Moisture Loss and Abrasion Resistance of Grooved Concrete Surfaces Cured With a Liquid Membrane-Forming Compound

PRAHLAD D. PANT and MARWAN M. SAADEH

ABSTRACT

The moisture loss and relative abrasion resistance of grooved concrete surfaces cured with a liquid membrane-forming compound are examined in this paper. First, the moisture loss and the loss in mass of concrete by abrasion for nongrooved concrete surfaces, cured with a membrane-forming compound as specified by AASHTO and ASTM, were determined. Next, the compound application rate was kept unchanged and the effects of various groove depths on the moisture loss and the relative abrasion resistance of concrete surfaces were examined. Finally, the groove depth was kept unchanged and the effects of higher compound application rates were examined. The analysis of variance showed that both groove depth and compound application rate were significant variables. A regression analysis showed the existence of a fairly strong relationship between compound application rate and moisture loss. However, loss in mass of concrete surfaces by abrasion had no linear relationship with compound application rate, indicating that the relative abrasion resistance of grooved concrete surfaces is not affected by higher amounts of liquid membrane-forming compounds employed in curing the surface.

Necessary tire-pavement friction under variable environmental and vehicle-operating conditions can be obtained by providing the pavement surface with textures. A burlap drag finish is not satisfactory as the sole means of providing surface texture on roadways with a design speed of 40 mph or greater. Grooving of unhardened concrete by using devices such as a cylindrical tube with ribs on the outside, steel-tined combs, and wire combs produce a deeper texture with better drainage. Grooving leads to an increase in the pavement surface area. This surface area increase is directly related to the length, width, and spacing of the grooves. To secure the intended strength of the concrete, however, it must be properly cured. Liquid membrane-forming compounds are widely used for curing portland cement concrete (PCC) pavements. AASHTO and ASTM standard specifications [AASHTO M 148-82 and ASTM C 809-81 (1); and AASHTO T 155-82 and ASTM C 156-80a (2)] require that for testing purposes, the curing compound be applied at the rate of 200 ft^2/gal (or rate specified by purchaser) and that the moisture loss be not more than 0.55 kg/m^2 of surface in 72 hr. It should be noted, however, that grooving of the concrete surfaces can cause sagging of the curing compound and, hence, disproportionate amounts of the curing compound will accumulate at the bottom of the grooves. The top, bottom, and vertical surfaces of the grooves, therefore, do not receive an equal amount of curing. A previous study has shown that moisture loss for grooved concrete surfaces cured with liquid membrane-forming compounds is considerably higher than that for nongrooved surfaces and, in many instances, exceeds the allowable amount of 0.55 kg/m^2 in 72 hr (3). The AASHTO Guide specifications suggest an application rate of not more than 150 ft^2/gal for use in the field (4), but this application rate should not be compared with use on test specimens. More coverage is specified in the field because there is more variability. Examined in this paper are the moisture loss and the relative abrasion resistance of grooved concrete surfaces cured with a liquid membrane-forming compound. The tests provide a better understanding of the variations in surface properties as affected by various compound application rates and groove depths.

TESTS

Three types of curing compound are specified by AASHTO. One of these, the white-pigmented Type II, was selected. A test was conducted to examine the moisture loss of nongrooved concrete surfaces in 72 hr, in accordance with the AASHTO standard method of test (AASHTO T 155-82). Standard sand and Type-1 portland cement that satisfied AASHTO requirements were used. The mold dimensions were 6 x 12-in. inside area and 1.875-in. inside depth with a flat rim of 0.25-in. at the top. The curing compound was applied by the use of a hand-operated spray gun with a detachable air connection. A total of 9.4 g of the curing compound was used, which corresponds to the application rate of 200 ft^2/gal as specified by AASHTO. The specimen was sealed against moisture loss between the edges of the specimen and the mold. It was weighed and placed in a curing cabinet that supplies a temperature of 100 ± 2°F (37.3 ± 1.1°C) and a relative humidity of 32 ± 2 percent, according to the AASHTO standards. The specimen was removed from the cabinet in 72 hr and weighed again.

The specimen was then removed from the mold and its mass was recorded. It was placed into the abrasion machine and locked in place under the center of the dressing wheels. The dressing wheels turn freely on a horizontal axle at the bottom of a free-floating vertical steel shaft. The set consisted of 42 dressing wheels that produce a circular abrasion path of approximately 5 in. in diameter. The test duration is 60 min, but the machine was stopped every 15 min and the loose materials were brushed off the surface. The specimen was removed from the abrasion machine in 60 min and its mass was again determined. Three specimens were tested for the concrete surface to be evaluated.

Before calculating the moisture loss of the concrete surfaces, the loss in mass of volatile matter from the liquid membrane-forming compound was determined. Three metal molds were weighed and 9.4 g of the curing compound was sprayed on the surface of each mold. The molds were placed in the curing cabinet at the temperature and relative humidity previously described. The molds were removed from the cabinet in 72 hr and their mass was again determined. The average loss in mass in 72 hr was found to be 32 percent, which has been used as a correction in calculating the moisture loss of concrete surfaces for all tests (see Table 1 for test results).

TABLE 1 Moisture Loss and Loss in Mass by Abrasion of Nongrooved Concrete Surfaces

Sample No.	Moisture Loss (g/cm^2)	Mass Loss by Abrasion (%)
1	0.021	0.6
2	0.025	1.04
3	0.044	1.76
Average	0.030	1.13
Standard deviation	0.012	0.58

For the test described in the preceding paragraph, the average moisture loss of nongrooved concrete surfaces in 72 hr and the standard deviation were 0.0303 g/cm^2 and 0.0124 g/cm^2, respectively, which are less than the respective amounts of 0.0550 g/cm^2 and 0.0130 g/cm^2 allowed by the AASHTO specifications (M 148-82 and T 155-82). It can thus be seen that the application of the curing compound at the rate of 220 ft^2/gal indeed satisfies the AASHTO requirements.

Several tests were conducted to examine the effects of groove depths and compound application rates on the moisture loss and on the abrasion resistance of grooved concrete surfaces. The width and spacing of the grooves were 0.1-in. and 0.75-in., respectively, which conform to the suggestion contained in the FHWA Technical Advisory (5). In addition, the FHWA suggests that the depth of grooves range from 0.125-in. to 0.1875-in. Different states employ different groove dimensions, but these dimensions seem to lie within the limits suggested by the FHWA. Two sets of tests concerning grooved concrete surfaces were performed. In the first set, three different groove depths were selected: 0.125-in., 0.15-in., and 0.1875-in. The grooving device consisted of a 20-in. long metal rod, 0.1-in. thick metal washers, 0.65-in. long metal tubes (that exactly fit the metal rod, as the spacers), two screws for controlling the washer's depth, two rails that assist the groover to slide on the edges of the mold, and two wooden handles (Figure 1). Thus the width and spacing of the grooves were kept constant at 0.1-in. and 0.75-in., respectively; however, the depth of the grooves could be changed by means of the adjustment screws. The amount of the curing compound applied on the concrete surface was 9.4 g as before. The average moisture loss and the average loss in mass of concrete surfaces by abrasion were determined for each specimen. Three specimens were tested for each groove type. In the second set, the depth of groove was kept constant at 0.15 in. This depth has been employed by several highway agencies including the Ohio Department of Transportation. The compound application rate increased from 5-40 percent above the specified rate in increments of 5 percent. Tests were conducted as before to determine the average moisture loss and the average loss of mass by abrasion. Three specimens were tested for the evaluation of each application rate.

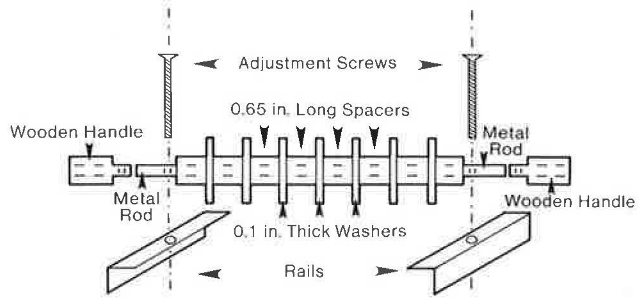

FIGURE 1 Groover components and its assembly.

ANALYSIS AND DISCUSSION

As seen before, the moisture loss in 72 hr of nongrooved concrete surfaces was .0303 g/cm^2, which is lower than the moisture loss of .0550 g/cm^2 allowed by AASHTO, indicating that the specified moisture loss restriction for the curing compound is satisfied (Table 1). For the nongrooved concrete surfaces, the loss of mass by abrasion was 1.13 percent. Because no previous standard for loss in mass by abrasion is available, the percent loss of mass found previously will be used as a base value in the examination of the relative variations in concrete surfaces as affected by different groove depths and compound application rates.

For concrete surfaces with 0.125-in. deep grooves, the average moisture loss increased sharply to 0.1042 g/cm^2--more than a threefold increase. The loss of mass by abrasion increased to 1.22 percent--an increase of a mere 0.09 percent. When the depth of the grooves was 0.15-in., the average moisture loss increased by an additional 17 percent, but the loss of mass by abrasion increased by a full 100 percent. Finally, when concrete surfaces with 0.1875-in. grooves were tested, the average moisture loss increased to 0.1446 g/cm^2--an increase of an additional 18 percent. The loss of mass by abrasion was found to be 2.22 percent, which is twice the loss for nongrooved surfaces. However, for reasons that cannot be explained, the loss in mass for the concrete surfaces with 0.1875-in. grooves is lower than that for the concrete surfaces with 0.15-in. grooves (Table 2).

In general, the tests have shown that moisture loss increases with deeper grooves and that the relationship between moisture loss and groove depth may be linear. The loss of mass by abrasion for grooved concrete surfaces is higher than that for nongrooved concrete surfaces, but mass loss and groove depth exhibit no linear relationship. It may be noted that the only factor being varied in the first set of tests was the depth of grooves and all other factors (e.g., curing compound) were kept constant. An analysis of variance was performed to examine the significance of groove depth. As shown in Table 3, groove depth was found to be significant at the 0.01 level. (Note: all statistical analyses de-

TABLE 2 Moisture Loss and Loss in Mass by Abrasion of Concrete Surfaces with Various Groove Depths

Groove Depth (in.)	Moisture Loss (g/cm²) Sample	Moisture Loss (g/cm²) Average	Moisture Loss (g/cm²) Standard Deviation	Mass Loss by Abrasion (%) Sample	Mass Loss by Abrasion (%) Average	Mass Loss by Abrasion (%) Standard Deviation
0.125						
Sample 1	0.089			1.15		
Sample 2	0.091			1.41		
Sample 3	0.132	0.104	0.024	1.12	1.22	0.16
0.15						
Sample 1	0.097			2.22		
Sample 2	0.130			2.51		
Sample 3	0.139	0.122	0.021	2.63	2.45	0.21
0.1875						
Sample 1	0.131			2.14		
Sample 2	0.142			2.18		
Sample 3	0.160	0.144	0.014	2.34	2.22	0.10

TABLE 3 Analysis of Variance of Groove Depth

Analysis of Variance	Source	Degrees of Freedom	Sum of Squares	Mean Squares	F Ratio	F Probability
Depth of groove (in.) Moisture loss (g/cm²)	Between groups	3	0.022	0.007	20.51	0.000
	Within groups	8	0.003	0.000		
	Total	11	0.025			
Depth of groove (in.) Mass loss (g)	Between groups	3	4.108	1.369	12.92	0.002
	Within groups	8	0.848	0.106		
	Total	11	4.956			

scribed in this paper were performed with the SPSS--Statistical Package For Social Sciences--computer programs.)

In the next set of tests, the only factor being varied was the compound application rate and all other factors (e.g., groove depth) were kept constant. The amount of liquid membrane-forming compounds increased from 5 to 40 percent above the specified rate. The results show that the moisture loss was minimum when the curing compound application rate increased to 40 percent above the specified rate (Table 4). However, the data indicate that a higher application rate does not necessarily reduce the moisture loss of grooved concrete surfaces, indicating that groove depth has effects of different magnitude for different application rates. The

TABLE 4 Moisture Loss and Loss in Mass of Grooved Concrete Surfaces Cured with Higher Compound Application Rates

Increase in Curing Compound Application Rate (%)	Curing Compound per 72 in.² (g)	Sample Number	Moisture Loss (g/cm²) Sample	Moisture Loss (g/cm²) Average	Moisture Loss (g/cm²) Standard Deviation	Mass Loss by Abrasion (%) Sample	Mass Loss by Abrasion (%) Average	Mass Loss by Abrasion (%) Standard Deviation
5 (1 gal/192 ft²)	9.87	1	0.102			1.32		
		2	0.110			1.52		
		3	0.121	0.111	0.009	1.76	1.53	0.22
10 (1 gal/183 ft²)	10.34	1	0.115			2.15		
		2	0.130			2.37		
		3	0.146	0.130	0.015	2.64	2.38	0.24
15 (1 gal/175 ft²)	10.81	1	0.114			1.81		
		2	0.131			2.04		
		3	0.146	0.131	0.015	2.30	2.05	0.24
20 (1 gal/168 ft²)	11.28	1	0.091			2.54		
		2	0.098			2.68		
		3	0.107	0.099	0.008	2.84	2.68	0.15
25 (1 gal/161 ft²)	11.75	1	0.092			2.19		
		2	0.107			2.58		
		3	0.136	0.112	0.021	2.74	2.50	0.28
30 (1 gal/155 ft²)	12.22	1	0.087			1.76		
		2	0.093			1.98		
		3	0.100	0.094	0.006	2.19	1.97	0.21
35 (1 gal/149 ft²)	12.69	1	0.077			1.78		
		2	0.081			1.76		
		3	0.087	0.082	0.005	1.90	1.81	0.07
40 (1 gal/144 ft²)	13.16	1	0.073			2.06		
		2	0.076			2.01		
		3	0.082	0.077	0.004	2.23	2.1	0.11

Note: Groove depth = 0.15 in. Base application rate = 9.4 g/72 in.², that is, 1 gal/200 ft².

TABLE 5 Analysis of Variance of Compound Application Rate

Analysis of Variance	Source	Degrees of Freedom	Sum of Squares	Mean Squares	F Ratio	F Probability
Compound application rate (g) and moisture loss (g/cm²)	Between groups	8	0.009	0.001	6.21	0.0006
	Within groups	18	0.003	0.000		
	Total	26	0.012			
Compound application rate (g) and mass loss (g)	Between groups	8	3.283	0.410	9.69	0.000
	Within groups	18	0.762	0.042		
	Total	26	4.045			

loss in mass by abrasion did not show any consistent pattern when the compound application rate increased from 5-40 percent above the specified rate. The data concerning abrasion resistance and compound application rate seem scattered. As before, an analysis of variance was performed to examine the significance of the compound application rate. As shown in Table 5, the compound application rate was found to be significant at the 0.01 level.

Although the analysis of variance indicates the existence of the effects of compound application rates, it does not give information on the overall strength of association between the compound application rates and moisture loss or loss in mass by abrasion. Regression analyses were therefore performed to measure the associations between the independent (compound application rate) and dependent (moisture loss or mass loss) variables. The analysis shows that moisture loss and compound application rate are related to each other, and that the correlation coefficient is 0.71 (Table 6 and Figure 2).

TABLE 6 Regression Analysis of Compound Application Rate and Moisture Loss

Variable	Mean	Standard Deviation	Samples	B Coefficient	F Ratio
Moisture loss—dependent (g/cm²)	0.106	0.022	27	-0.01275	25.66
Curing compound independent (g)	11.28	1.23	27		
Constant	0.2506				

Note: Multiple R = 0.71, R^2 = 0.50, and standard error = 0.01.

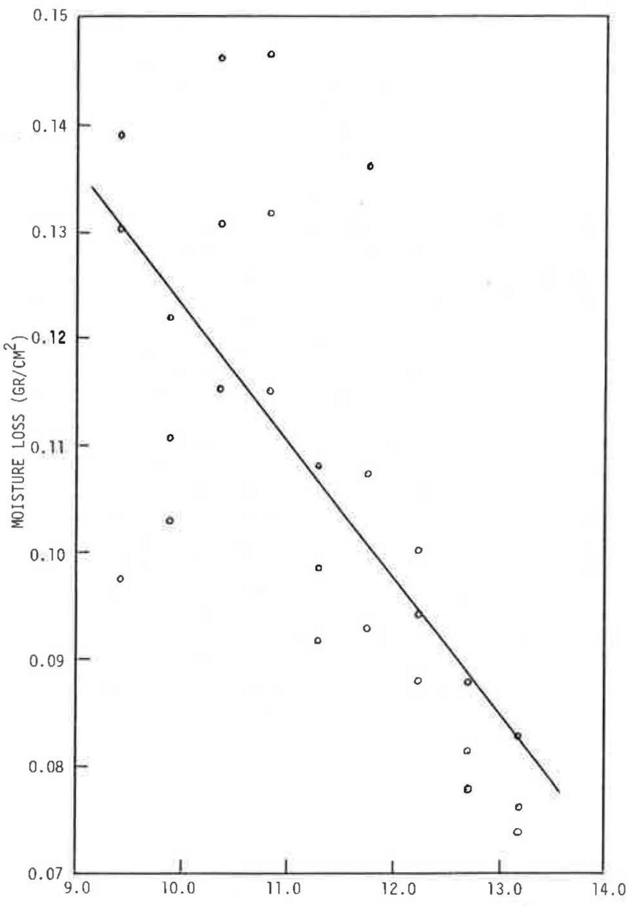

FIGURE 2 Scatter diagram and regression line of moisture loss and curing compound.

The coefficient of determination, R^2, is 0.50, indicating that 50 percent of the variation in moisture loss is explained by the compound application rate. The F value of the regression equation is 25.66, which shows that the equation is significant at the 0.01 level. The linear relationship between moisture loss and compound application rate is

Moisture Loss = 0.2506 - 0.01275 (curing compound)

where moisture loss is expressed in g/cm², and curing compound is expressed in g.

A similar regression analysis of loss in mass by abrasion and compound application rate showed that mass loss by abrasion had no linear relationship with compound application rate. The coefficient of determination (R^2) was 0.01 and the F value was 0.27. It is clear that the compound application rates have no linear effects on the abrasion resistance of the grooved concrete surfaces. The correlation coefficient of moisture loss and mass loss was 0.40, indicating that the observed mass loss tended to increase with higher moisture loss. However, the analysis showed that mass loss by abrasion is not related to compound application rates.

SUMMARY AND CONCLUSIONS

The moisture loss and abrasion resistance of grooved concrete surfaces cured with liquid membrane-forming compounds have been examined. First, the moisture loss and mass loss by abrasion for nongrooved concrete surfaces cured with the specified amount of membrane-forming compounds were determined, which provided base values for the examination of moisture loss and abrasion resistance as affected by different groove depths and compound application rates. Next, the compound application rate was kept constant and the effects of three types of groove depths--0.125-in., 0.15-in., and 0.1875-in.--were examined. Finally, the groove depth was kept constant at 0.15-in., and the effects of higher compound application rates were examined by increasing the application rates from 5-40 percent above the previous amount. The width and spacing of grooves for all tests were 0.1-in. and 0.75-in., respectively--a practice suggested by the FHWA and adopted by many states.

The tests have shown that the relationship between moisture loss and groove depth may be linear, but mass loss and groove depth exhibit no such linear relationship. An analysis of variance showed groove depth to be significant at the 0.01 level, indicating that the effects of groove depths should not be ignored in any future analysis concerning the curing and abrasion resistance of concrete surfaces cured with liquid membrane-forming compounds.

For tests involving different compound application rates, the analysis of variance showed that compound application rate is a significant variable in the determination of moisture loss and loss in mass by abrasion of the grooved concrete surfaces. Separate regression analyses were performed to examine the linear associations between the compound application rate and moisture loss, and between the compound application rate and mass loss by abrasion. The compound application rate and moisture loss were found to exhibit a fairly strong linear relationship. However, the analysis showed that mass loss had no relationship with the compound application rates.

The moisture loss data support the findings of a previous study (3) in which the regression analysis of moisture loss and compound application rate showed an R^2 of 0.57. In this study, the R^2 is 0.50. It can be seen, therefore, that approximately 50-60 percent of the variation in the moisture loss is explained by the compound application rate.

The tests have shown that abrasion resistance of grooved concrete surfaces is lower than that of non-grooved concrete surfaces. No attempt is made here to provide a quantitative measurement of the length of service that may be expected from a specific surface. However, the tests have shown that the relative abrasion resistance of grooved concrete surfaces is not affected by extra amounts of the liquid membrane-forming compound employed in curing the surface.

It is suggested that in future studies, both factors (compound application rate and groove depth) be varied in the experimental set-up, which will allow an examination of the main effects of the separate factors as well as the interaction effects resulting from the unique combination of the factors. The information obtained from such a study will assist in determining compound application rates for concrete surfaces with different groove depths. It seems that the efficiency of a curing compound on a grooved surface will depend on its viscosity, but this characteristic has not been covered by AASHTO M 148-82 or ASTM C 309-81. It is further suggested that the viscosity of curing compounds be examined in future studies.

REFERENCES

1. AASHTO Materials, Part I. 13th Edition, AASHTO, Washington, D.C., 1982.
2. AASHTO Materials, Part II. 13th Edition, AASHTO, Washington, D.C., 1982.
3. S.M. Samsam Shariat and P.D. Pant. Curing and Moisture Loss of Grooved Concrete Surfaces. Transportation Research Record 986, TRB, National Research Council, Washington, D.C., p. 4.
4. Guide Specifications For Highway Construction. AASHTO, Washington, D.C., 1979.
5. Texturing and Skid Resistance of Concrete Pavements and Bridge Decks. Technical Advisory T5140.10. FHWA, U.S. Department of Transportation, Sept. 1979.

Publication of this paper sponsored by Committee on Mechanical Properties of Concrete.