concrete properties varied with the depth. Of the tests conducted (maturity, sorptivity, permeability, and conductivity), conductivity appears to be the best method to evaluate the curing effects in the field and bears potential for field application. The results indicated that currently approved curing materials in Iowa, when spread uniformly in a single or double application, provide adequate curing protection and meet the goals of the Iowa Department of Transportation. Experimental curing methods can be compared to this method through the use of conductivity testing to determine their application in the field.

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Investigation into Improved Pavement Curing Materials and Techniques: Part 2 (Phase III)

Iowa DOT Project TR-479
CTRE Project 02-77

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INTRODUCTION

Background

The performance of portland cement concrete (PCC) pavement is greatly enhanced by good curing during the early age of its life. When cement hydration takes place during the early days after construction, curing must be applied to prevent premature loss of the moisture on hot days and loss of the temperature during cold days. Failure to protect the pavement during the early age can result in premature deterioration in the form of shrinkage and transverse cracking, scaling, and joint spalling. Good curing will improve the quality of concrete. Therefore, the contractor could extend the construction season and open the pavement to the traffic earlier.

Concrete curing practice employs burlap or insulating blankets and sprayed liquid membrane-forming curing compounds on pavements to reduce moisture and heat loss during the early age of cement hydration (first seven days). 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 could provide a similar insulation and be applied much more easily.

Presently, white-pigmented curing compounds are commonly used in Iowa, while poly-alpha methylstyrene and other curing products are common elsewhere. Although curing compounds are widely used, there is no good method to evaluate the effect of the curing compounds.

Research Objectives

This curing project focused on evaluating curing compound materials, application methods, and effects of curing on concrete properties.

Part 1 of the project, completed in April 2002, included a literature survey (Phase I) and laboratory testing (Phase II). In Phase II, eight different tests—moisture content, conductivity, maturity, compression test, sorptivity, degree of hydration, thermogravimetric analysis (TGA), and flexural test—were conducted.

Part 2 of the project, report on here, is the Phase III field evaluation of products and application rates identified in Phases I and II.

Part 1 Conclusions

The following are major conclusions from Part 1 (Phases I and II):

- Concrete practice has indicated that the performance of curing compounds is closely related to the characteristics of the curing materials and application methods. Curing especially influences properties of the near-surface-area concrete. The test results showed that regardless of whether or not a curing compound was applied, the properties of the near-surface-area concrete, such as degree of hydration and moisture content, differed from those of the internal concrete. The effects of type of curing compound on the properties of the near-surface-area concrete appear to be more significant in hot weather conditions.

- Generally, the high-efficiency-index curing compounds, such as 1645 and 2255, had lower sorptivity, higher conductivity, higher degree of hydration, and higher compressive strength values than specimens applied with a low-efficiency-index curing compound.

- The weather conditions can affect the application time. The curing compound should be applied earlier in hot weather than in mild weather.

- Conventional compressive and flexural strength tests did not provide good indicator for the subtle changes in the near-surface-area concrete. Of all the test methods applied, the sorptivity test is the most sensitive one as a good indicator for the subtle changes in microstructure of the near-surface-area concrete caused by different curing materials and application methods. The tests also showed that sorptivity has a close relationship with moisture content and degree of hydration. Conductivity measurements of the near-surface-area concrete showed a close relation with moisture content of the concrete.

Recommendations for Part 2

Based on the research results, the following recommendations were suggested for the Part 2 (Phase III) field research:

- Because of the difference between field and laboratory conditions, three curing compounds were recommended for the field tests: 2255-White, 1645-White, and 1600-White. For 1600-White, a double application was recommended for the field test.

- The nondestructive conductivity test method may be modified and adopted for field tests. Water retention ability of a curing compound may be estimated by monitoring the conductivity of the surface concrete in the field, based on the conductivity–moisture content relationship obtained from the Phase II study.

- Although the maturity method was not sensitive enough to show the effects of different types of curing compounds and different application times, the tests did demonstrate the difference between specimens with and without curing compound. Therefore, this test will be conducted in the field test.

- Properties of the near-surface-area concrete have more significance influence on concrete durability than on concrete strength. To further study the effects of curing compounds on properties of the near-surface-area concrete, permeability tests may be conducted for the surface concrete in the field study.

EXPERIMENTAL DESIGN

Concrete

The field tests were applied on highway US 65 in Polk County. The Fred Carlson Company placed the concrete pavement. Table 1 shows the mix proportions.

Table 1. Concrete Mix Proportions

	Source	Weight (lb./batch)
Coarse stone	Ames Mine	1430
Limestone chips	Ames Mine	477
Sand	IA DOT source A50502	1159
Cement	Ash Grove, Type I/II	476
Fly ash	North Omaha	84
Water	On site	224

Curing Methods

The curing compounds used in this project are 1645-White, 1600-White, and 2255-White, which are from the W.R. Meadows Company. Compound 1645-White and 1600-White are water-based curing compounds. Compound 1645 is currently used by the Iowa Department of Transportation (Iowa DOT). Compound 2255-White is a resin-based curing compound currently used by Minnesota Department of Transportation. The main properties of these three curing compounds are shown in Table 2.

Table 2. Typical Properties of the Curing Compounds

	ASTM Specification	Efficiency Index	Solids Content	Estimated Cost ($/gal.)
1645-White	Type 2 Class A	95.9	29.2%	2.0
1600-White	Type 2 Class A	89.0	17.1%	1.0
2255-White	Type 2 Class B	98.1	43.5%	6.5

Two different application methods, single and double applications, were employed in this project for the liquid cures. The test results of the Phase II laboratory tests indicated that the single application of the curing compound 1600 would result in less desirable properties. But the double application appeared to improve the properties. Therefore, double application of the curing compound 1600 was used for the field study. It was applied in a single pass at double the application rate. Since the curing compound 2255 is very expensive, only one layer was applied to the pavement.

The wet curing was applied as the historical best curing method and the omission of curing material as the worst curing method. The double application was applied in a single pass at increased rates of application. The wet cure and no cure methods are considered as references.

All curing materials were placed immediately behind the pavement placement operation and applied continuously for each 600-foot section. For the wet curing, the blanket was applied immediately after the pavement placement operation. Then the water was applied on the blanket. After that the plastic sheet was used to cover the blanket.

The test sections included the following:

- 600 linear feet of curing compound 1645 single application
- 600 linear feet of curing compound 1645 double application
- 600 linear feet of curing compound 1600 double application
- 600 linear feet of wet curing
- 600 linear feet of curing compound 2255 single application
- 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 was considered as a test section.

Data Collection Methods

The research team for this project consisted of personnel from the Department of Civil and Construction Engineering, Iowa State University, with assistance from Iowa DOT personnel on the project. The data collected included the concrete temperature, moisture content, conductivity, permeability, air temperature, wind speed, relative humidity, and cloud condition.

There was a total of 16 test stations for this project. Each test station was two feet from the edge of the slab. The measurements were taken every two hours from the morning to the night (about 8:00 a.m. to 9:00 p.m.). The gathering of measurements lasted seven days.

A thermocouple attached to a wood dowel was used to measure the temperature at the top (1 inch below top surface), mid-depth, and bottom (1 inch above the base) of the slab. The copper plates were inserted to the top and mid-depth of the slabs to get the conductivity.

In addition, handheld temperature and relative humidity recording devices were used to measure the air temperature, relative humidity, dew point, and wet bulb temperature. The moisture content meter measured the moisture content of the upper one to two inches of concrete. The wind velocity was also tested on each station.

Sorptivity and permeability of the concrete pavement were also performed in the lab on the seven-day field samples to evaluate the effect of curing. Three two-inch-diameter cores were taken at each test site to conduct the sorptivity test. Twelve four-inch-diameter cores were drilled from the 1645 double, wet cure, no cure sections for the permeability tests.

Instrumentation Data Collection Device Selection

Maturity temperatures were measured with the use of HH-25TC digital thermometers manufactured by Omega Industries, shown in Figure 1. This meter can only connect to one thermocouple. The device is connected to the pavement by a simple two-pole connector and "T" thermocouple wire. One end of the wire is attached to the connector and the other end is stripped to allow for twisting of the metal wire ends. The twisted end of the wire was positioned on a wood dowel for the desired depth of measurement. The dowel is then inserted into the concrete pavement to measure the temperature at the top, middle, and bottom.

Figure 1. Omega Industries Digital Thermometer

Conductivity was measured with the Solomat MPM 2000 conductivity meter, which is shown in Figure 2. The conductivity meter was used to measure the resistivity between the two copper plates at relatively low alternate current (A.C.) frequency (1000 Hz). This A.C. technique avoids errors due to polarization of the electrodes. The distance between two copper plates—one inch wide, four inches long, and 1/8-inch in thickness—was six inches. The copper plates (Figure 3) were buried in the top one inch and mid-depth of the pavement. The two bars on the sides of the copper plates are fiber reinforced plastic bars. The bars were attached to the copper plate by five-minute epoxy. These bars were used to ensure that the copper plates could be inserted vertically into concrete.

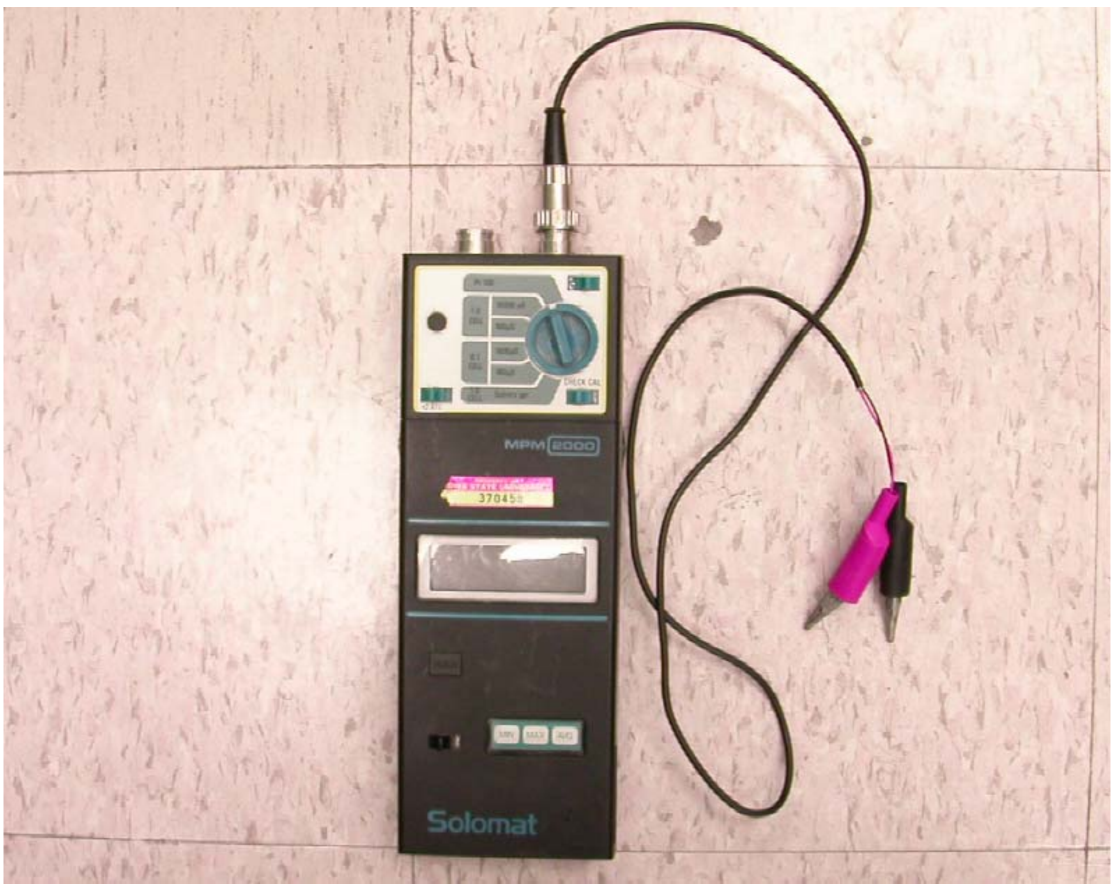

Figure 2. Solomat MPM 2000 Conductivity Meter

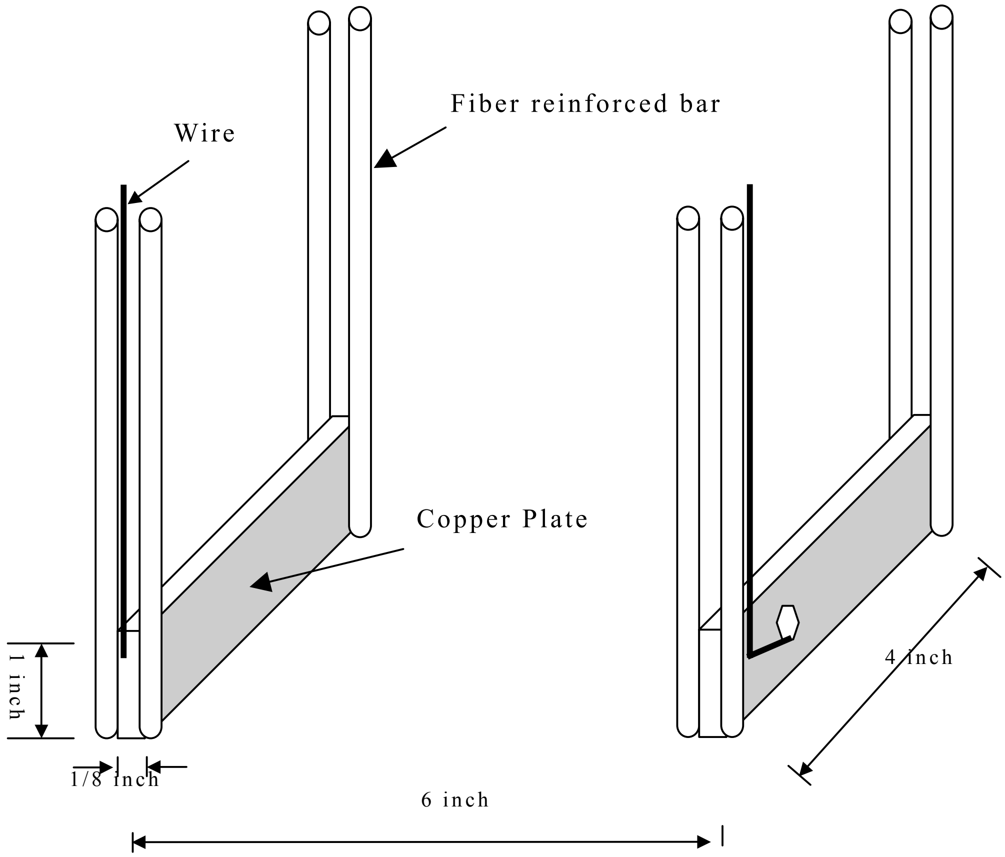

Figure 3. Copper Plate Used for the Conductivity

The moisture meter selected for this project is the M-60 Moisture Meter, manufactured by James Instruments, Inc. The meter is shown in Figure 4. This device has separates models for concrete, brick, and gypsum. The meter uses a nondestructive method to measure the moisture content. It can only measure the surface moisture of the concrete pavement. The moisture is displayed in percentage.

Permeability was measured following AASHTO T 277-96 (2000). The permeability device is from Germann Instruments, Inc. In order to get the permeability of samples under different curing conditions, three samples from three different sections were measured simultaneously. Each sample was a 4×2 inch cylinder. The side was sealed with the concrete sealing materials. A sample is shown in Figure 5.

Figure 4. Moisture Meter

Figure 5. Sample for Permeability

The wind velocity was recorded by the wind meter, which is shown in Figure 6.

Figure 6. Wind Meter

The final device selected for this project consisted of a simple handheld temperature and relative humidity meter. The RH83 Thermo-Hygrometer distributed by Omega was selected for this project. The device measures air temperature, dew point, and wet bulb temperature in degrees Fahrenheit or Celsius and the relative humidity of the air at the site. In this project, all temperatures were recorded in degrees Celsius. This device can be carried in a pocket. The air temperatures and humidity were measured to provide information about the environmental effect on the concrete heat signature maturity. The meter is shown in Figure 7.

Figure 7. RH83 Thermo-Hygrometer

RESEARCH RESULTS

Maturity

Cement hydration is an exothermal reaction, which generates heat. The hydration of the cement is highly affected by both the temperature and the time of the hydration. Therefore, the strength of the concrete in the field is often evaluated by the maturity. The maturity was calculated by the following equation:

$$M(t) = \Sigma\,(T_a - T_o)\Delta t$$

where

$M(t)$ = maturity (degree-hours)
T_a = average concrete temperature during interval (ºC)
T_o = datum temperature (-10ºC)
Δt = time interval (hours)

For this project, the temperature was monitored near the top surface, mid-depth, and near the bottom one inch of the slab, one foot from the outside edge of the slab. The temperature was measured by the handheld temperature-measuring device every two hours. For each curing condition, three sets of data were available. The maturity data for different curing methods were compared to evaluate the curing effect.

Figures 8 through 10 illustrate the differences in the calculated maturity values between pavements cured with different curing compounds and application methods. Each data point was representative of the average value of three stations cured with the same method. These figures show that pavements had little differences in their maturity values. For the top part, the pavements with wet curing or without curing had slightly higher maturity values than pavements cured with the curing compounds. The difference was reduced in the bottom portion of the slab. The bottom pavement sites had almost the same maturity values. This also indicates that the curing primarily affects the top of the concrete pavements. The wet curing, applied with the wet blanket and plastic sheets, can keep both moisture and temperature inside concrete efficiently, while the curing compound generally keeps moisture in concrete. Therefore, the pavements with wet curing had higher maturity.

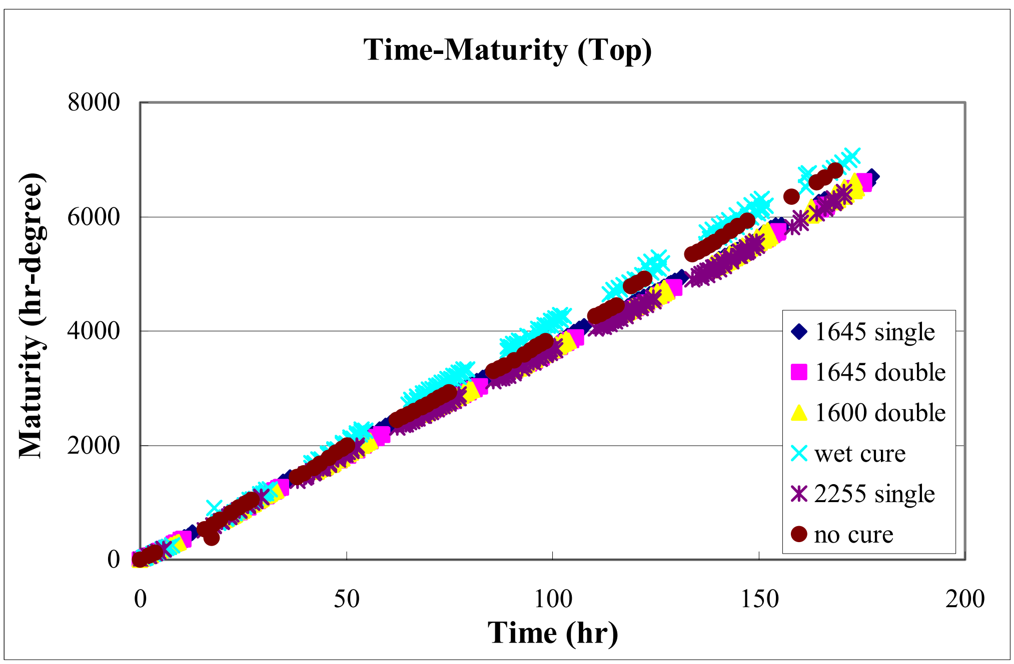

Figure 8. Maturity vs. Time (Top of the Pavement)

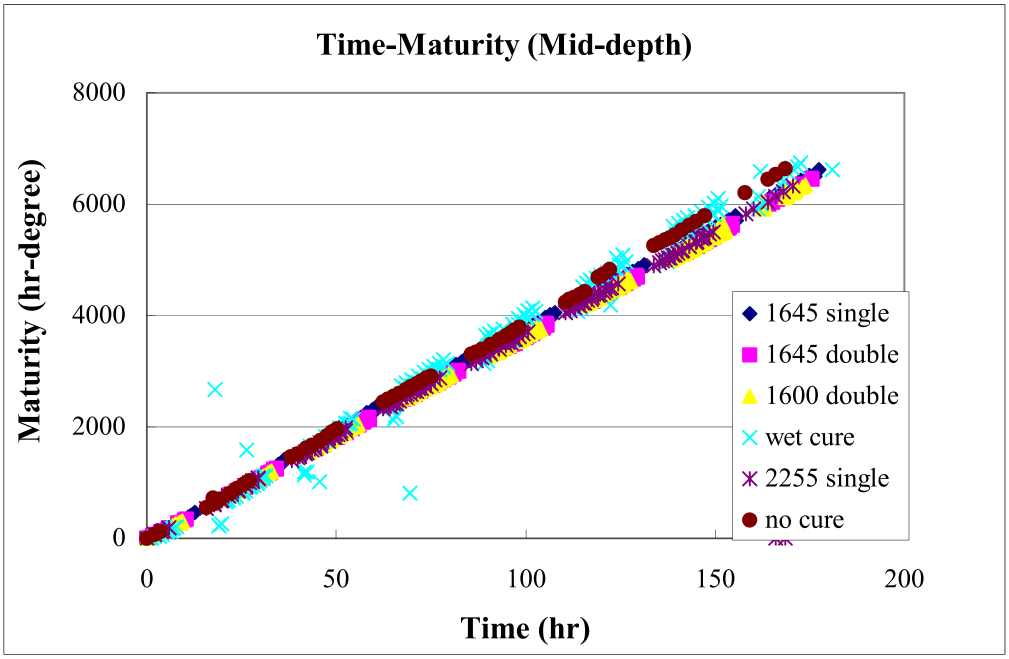

Figure 9. Maturity vs. Time (Mid-depth of the Pavement)

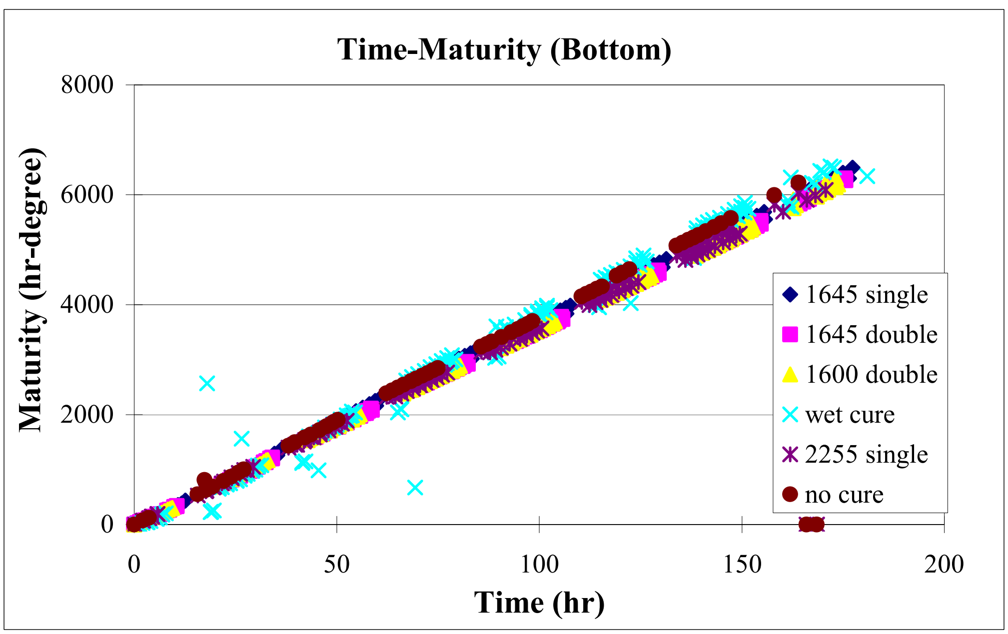

Figure 10. Maturity vs. Time (Bottom of the Pavement)

For the pavement without cure, the temperature of the top part of the pavement was affected greatly by the air temperature. Figure 11 indicates how the air temperature will affect the near-surface concrete temperature. The temperature of the pavement without cure changes faster than that of the pavements with cure. Since the project was conducted in late June, the air temperature was high. Therefore, the temperature of the pavement remained high. For the middle and bottom parts of the pavements, the effect is smaller, which is illustrated by Figure 12. The temperature was measured only until around 10:00 p.m. each day. The temperatures at night were not available. In order to calculate the maturity, the night temperatures were assumed to decrease linearly from the last measured temperature to the first temperature of the next day. This assumption may bring error to the maturity values. Also, there was a shower during the curing period. This provided the pavement with water. All these factors may contribute to the high maturity of the pavement without curing.

During the period of the curing, the average air temperature was about 28 degrees Celsius and the relative humidity was 47 percent. The wind velocity was also very low, less than 10 mph for the most time. Under this condition the evaporation is around 0.1 pound/square foot/hour (ACI 308-92). Therefore, not much water will evaporate from the pavements even without curing. This may be one of the reasons why there was no difference between the different curing methods.

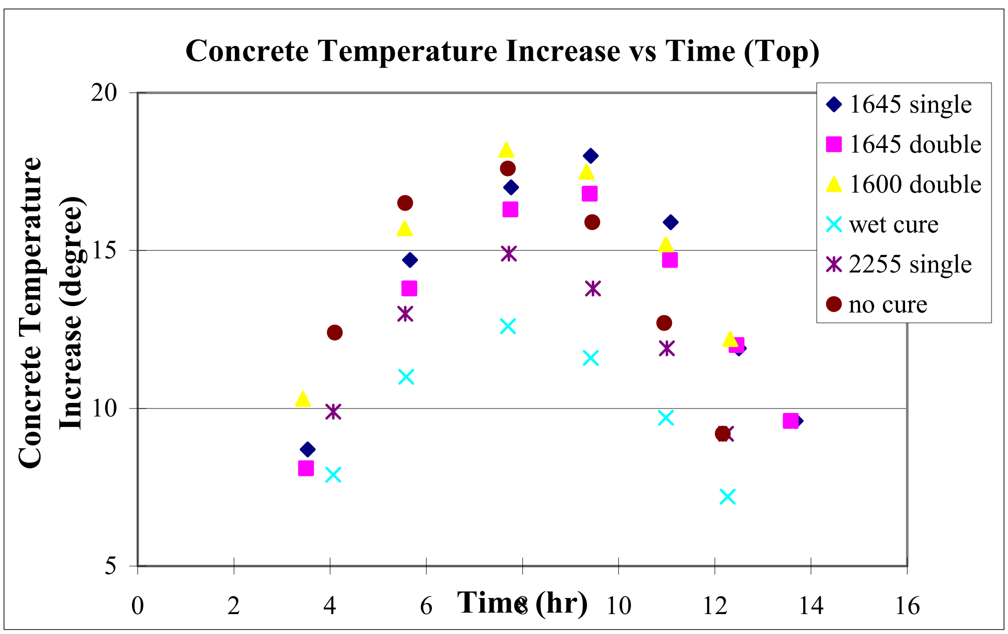

Figure 11. Temperature Increase vs. Time (Top of the Pavement)

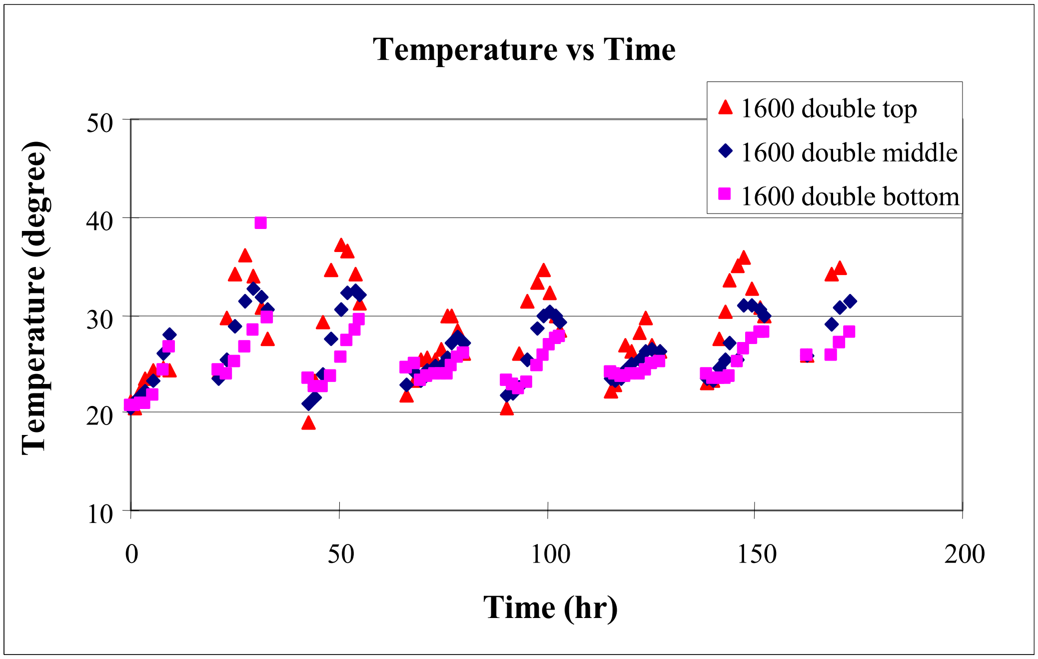

Figure 12. Temperature vs. Time

For this project, the temperature differences between top, middle, and bottom did not have a large impact on the maturity results. Figure 13 shows the differences. All maturity data imply that the maturity method may be not a good method for evaluating the effectiveness of curing, at least for the summer.

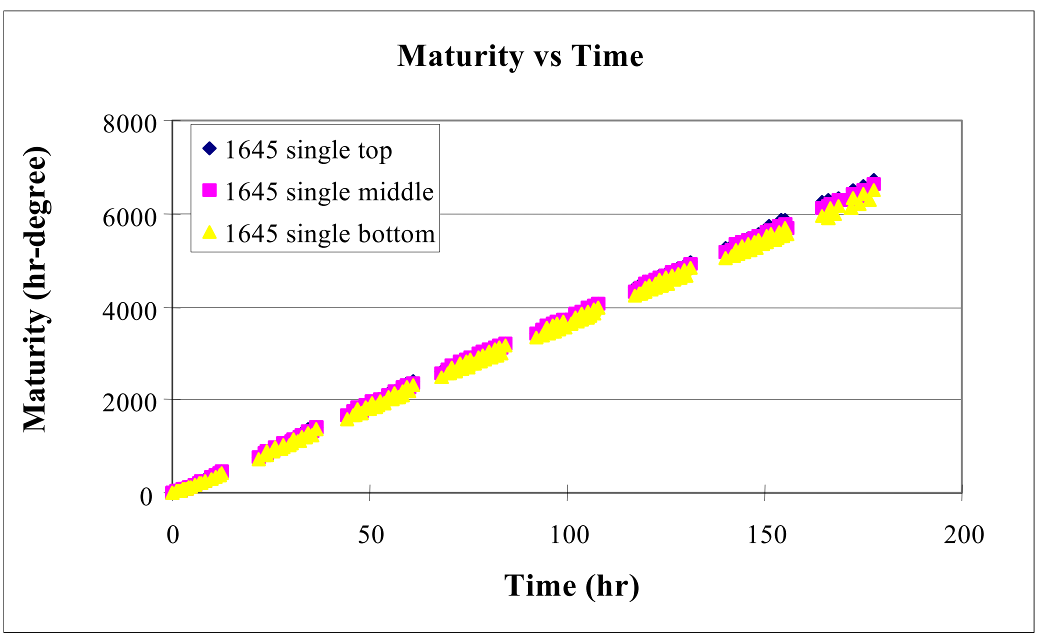

Figure 13. Maturity vs. Time

Permeability

Durability is one of the most important properties of concrete structures. The permeability of concrete is important for the durability, because it controls the entry rate of the moisture flow that may contain aggressive chemicals. There are several methods to measure concrete permeability. Rapid chloride penetration is one of these methods.

For this project, the permeability tests were conducted at the Iowa DOT. The cores were drilled at the seventh day after the casting. The samples were taken to the Iowa DOT material laboratory and were left there for the weekend. After that, three two-inch-thick cylinders were cut from the top, middle, and bottom of the cores. The side of each piece was sealed with two coats of epoxy. The samples were dried and saturated with the distilled water on the day after the sealing totally dried. The saturated samples were then ready for the test. Samples were only taken from three observation stations, 187+00, 175+00, and 166+00. These three stations represent the 1645 double curing, wet curing, and no curing separately.

Table 3 shows the test results from the permeability tests. Three samples were not used due to the specimen preparation. One sample was too short and the other two were too thick. These samples could not be sealed in the cell. In this case there were only two data points for some curing methods. The test data show that, on average, there is no difference for middle and bottom parts between different curing conditions. This conclusion is consistent with the results from the maturity method. For the top part of the pavement, the pavement without curing had higher permeability, which is an average of 3289 Coulomb. The pavements cured with 1645 and wet cures have the same values, 3084 Coulomb. Also, the top part had a higher variation, 653 Coulomb, compared with the other parts. Figure 14 demonstrates the effect of the depth. The permeability decreases as the depth increases. The permeability of the top and middle portions belong to the moderate range, 2000–4000 Coulomb. But the value of the bottom is in the range of low permeability, 1000–2000 Coulomb.

Table 3. Permeability for Different Curing Conditions

	Permeability (Coulomb)								
	1645 Double			Wet Curing			No Curing		
Top	3071	3069	3113	3010	3016	3225	3616	2963	3288
Middle	2313	2219	2110	—	2222	2675	2264	2208	2392
Bottom	1567	—	1406	1501	—	1457	1514	1497	1489

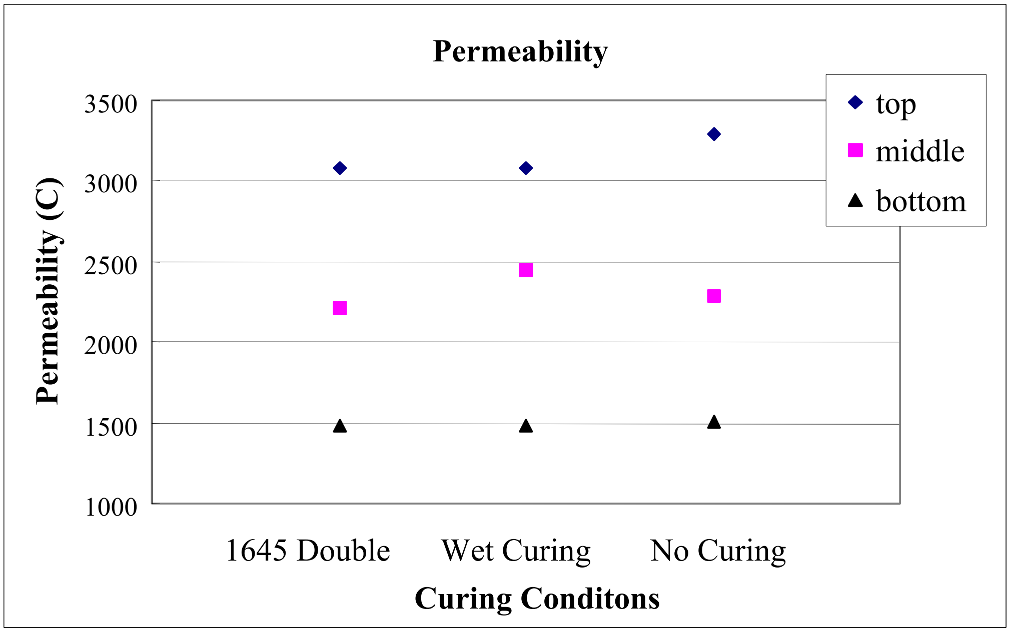

Figure 14. Permeability at Different Depths

Electrical Conductivity

As cement hydration progresses and free water inside concrete is lost, the number and/or the mobility of ions in the concrete pore solution changes. This in turn causes a change in the electrical conductivity of the concrete. For a given material, the electrical conductivity depends primarily on the cement hydration process and the moisture content inside concrete. In Phase II of this project, the electrical conductivity of the mortar specimen was measured. The results indicated that there is a statistical relationship between the electrical conductivity and moisture content with an r^2 equal to 0.79. Therefore, the electrical conductivity test was recommended for Phase III.

Figures 15 and 16 show the results of the conductivity at the top and middle, respectively. For Figure 15, there is a boundary formed by the wet curing and no curing. Other conductivities for different curing compounds are in the bounds. But it is hard to tell which curing compound is better. There is no such boundary in Figure 16. That indicates that the curing methods have less effect on the middle part of the pavement than the top. The conductivity shown in Figure 16 increased suddenly after about 60 hours. This may be caused by the rain at that time. The cooper plates were inserted into the concrete pavement. There were small fissures between the fiber rod and concrete. The water could penetrate into the concrete easily. The moisture then increased the conductivity.

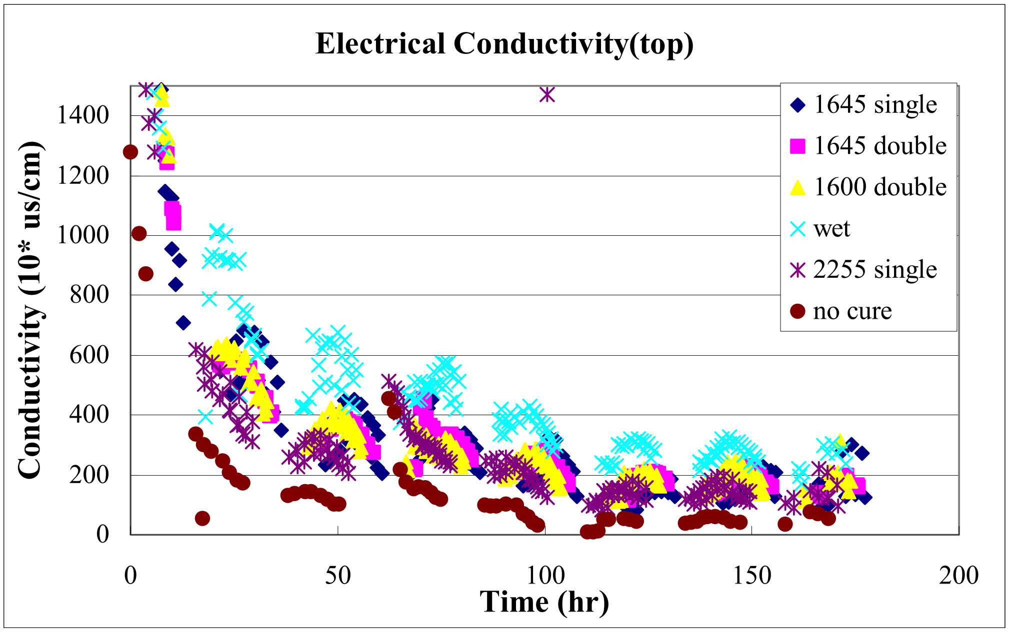

Figure 15. Electrical Conductivity vs. Time (Top of the Pavement)

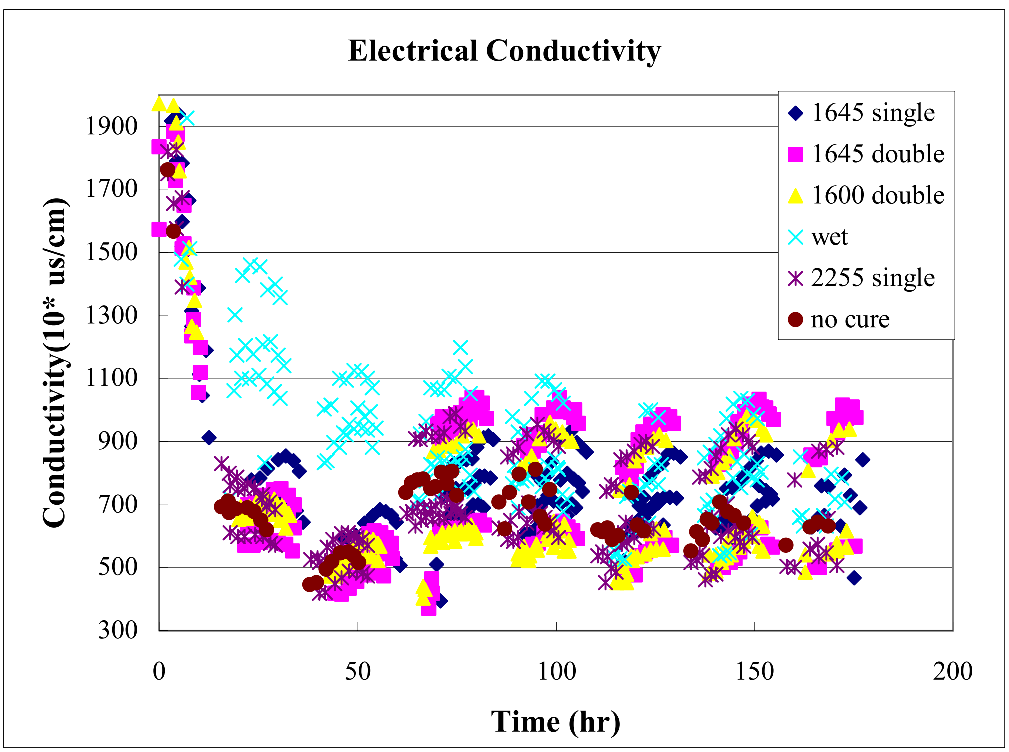

Figure 16. Electrical Conductivity vs. Time (Middle of the Pavement)

Figure 17 shows the effect of depth on the electrical conductivity. The middle part of pavement had higher conductivity than the top. The moisture evaporated from the top. Therefore, the top had lower moisture content. This caused the lower conductivity. This figure is for the curing compound 1645 and double application. Other conductivities for other curing methods had the same trend.

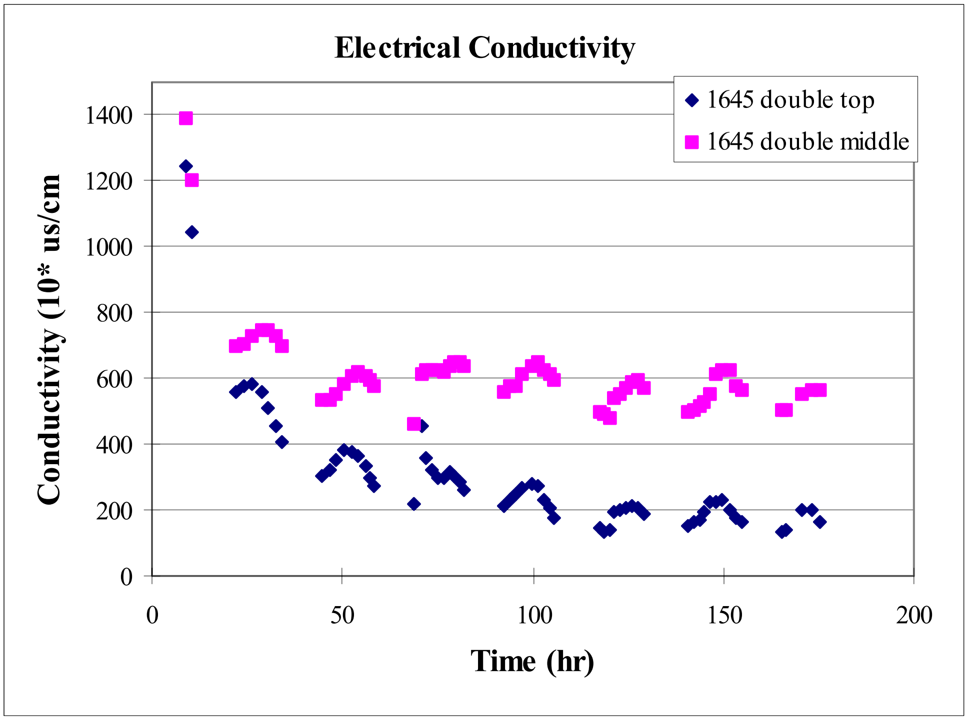

Figure 17. Electrical Conductivity vs. Time for Different Depth

In order to identify the different effects of the curing methods, another parameter, the difference between the initial conductivity and the current conductivity, was calculated. The result was shown in Figure 18. The figure indicates the effects of different curing methods on the conductivity deviation (the difference between the conductivity and the initial value). The small deviation indicates that most moisture is captured inside concrete by the film of the curing compound.

According to Figure 18, the conductivity deviation of the wet curing is the smallest. Therefore, the wet curing is the best curing method followed by the 2255 single layer, 1645 double layer, 1645 single layer, and 1600 double layer. This trend is consistent with the efficiency index of curing compounds, which is used to evaluate curing compounds at the Iowa DOT, and with results from Phase II. Note that the conductivity deviation for no curing, rather than that for wet curing, is the smallest. This may be due to the lower initial conductivity. The initial conductivity was about 1 to 2 hours after the paving. Therefore, the measured value was lower than the true initial values. For the adjusted cure–no cure test, the initial value was estimated by averaging the initial values from other stations. The figure shows that the deviation for no curing is higher at least for the first two days.

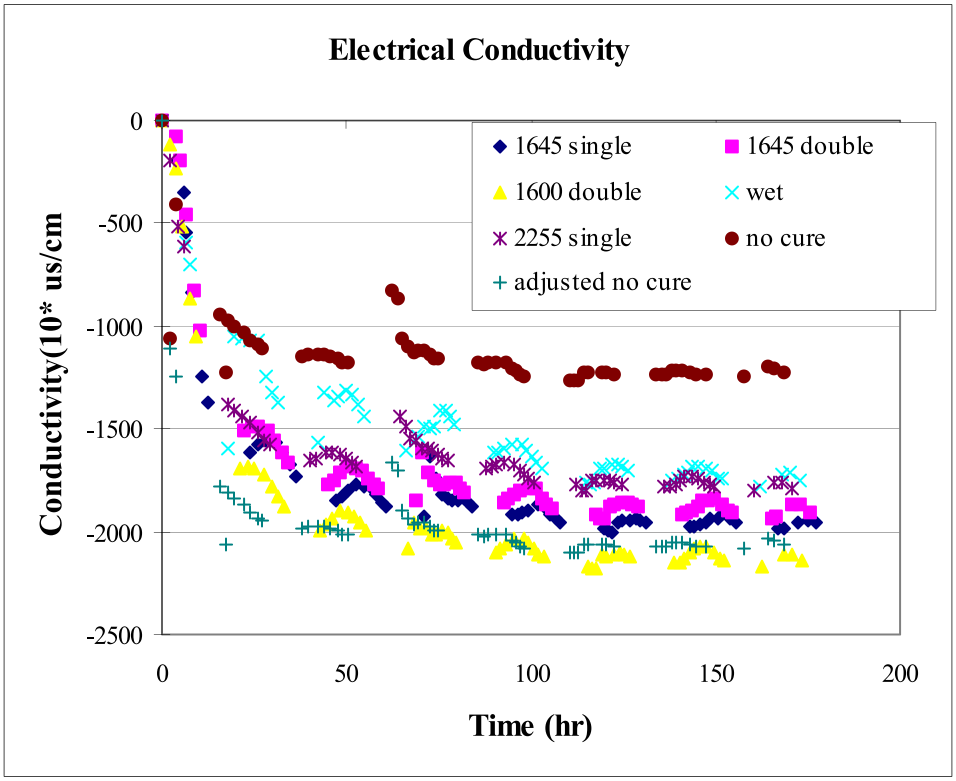

Figure 18. Electrical Conductivity Difference vs. Time (Top of the Pavement)

It seems that the technique described here is an applicable method to evaluate the curing effect. The important factor for this evaluation is the initial conductivity. More tests are needed to verify the method.

Sorptivity

Exposed to the surface of free water, concretes absorb the water at a constant rate, which is sorptivity. Sorptivity is closely related to the pore structure characteristics of concrete. Poor pore structure will result in high sorptivity. Bentz et al. (1999) believed that water absorption was one of the most reliable test methods to access the effects of curing.

In this field test, two-inch cores were taken from the pavements with 1645 single-layer curing, 1645 double-layer curing, 1600 double-layer curing, wet curing, 2255 single-layer curing, and no curing.

Different from the lab samples, the test data from the field specimens did not show any linear relationship between the absorbed water and time increase. This may have been caused by improper sample-handling procedures. Although the test failed, it does not mean this test is not good for evaluating the curing effect. The factors mentioned above may have caused the failure. Further investigation may be needed.

Moisture Content

Moisture content was included to evaluate the curing effect on the surface of concrete, and also to relate it to other variables.

The reading of the moisture meter was found not stable during the measurement, which is shown in Figure 19. The reading will be affected by several factors: (1) texture of the pavement, (2) pressure applied to the meter, (3) measuring position, and (4) environmental change, such as the change of relative humidity. Because of the large variation of the reading, the results were not used to evaluate the curing effects.

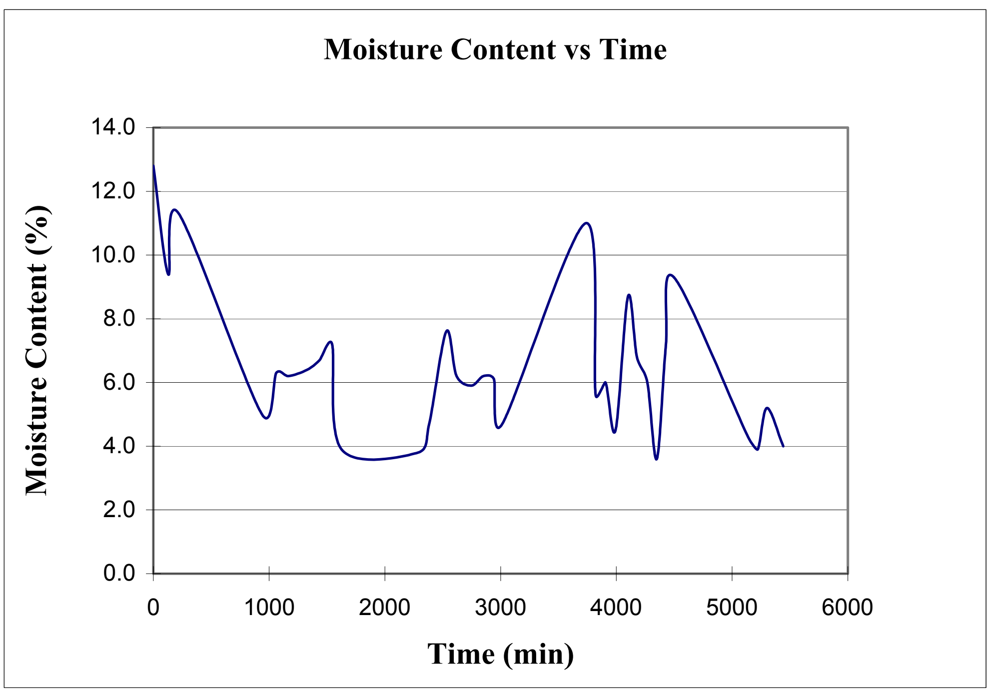

Figure 19. Moisture Content

SUMMARY AND CONCLUSIONS

This research was designed to investigate the effects of curing compound materials and application technology on concrete properties. As the second part of this project, this report presents the test results from the field tests. Three curing compounds—1645-White, 1600-White, and 1645-White—were selected and applied to concrete. Two application rates—single and double applications—were employed. Five tests—maturity, sorptivity, conductivity, moisture content, and permeability—were performed.

The following observations were made from the investigation:

- The conductivity test does relate the moisture content at the various levels to the efficiency of the curing material to retain the moisture in the slab for hydration.

- The conductivity test identified the relative ranking of the materials tested from most to least effective at moisture retention: wet cure, 1645 double application, 1600 double application, 1645 single application, 2255 single application, and no cure. The difference in moisture between single and double application rates of 1645 was small and indicated that uniform single application rates are sufficient protection.

- The difficulties in handling and distribution of curing material 2255 make it less desirable for field application.

- Permeability tests indicated that the effect of wet curing and each of the curing materials tested was not statistically different at the surface of the pavement.

- Temperature control of the surface concrete by the curing methods identified the most to least efficient: wet curing, 2255 resin cure, 1645 double rate cure, 1645 single rate cure, 1600 double rate cure, and no curing. Adequate and total coverage of the surface is the key to temperature control in any of the methods.

- Regardless whether or not a curing compound was applied, the rapid chloride permeability values and electrical conductivity of the near-surface concrete differed from those of internal concrete, indicating the need to protect the surface during curing.

- Maturity only showed slight differences between the wet curing, no curing, and curing with compounds. No difference is shown between individual curing compounds.

- When concrete is cast in the summer, maturity is not a good method to evaluate the curing effect but is a good indicator of strength gain.

- No conclusions could be drawn from the field samples of the sorptivity tests. Although the sorptivity test failed in this project, it may still be a possible way to evaluate curing effects. For future testing, the samples can be dried before the test. The difference between the conductivity and the initial values gives a better indication of curing. More testes are needed to verify the relationship.

- Electrical conductivity measurement may be further modified for future evaluation of curing effects in both laboratory and field tests.

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