REFERENCES

1. P. Klieger, G. Monfore, D. Stark, and W. Teske. D-Cracking of Concrete Pavements in Ohio. Portland Concrete Association, Skokie, Ill., Oct. 1974.
2. M.L. Taylor. Efforts to Eliminate D-Cracking in Illinois. In Transportation Research Record 853, TRB, National Research Council, Washington, D.C., 1982, pp. 9-14.
3. A.D. Halverson. Recycling Portland Cement Concrete Pavements. Interim Report. Minnesota Department of Transportation, Saint Paul, May 1981.
4. Energy Requirements for Roadway Pavements. The Asphalt Institute, College Park, Md., Nov. 1979.

Publication of this paper sponsored by Committee on Rigid Pavement Construction.

Curing and Moisture Loss of Grooved Concrete Surfaces

SEYED MEHDI SAMSAM SHARIAT and PRAHLAD D. PANT

ABSTRACT

Several tests were conducted to evaluate the curing of grooved concrete surfaces with a liquid membrane-forming compound. The grooves were 1/10 in. (2.5 mm) wide at spacing of 3/4 in. (19 mm) and the depth varied from 1/8 in. (3 mm) to 3/16 in. (5 mm). The curing compound was applied at the rate of 200 ft^2/gal as specified by AASHTO and ASTM. In all cases the moisture loss exceeded the allowable amount of 0.55 kg/m^2 in 72 hr. Moisture loss data were also obtained for concrete surfaces with groove depths of 0.15 in. (3.8 mm). A regression analysis of the data estimated that the moisture loss would be restricted to 0.55 kg/m^2 when the compound application rate increased by 23 percent of the standard rate. It is suggested that increasing the compound application rate will not be a satisfactory solution because of problems associated with sagging of the curing compound on vertical surfaces. Further investigations on the methods and materials for curing grooved concrete surfaces with liquid membrane-forming compounds are suggested.

Several concerns have been raised in recent years about the adequacy of the methods and materials for curing grooved concrete pavements with liquid membrane-forming compounds. The standard specifications for liquid membrane-forming compounds for curing concrete surfaces [AASHTO M 148-82 and ASTM C 309-81; and AASHTO T 155-82 and ASTM C 156-80a (1-3)] require that the curing compound be applied at the rate of 200 ft^2/gal and that the moisture loss be not more than 0.55 kg/m^2 of surface in 72 hr. Early in 1970 the Transportation Research Board Circular 280 (4,pp.5-6) had indicated that "the trend toward deeply textured pavements such as those textured with a steel wire comb requires a larger quantity of curing membrane than pavements textured with a broom or burlap drag." When the pavement is grooved, the surface area is not only increased, but the vertical sides of the grooves may not receive the same amount of curing as the horizontal surfaces. It is understood that several highway agencies have been using an application rate of 150 ft^2/gal for some years, but this rate was not adopted by AASHTO in the new guide specifications published in 1982.

In September 1980 the National Cooperative Highway Research Project (NCHRP) of the Transportation Research Board distributed briefs of research problem statements considered by the Special AASHTO Select Committee on Research for the FY 1982 Program of the NCHRP (5) in the hope that some of the problems might be addressed by other agencies. One of the research problem statements that related to the evaluation of methods and materials to assure adequate curing of grooved concrete pavement received a ranking of 11 on a scale of 1-19. The research described in this paper was motivated, at least in part, by the research problem statement distributed by the NCHRP.

The direction of grooves (transverse or longitudinal) varies from one state to another. A Portland Cement Association publication (6) presents the types and directions of surface textures in various states. A selected groove dimension that would be acceptable to all agencies involved in the design and construction of highway pavements has not been set as a standard. The Federal Highway Administration Technical Advisory (7) recommends the use of grooves 0.095 in. (2.4 mm) wide spaced at 3/4-in. (19-mm) centers. It is recommended that the depth of the grooves range from 1/8 in. (3 mm) to 3/16 in. (5 mm). The FHWA suggests that groove spacing of less than 1/2 in. (13 mm) may not have adequate durability. Similarly, an increase in the groove spacing beyond 3/4 in. (19 mm) cannot be expected to increase durability by a significant amount and may lead to noise problems. The groove dimensions specified by most agencies appear to lie within the limits suggested by the FHWA. For example, the Ohio Department of Transportation (8) specifies that "grooves shall be spaced at approximately 3/4 inch centers and shall be approximately 0.15 inches deep and 0.10 inches wide."

MATERIALS

The experiments for this study were conducted at the U.S. Army Corps of Engineers Laboratory in Cincinnati, Ohio. Materials used were standard sand and portland cement conforming to standard AASHTO (and ASTM) specifications. AASHTO M 148 specifies three types of liquid membrane-forming compound from which the white pigmented Type 2 was selected. An experiment was conducted to estimate the weight loss of the curing compound itself. The compound was placed in a curing cabinet that supplied 100 ± 2°F (37.3 ± 1.1°C) temperature and 32 ± 2 percent humidity (AASHTO and ASTM standards). It was found that the weight loss was 28 percent in 72 hr (3 days) and 36.2 percent in 168 hr (7 days). This loss in the weight of the curing compound was used as a correction in calculating the moisture loss for the experiments described in the next section.

A test was conducted in accordance with AASHTO T 155-82 (ASTM C 156-80) to determine the water retention ability of the curing compound on nongrooved concrete surfaces 72 hr after application. Molds were made of Plexiglas (sides) and metal sheets (bottom). The mold dimensions were 6 in. x 12 in. inside area and 1 7/8 in. inside depth. The curing compound was applied at the rate of 200 ft^2/gal by use of an air-operated spray gun. The curing cabinet supplied the temperature and humidity described previously. To assure the accuracy of the test, three specimens were tested. It was found that, for this curing compound, the average moisture loss in 72 hr was 0.024 g/cm^2, which is considerably less than the maximum amount of 0.055 g/cm^2 allowed by the AASHTO and ASTM specifications.

WATER RETENTION TESTS

Tests were conducted in accordance with AASHTO T 155-82 (ASTM C 156-80a) to examine the moisture loss of grooved concrete surfaces with different groove configurations. The curing compound was applied at the rate of 200 ft^2/gal as specified by the AASHTO (and ASTM) standards. The water loss was determined at 72 hr (3 days) and 168 hr (7 days). It may be noted that AASHTO (and ASTM) specify the amount of moisture loss in 72 hr only. But the moisture loss in 168 hr was also determined in anticipation of a better understanding of the water retention ability of the curing compound on grooved concrete surfaces. Four sets of tests were conducted. Three specimens were examined for each of these tests. The first three tests examined the effects of different groove depths on the moisture loss of the concrete surfaces. The fourth test was done to determine a proper compound application rate for concrete surfaces with a specific groove size. These tests are described in the following paragraphs.

The first test consisted of the measurement of the moisture loss of concrete surfaces with grooves 0.1 in. (2.5 mm) wide at spacings of 0.75 in. (19 mm). The groove depth of 1/8 in. (3 mm) was chosen for this test. It is the lower limit of groove depth suggested by the FHWA.

The results of this test and the following two tests are tabulated in Tables 1 and 2 for 3 and 7 days, respectively. These results indicate that the average moisture loss in 72 hr is 0.070 g/cm^2, which is higher than the maximum amount of 0.055 g/cm^2 allowed by the AASHTO and ASTM specifications. The average moisture loss in 168 hr is 0.102 g/cm^2.

The second test was conducted to examine whether an increase in the depth of the grooves affects moisture loss behavior. The groove depth of 0.15 in. (3.8 mm) was chosen for this test. It is the depth used by many state agencies including the Ohio Department of Transportation. It is seen that increasing the depth of grooves from 0.125 in. (3 mm) to 0.15 in. (3.8 mm) causes the average moisture loss to increase from 0.070 g/cm^2 to 0.084 g/cm^2 at 72 hr. These values exceed the allowable moisture loss specified by AASHTO and ASTM. The average moisture loss increased from 0.102 g/cm^2 to 0.128 g/cm^2 in 168 hr.

For the third test, the groove depth was changed to 3/16 in. (5 mm), which is the maximum depth suggested by the FHWA. The result of this test shows that the average moisture loss was indeed higher than 0.55 g/cm^2 as specified by AASHTO M 148-82 (ASTM C 309-81).

Finally, for the fourth test, the width, spacing, and depth of the grooves were kept constant at 0.1 in. (2.5 mm), 0.75 in. (19 mm), and 0.15 in. (3.8 mm), respectively, and the specimens were subjected

TABLE 1 Moisture Loss of Grooved[a] Concrete Surfaces in 72 Hours

Groove Depth (in.)	Mold No.	Moisture Loss (g/cm^2)
1/8	1	0.076
	2	0.097
	3	0.036
Average		0.070
Standard deviation		0.031
0.15	1	0.089
	2	0.113
	3	0.056
Average		0.084
Standard deviation		0.028
3/16	1	0.074
	2	0.079
	3	0.074
Average		0.076
Standard deviation		0.003

[a]Groove configuration: width = 0.1 in., spacing = 0.75 in.

TABLE 2 Moisture Loss of Grooved[a] Concrete Surfaces in 168 Hours

Groove Depth (in.)	Mold No.	Moisture Loss (g/cm^2)
1/8	1	0.104
	2	0.134
	3	0.079
Average		0.102
Standard deviation		0.032
0.15	1	0.130
	2	0.162
	3	0.093
Average		0.128
Standard deviation		0.034
3/16	1	0.110
	2	0.121
	3	0.106
Average		0.112
Standard deviation		0.008

[a]Groove configuration: width = 0.1 in., spacing = 0.75 in.

to various compound application rates ranging from 95 to 145 percent of the AASHTO requirement (200 ft^2/gal). The results are presented in Table 3 for 3 and 7 days. A regression analysis using the Statistical Package for Social Sciences (SPSS) computer program was run to estimate a linear relationship

TABLE 3 Moisture Loss of Grooved[a] Concrete Surfaces with Different Compound Application Rates

	Curing Compound Application		Moisture Loss ($g/100\ cm^2$)	
Mold No.	$g/100\ cm^2$	Change from AASHTO and ASTM Rate (%)	72 Hr	168 Hr
1	2.024	0	8.370	13.049
2	2.024	0	11.342	16.258
3	2.024	0	5.614	9.345
4	1.923	-5	7.263	10.874
5	2.125	+5	9.584	14.707
6	2.227	+10	10.239	15.547
7	2.328	+15	10.377	15.633
8	2.429	+20	6.916	13.630
9	2.530	+25	9.121	14.944
10	2.631	+30	4.500	8.764
11	2.733	+35	2.033	4.177
12	2.834	+40	0	1.809
13	2.935	+45	0.433	9.173

[a]Groove configuration: width = 0.1., spacing = 0.75 in., depth = 0.15 in.

between the moisture loss and the compound application rate. The following two equations were obtained, Equation 1 for moisture loss in 72 hr and Equation 2 for moisture loss in 168 hr:

$$MOSTLOSS = 26.734 - 8.507 \times CURCOMP \quad (1)$$

$$MOSTLOSS = 30.262 - 7.979 \times CURCOMP \quad (2)$$

where MOSTLOSS represents moisture loss of the grooved specimens in grams per 100 cm^2 and CURCOMP represents curing compound application rate in grams per 100 cm^2. The results of the regression analysis are presented in Table 4 and Figure 1 and Table 5 and Figure 2 for 3 and 7 days, respectively.

In studying the linear relationship between the moisture loss and the compound application rate in 72 hr, it is seen that the rate should be increased by 23.5 percent to restrict the loss of water to not more than 0.55 kg/m^2 as specified by AASHTO and ASTM. This modification calls for an application rate of 163 ft^2/gal of the curing compound when the groove configuration is 0.1 x 0.15 x 0.75 in.

The 3-day data and the 7-day data have R^2 values of 0.57 and 0.35, respectively. It is seen that the 3-day data represent a better fit for a linear relationship than do the 7-day data.

CONCLUSIONS

In this study the standard water retention test procedures were used to measure the moisture loss of concrete surfaces cured with liquid membrane-forming

TABLE 4 Regression Analysis for Moisture Loss in 72 Hours

Variable	Mean	Standard Deviation	B	Standard Error	F
MOSTLOSS	6.599	3.837			
CURCOMP	2.366	0.342	-8.507	2.204	14.89

Note: Constant = 26.733, Multiple R = 0.75, R^2 = 0.57, Standard error = 2.612, MOSTLOSS = moisture loss in $g/100\ cm^2$, and CURCOMP = curing compound application rate in $g/100\ cm^2$.

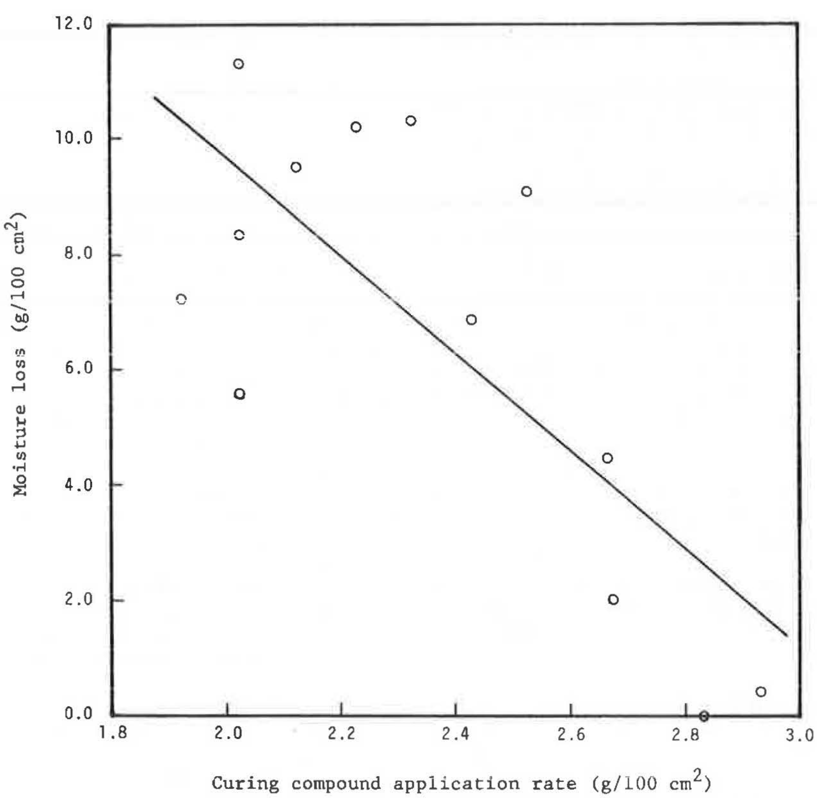

FIGURE 1 Scatter diagram and regression line of moisture loss in 72 hours.

compounds. The first three tests were conducted to examine the relationship between moisture loss and groove depths. The grooves were 1/10 in. (2.5 mm) wide at spacings of 3/4 in. (19 mm) and the depth varied from a minimum of 1/8 in. (3 mm) to a maximum of 3/16 in. (5 mm) as suggested by the FHWA. In all cases the moisture loss in 72 hr exceeded the amount allowed by AASHTO M 148 (ASTM C 309). The tests confirmed that the amount of liquid membrane-forming compound that has been specified for curing non-grooved concrete surfaces is not adequate for curing grooved concrete surfaces. The tests showed that moisture loss is related to groove size.

TABLE 5 Regression Analysis for Moisture Loss in 168 Hours

Variable	Mean	Standard Deviation	B	Standard Error	F
MOSTLOSS	11.377	4.568			
CURCOMP	2.366	0.342	-7.979	3.228	6.108

Note: Constant = 30.261, Multiple R = 0.59, R^2 = 0.35, Standard error = 3.826, MOSTLOSS = moisture loss in g/100 cm^2, and CURCOMP = curing compound application rate in g/100 cm^2.

An effort was made to develop a linear relationship between the compound application rate and the moisture loss of concrete surfaces with groove dimensions of 0.1 x 0.15 x 0.75 in. (2.5 x 3.8 x 19 mm). The regression analysis estimated that the moisture loss would be restricted to 0.55 kg/m^2 when the compound application rate increased by 23.5 percent of the standard rate (163 ft^2/gal). Further investigations are needed to develop proper application rates for other groove configurations.

It should be noted, however, that increasing the compound application rate will not be a satisfactory solution because of problems associated with the sagging of the curing compound on vertical surfaces. It is clear that the three types of surfaces, that is, the top horizontal surfaces, the vertical surfaces, and the bottom surfaces of the grooves, did not receive equal amounts of curing because of the sagging problem. When the curing compound was increased by 45 percent of the standard rate, the grooves were completely filled with the compound. The development of a separate guide specification for curing grooved concrete surfaces and, more important, the development of a new curing compound that would minimize these application problems are suggested.

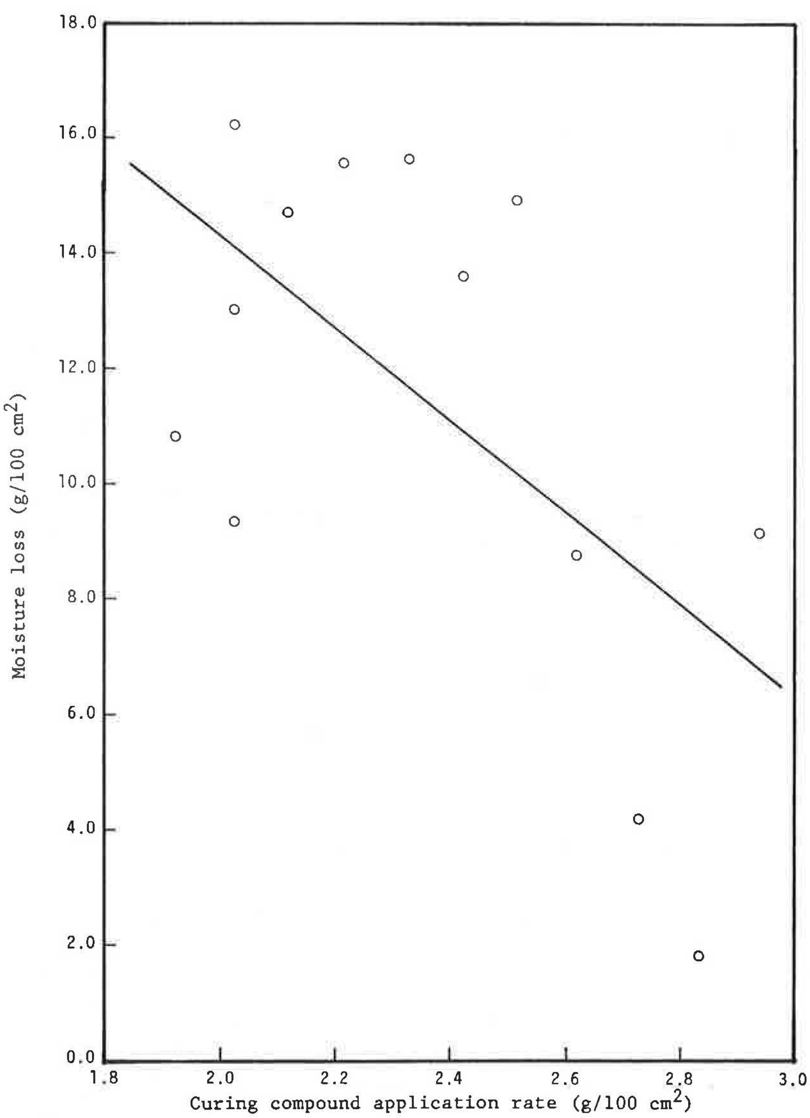

FIGURE 2 Scatter diagram and regression line of moisture loss in 168 hours.

ACKNOWLEDGMENT

The authors extend their sincere appreciation and thanks to Ronald Sprague and the U.S. Army Corps of Engineers for their help and support in the conduct of this study.

REFERENCES

1. AASHTO Materials, Part I: Specifications, 13th ed. American Association of State Highway and Transportation Officials, Washington, D.C., 1982.
2. AASHTO Materials, Part II: Tests, 13th ed. American Association of State Highway and Transportation Officials, Washington, D.C., 1982.
3. ASTM Standards. American Society for Testing and Materials, Philadelphia, Pa., 1980.
4. Curing of Concrete Pavements. Transportation Research Circular 208. TRB, National Research Council, Washington, D.C., 1970.
5. Briefs of Research Problem Statements Considered by the Special AASHTO Select Committee on Research for the FY 1982 Program of the NCHRP. TRB, National Research Council, Washington, D.C., Sept. 1980.
6. A Chartered Summary of Concrete Highway Pavement Practice in the United States. Portland Cement Association, Skokie, Ill., 1982.
7. Texturing and Skid Resistance of Concrete Pavements and Bridge Decks. FHWA Technical Advisory T5140.10. FHWA, U.S. Department of Transportation, Sept. 18, 1979.
8. Construction and Material Specification. State of Ohio Department of Transportation, Columbus, Jan. 1, 1981.

Publication of this paper sponsored by Committee on Rigid Pavement Construction.

Effects of Sawed-Groove Texturing on Concrete Bridge Decks

JOHN E. GRADY

ABSTRACT

The experimental application of a sawed-groove texture on two New York bridge decks and one operational use of diamond grinding to rectify an aggravated friction problem on a third deck are discussed. Although tine-texturing has been the chosen concrete deck texturing method in New York, inability to obtain grooves deep enough to provide a long-lasting, high-friction surface has generated interest in trying to saw grooves in new decks. Although used widely for restoring texture on worn concrete pavements, this method had not been generally accepted or promoted for use on new concrete decks. The purpose was to determine if sawing a new concrete deck to produce texture would adversely affect concrete durability and to assess the frictional properties and durability of the texture itself compared with tined surfaces. The determination is based on laboratory tests for chloride permeability and resistance to deicer scaling, and microscopic examinations for microfracturing, as well as field measures of friction and texture depth. Results show that accumulation of chlorides in sawed samples was slightly greater at shallow depths than accumulation in tined textures. At greater depths, no significant difference was found. Tests showed that sawed texturing did not increase the occurrence of scaling, nor cause any small-scale fracturing. Sawed textures were shown to provide a deep and durable frictional riding surface. A disadvantage of sawing is the increased cost compared to tining.

Concrete bridge decks, as well as portland cement concrete pavements, in New York State are finished with a transverse texture produced by a tined metal rake. Although this texturing device has the potential to produce grooves deep enough to provide a long-lasting, high-friction surface on concrete pavements, grooves deep enough to meet the specified minimum depth of 2/16 in. have been hard to attain, particularly on bridge decks on which hand tools are used (1). The problem is aggravated by use of stiffer high-density, low-slump (HDLS) concretes that resist penetration and by latex-modified concretes (LMC) that are too fluid when first placed to hold the grooves. An alternative that has been considered for better assurance of the desired texture depth is to saw grooves after the concrete has cured. Although used widely for restoring texture on worn concrete pavements, this method has not been generally accepted or promoted for new concrete decks. The experimental application of a sawed-groove texture on two New York bridge decks and the