Use of Blank and Ribbed Test Tires for Evaluating Wet-Pavement Friction

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Skid-resistance data are compared by the ASTM E274 locked-wheel test method that uses blank E524 and ribbed E501 test tires on 59 pavements. The ribbed E501 tire is shown to be a poor discriminator of the drainage capability from the tire-pavement interface produced by pavement macrotexture. The blank E524 test tire is shown to produce data sensitive to both macrotexture and microtexture. The pavements included in the study range from well-polished and worn dense-graded asphalt and portland cement concrete to open-graded asphalt grooved portland cement concrete; they ranged in SN_{40} from 24 to 69 with the ribbed tire. It is also noted that the ribbed E501 tire provides better drainage than do most passenger car tires during the latter third of their usable life.

Wet-pavement friction of the primary highway systems of most states is monitored in annual surveys by using the full-scale locked-wheel skid-test procedure specified by ASTM E274. The skid resistance is reported as a skid number (SN), which is the friction force as a percentage of the vertical load for a test tire that is sliding at the speed of the test, usually 65 km/h (40 miles/h). The application of water to the pavement, range of vertical load, operating conditions, and all other details specified by the procedure are implied when pavement friction is reported by SNs. Also implied is the use of the ASTM ribbed test tire specified by ASTM E501.

The E501 tire has seven circumferential ribs that form six grooves to provide for drainage of water from the tire-pavement interface as the tire slides over the wet pavement during a test. The specification requires that the tire not be reused when the minimum depth of the grooves reaches 4 mm (0.16 in). The use of excessively worn test tires produces lower SNs. Figures 1 and 2 show a conceptualized ribbed test tire on actual profiles of dense-graded and open-graded asphalt concrete pavement (ACP). The scale is distorted by the differences in vertical and horizontal magnifications (vertical = 8X; horizontal = 1.5X for both pavement profile and tire). From these figures it can be seen that the tire contributes a significant amount of the drainage area. Furthermore, the drainage area provided by the tire grooves is continuous and unimpeded in the longitudinal direction, unlike that provided by the pavement.

It is an accepted procedure to rehabilitate portland cement concrete (PCC) pavement by sawing longitudinal grooves into the surface. It has been noted (1,2) that the SN is not significantly improved by grooving. Figure 3 shows the profile of the ribbed test tire superimposed on a typical grooving pattern [6.4x4-mm grooves on 25-mm spacing (0.25x0.25-in grooves on 1-in spacing)]; the figure is scaled with the same magnification as in Figures 1 and 2 for comparison. Since the presence or absence of the grooves does not affect the SN, it is apparent that sufficient drainage is provided by the tire grooves. If the SN were a true measure of the safety, grooving of PCC pavements could not be justified.

Passenger car tires have tread patterns that provide varying amounts of drainage area. Ink-impression prints of a passenger car tire when new and when worn were made, and the mean effective tread depth (open area divided by total area times mean tread depth) was computed. A comparison of mean effective tread depth measured for passenger car tires and the E501 ribbed test tire is given below (1 mm = 0.04 in):

Tire	Minimal Tread Depth (mm)	Mean Effective Tread Depth (mm)
Passenger car		
New	10.4	1.98
Worn (legal limit)	2.4	0.41
E501		
New	9.5	2.01
Worn	4.0	0.97

Although the new test tire and passenger car tire have the same drainage capabilities, their worn counterparts do not. The worn test tire has approximately one-half the mean effective tread depth of the new test tire. For more than one-third of its useful life, the passenger car tire has less mean effective tread depth than the completely worn test tire if one assumes that the tread wears linearly with time. It also should be noted that the passenger car tire used here has an above-average tread depth.

Attempts to relate wet-weather accident frequency to SNs have not been encouraging. The most extensive studies, conducted in Kentucky (3,4), suggest a trend, but the scatter is large and the correlation coefficients are low. A conclusion that might be drawn is that actual tires depend to a greater extent on the contribution of pavement texture to drainage than does the ribbed test tire. Conversely, it could be stated that testing by using the ribbed tire is not sufficiently sensitive to the pavement texture that actual tires depend on for prevention of wet skidding.

ROLE OF PAVEMENT TEXTURE

The two scales of pavement texture of significance to wet-pavement friction are microtexture, which has a space frequency content of more than 2000 cycles/m (50 cycles/in), and macrotexture, which has a space frequency range from 25 to 2000 cycles/m (0.65-50 cycles/in) (5). Microtexture influences the general level of the SN, whereas macrotexture determines the rate of decrease of skid resistance with speed. SN data are shown (5) to decrease experimentally with speed according to the following model:

$$SN = SN_0 \exp[-(PNG/100)v] \quad (1)$$

where, for ribbed-tire data, SN_0 is found to be linearly related to measures of microtexture, whereas PNG is inversely related to the square root of macrotexture parameters. The parameter SN_0 also has the significance of being the zero-speed intercept of fit to the SN data and PNG is the percent normalized gradient, related to the SN and SN-speed gradient (SNG) as follows:

$$PNG = (SNG/SN) \times 100 = (-100/SN)(dSN/dV) \quad (2)$$

The low-speed or zero-speed friction indicated by the value of SN_0 increases with such microtexture

Figure 1. ASTM ribbed test tire on dense-graded ACP.

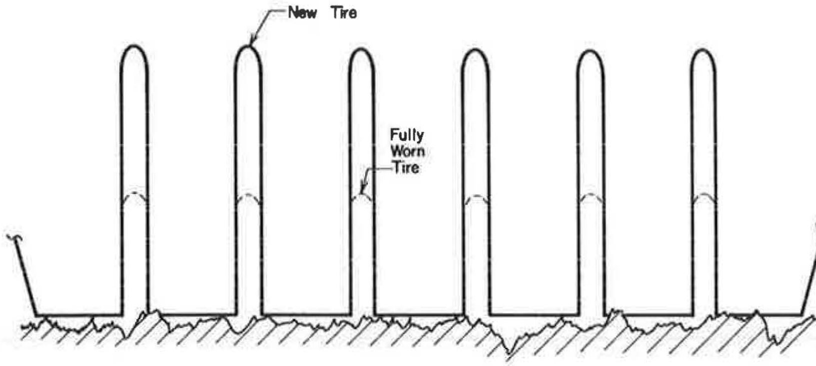


Figure 2. ASTM ribbed test tire on open-graded ACP.

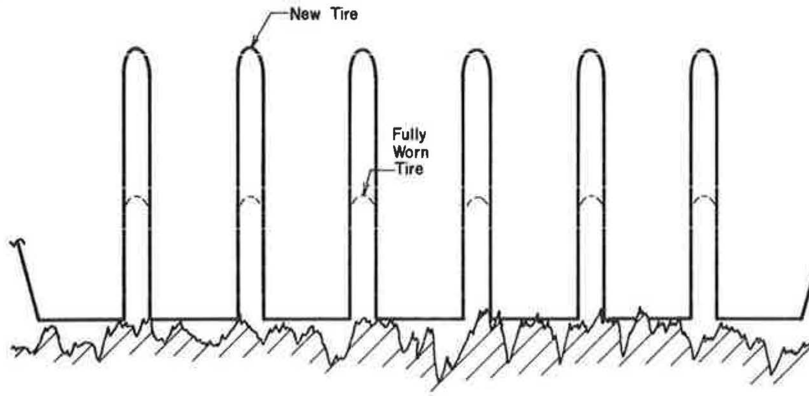
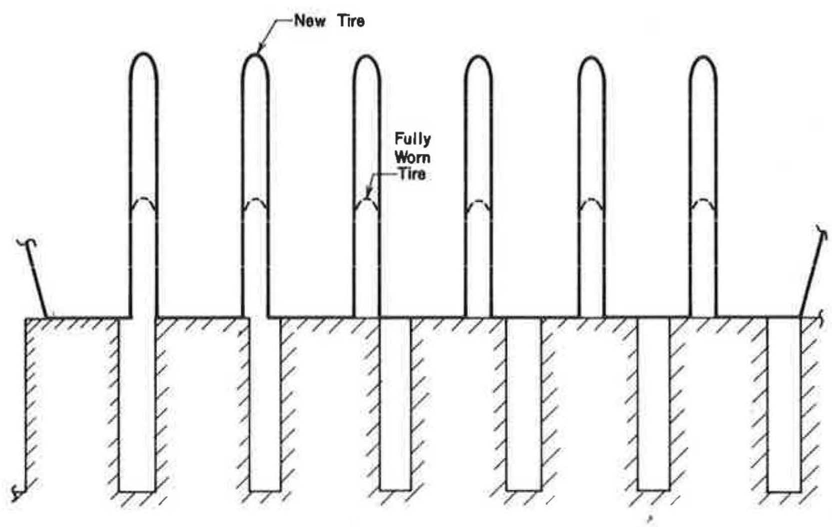


Figure 3. ASTM ribbed test tire on grooved PCC pavement.



parameters as height of the microtexture profile and British pendulum number (BPN). The rate at which the SN decreases with speed decreases with increasing macrotexture parameters such as the height of the macrotexture profiles and sandpatch mean texture depth. Good skid resistance at traffic speeds such as 65 km/h (40 miles/h) requires high levels of both macrotexture and microtexture. The comparisons of the drainage capabilities provided by the test tire and a passenger car tire given in the previous section and the drainage provided by the pavement macrotexture led to the question whether the ribbed tire has sufficient sensitivity to the macrotexture.

BLANK TEST TIRE

The blank test tire specified by ASTM E524 is, except for the absence of the grooves, the same as the E501 ribbed tire. Clearly, its contribution to drainage capability from the tire-pavement interface is zero, and one would therefore expect it to produce data that have a strong dependence on macrotexture for measurements at 65 km/h. The blank tire is an extreme case; actual tires rank between it and the ribbed tire in drainage capability. However, an intermediate test tire--for example, one with shallower grooves--would be impractical, since it would have a very limited useful life. That is, either the grooves must be sufficiently deep so that their

Figure 4. Effects of water-flow rate on skid-resistance measurements (Pennsylvania State nozzle).

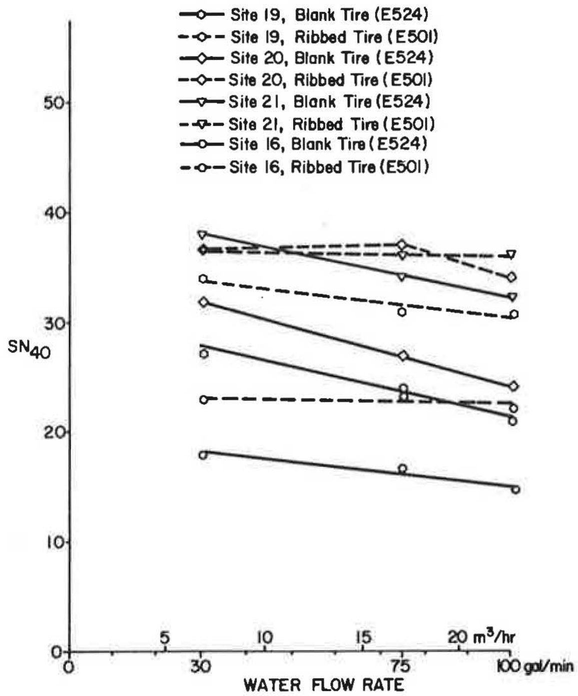
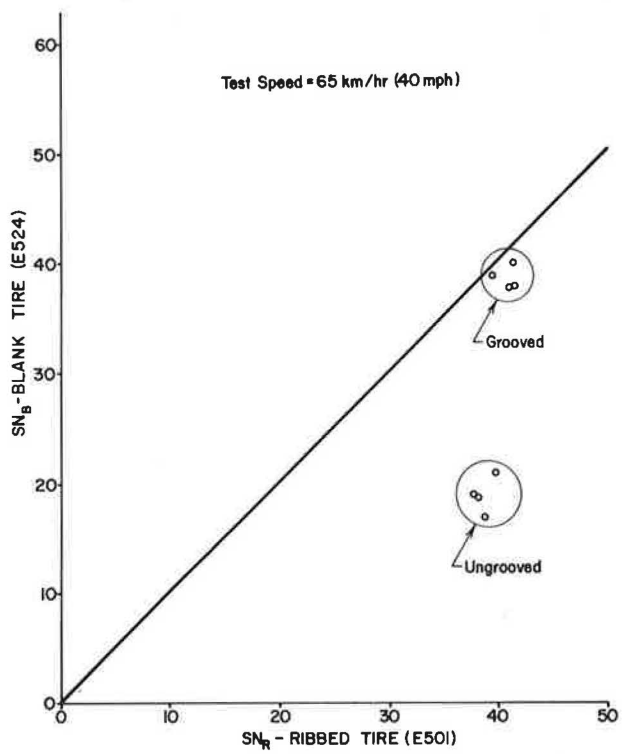


Figure 5. Blank- and ribbed-tire test data on PCC pavement.



depth does not affect the test or they must be absent.

It has been suggested that a disadvantage of the blank tire is that it also is sensitive to the amount of water on the pavement. ASTM E274 specifies water-flow rates that would produce a water-film thickness of 0.5 mm (0.020 in) if all the water were to lie uniformly on the pavement in the tire path. Actual film thicknesses are undoubtedly somewhat less. The ribbed test tire, which has a terminal mean effective tread depth of 0.97 mm (0.038 in), can easily permit the escape of this amount of water or more without a noticeable decrease in friction. Tests were run by using both tires over four pavements and water flow from 6.8 to 22.7 m^3/h (30-100 gal/min); the results are shown in Figure 4. Although the effect of the rate of water delivery to the test tire is pronounced for the blank tire, there is no severe problem if reasonable calibration of the water-flow rate is maintained. At 65 km/h the ribbed tire can accept as much as three times the normal water-flow rate without the data being affected by more than three SNs. The fact that it is insensitive to water-flow rate casts doubt on the validity of the ribbed tire as a means of evaluating pavements for wet-weather safety. It is, however, convenient in that the data are not affected seriously by variations in water delivery caused by poorly calibrated watering systems.

COMPARISON OF SKID TESTING BETWEEN BLANK AND RIBBED TEST TIRES

Data are available from tests that used both the blank and ribbed tires for skid-test programs in Pennsylvania and in Virginia. Early interest in the blank tire for evaluating grooved PCC pavements prompted tests on grooved and ungrooved sections of an Interstate highway (2). All tests were conducted at 65 km/h according to ASTM E274 with the exception that the E524 tire was used for blank-tire testing and is reported as SN_B. All testing was performed on the same day on four sets of grooved and ungrooved pavements. The data are presented below and plotted in Figure 5 (2).

	Grooved		Ungrooved	
Test Site	SN_B	SN_R	SN_B	SN_R
A	38	42	19	38
B	40	42	17	39
C	39	40	19	38
D	38	42	21	40

The measurements indicate a distinct improvement in SN_B as a result of grooving. In fact, there is only a small difference between SN_B and the ribbed-tire data (SN_R) on the grooved sections, which indicates that there is adequate macrotexture in the pavement to provide for drainage.

On the ungrooved sections, the ribbed tire provides adequate drainage and can barely distinguish ungrooved from grooved sections, whereas the blank-tire data clearly demonstrate the lack of macrotexture.

A study in Virginia that used both tires (6) indicates similar results with a wide variety of pavement types, including special surface treatments, tined surfaces, and open-graded and conventional pavements. The data from this study are plotted in Figure 6. Three groups of data are indicated on Figure 6--surfaces described in the text as having "good macrotexture," as having average macrotexture, and as being "smooth." Surfaces on which the pavement provides good drainage lie close to or above the line of equality. The blank tire ranks the pavement into groups according to the qualitative descriptions of their texture.

At Pennsylvania State University in the fall of 1978 and spring of 1979, 22 sites were tested with both tires. Sandpatch data [mean texture depth (MTD) according to the Portland Cement Association method (7)] and British pendulum tests (BPN

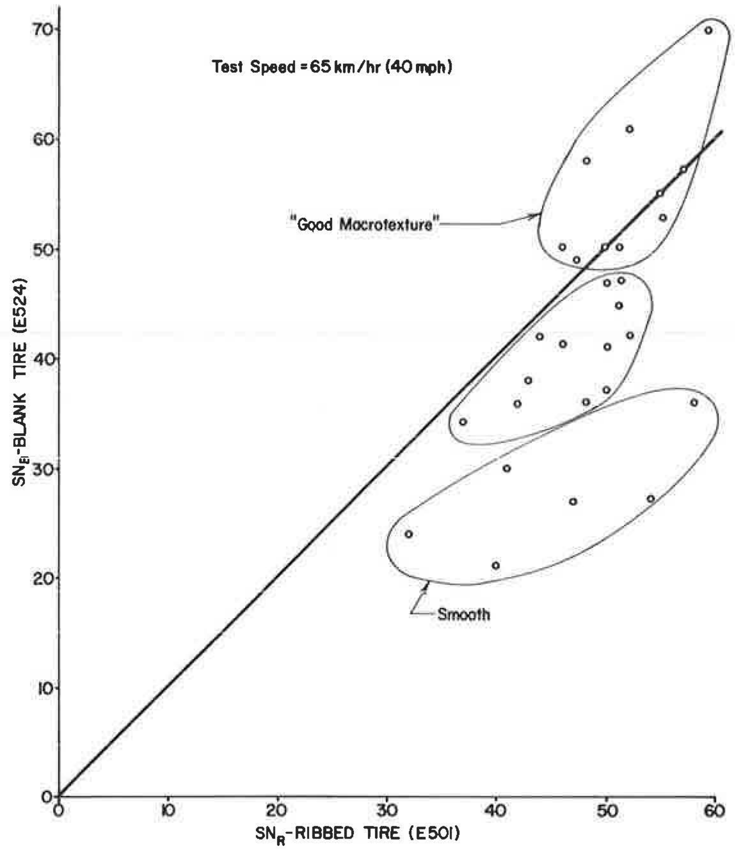


Figure 6. Data from Virginia study by Mahone.

Table 1. Pennsylvania State University data.

Site Characteristics				Fall 1978				Spring 1979			
No.	Year Constructed	Type[a]	ADT	SN_B	SN_R	MTD (milli-in)	BPN	SN_B	SN_R	MTD (milli-in)	BPN
1	1970	DG	6630	22.8	32.4	16	50.7	22.7	31.7	14	46.3
2	1950	PCC	7700	19.0	28.2	14	59.0	14.7	27.4	16	51.7
3	1973	PCC	3640	28.4	49.4	13	69.9	19.7	38.0	15	68.1
4	1972	DG	3640	25.6	39.4	12	58.7	23.3	35.0	13	50.1
5	1976	OG	7700	56.0	53.0	51	86.0	-	-	-	-
6	1976	DG	7700	42.5	52.5	22	81.1	-	-	-	-
7	1973	PCC	1820	27.2	48.5	16	70.4	23.4	40.4	15	64.0
8	1972	DG	1820	44.2	46.2	29	59.3	26.7	32.2	28	52.0
9	1972	DG	1710	46.8	52.2	27	66.0	34.6	43.2	31	56.9
10	1973	PCC	1710	26.2	48.4	14	73.0	22.7	43.2	13	70.1
11	1963	DG	4490	21.6	30.2	14	59.9	18.8	27.3	19	47.8
12	1970	DG	4490	34.8	39.8	40	67.7	31.0	40.6	31	57.6
13	1969	OG	7920	61.4	60.0	41	94.2	60.7	64.5	52	88.7
14	1967	PCC	8770	24.8	37.0	16	63.8	21.4	37.9	18	61.1
15	1969	OG	7920	61.1	62.6	51	96.9	62.2	68.6	54	86.6
16	1966	DG	6500	17.8	25.4	26	55.5	14.7	24.1	23	44.1
17	1961	DG	800	33.0	35.8	40	58.0	29.4	35.4	44	50.0
18	1973	PCC	1200	37.8	50.6	20	69.5	34.0	47.6	21	67.0
19	1968	DG	7000	26.6	37.4	17	63.0	19.5	30.3	20	49.1
20[b]	1968	DG	-	37.5	47.5	21	65.0	25.3	33.6	22	57.0
21	1969	OG	2500	36.6	36.2	49	70.0	32.3	36.2	48	53.2
22	1969	OG	2500	61.4	57.6	55	87.5	56.2	60.2	64	87.7
24	1963	DG	4490	-	-	-	-	14.4	26.1	16	46.2
25	1969	OG	7920	-	-	-	-	40.8	53.8	27	76.7

Note: 1 milli-in = 0.025 mm.
[a]PCC = Portland cement concrete; DG = dense-graded asphalt concrete; OG = open-graded asphalt concrete.
[b]Site 20 is between the wheel tracks at site 19.

according to ASTM E303) were obtained. The data from these tests are given in Table 1. The test in the fall of 1978 and the four tests in the spring of 1979 are treated separately, since the winter affected the texture. Also, sites 5 and 6 were replaced by 24 and 25 in 1979 due to the complete failure of site 5 as a result of snow-removal activities. The data are plotted in Figures 7 and 8, in which the site number, MTD, and BPN (rounded) are indicated for each point.

Examination of Figures 7 and 8 shows that the ribbed tire ranks the pavements more strongly according to microtexture (BPN) than does the blank tire. The blank tire, however, ranks both according

Figure 7. Data from Pennsylvania State study, fall 1978.

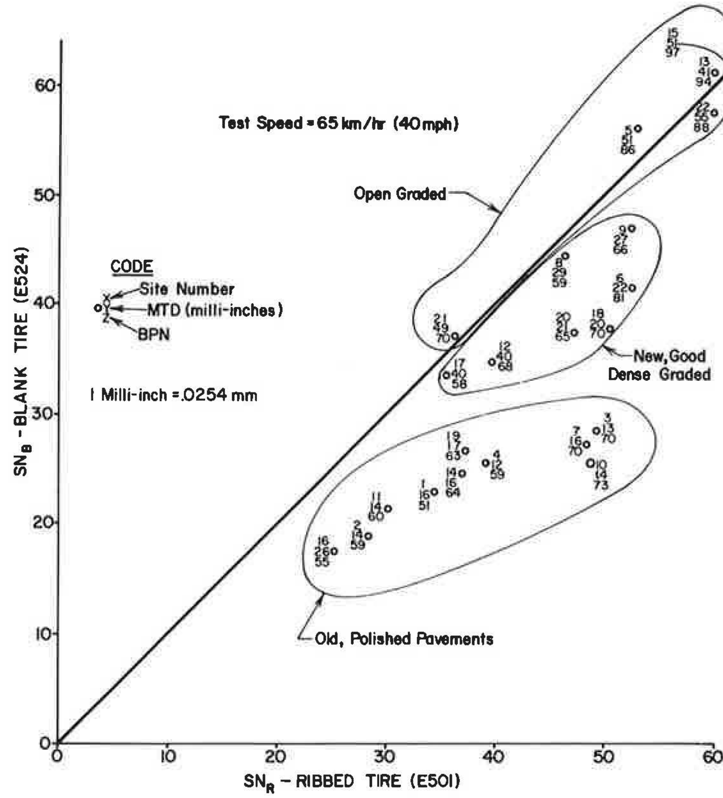
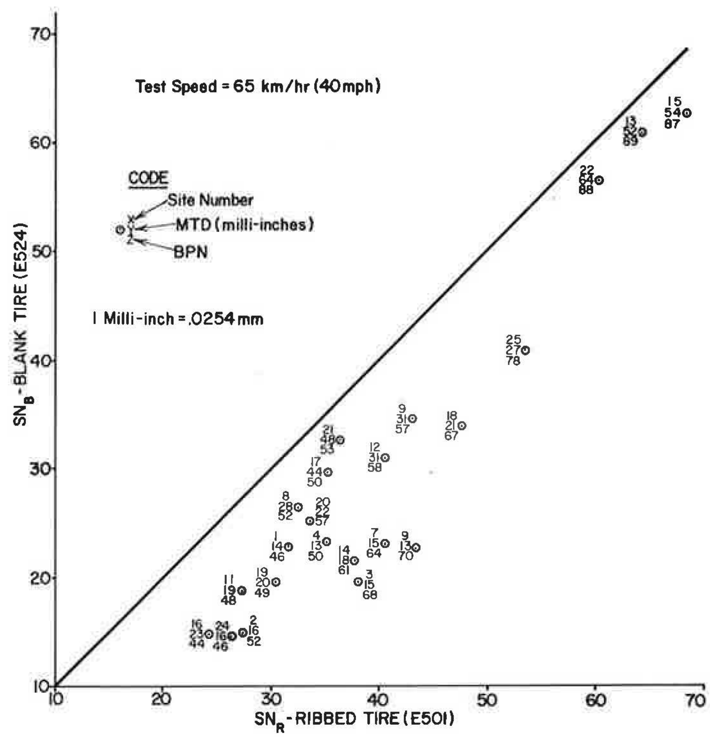


Figure 8. Data from Pennsylvania State study, spring 1979.



to microtexture (BPN) and macrotexture (MTD), whereas the ribbed tire is unable to distinguish differences in macrotexture.

A multiple linear regression was performed on the data in the following form:

$$SN = a_0 + a_1(BPN) + a_2(MTD) \quad (3)$$

Table 2 shows the results of the regression, which summarizes the coefficients (a_1) and the correlation coefficients (R^2). The values of the coefficients are of interest in evaluating the sensitivity of the test tires to microtexture and macrotexture. The coefficient of macrotexture a_2 is small for the ribbed tire and even has a dif-

Table 2. Correlation of skid numbers with texture data.

Test	Tire Data Type	Coefficient a_0	a_1	a_2	R^2
Fall 1978	SN_B	-19.68	0.64	0.41	0.813
	SN_R	-7.83	0.80	-0.12	0.740
Spring 1979	SN_B	-16.87	0.54	0.50	0.906
	SN_R	-9.19	0.74	0.15	0.926

ferent sign for the two data sets. The coefficients a_1 and a_2 for the blank tire are similar in magnitude, which indicates comparable sensitivity to microtexture and macrotexture.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that the ribbed E501 test tire provides a good evaluation of microtexture but is not sensitive to macrotexture, which is felt to be a significant factor in wet-pavement safety. This may account for a lack of correlation between skid-resistance measurements by using the ribbed tire and accident statistics.

Ideally, a pavement skid-resistance survey would be performed by using both the ribbed E501 and the blank E524 tires. By comparing the skid-resistance values from both tires, one can readily estimate the levels of microtexture and macrotexture and assess the cause of poor skid resistance and likelihood of success of corrective action.

In the event that skid-resistance surveys can be performed with one tire only, the blank E524 tire appears to be the stronger candidate. At this writing, no attempts to correlate smooth-tire data with accident frequency are known to me, although in one state some data are reportedly being collected. A study to relate blank-tire data to accident frequency should be conducted to verify this conclusion.

Since this research was initiated, the manufacture of the E524 tire has been suspended due to lack of demand. Preliminary tests indicate that a used E501 tire that has the ribs machined away completely and has been subjected to a 350-km (200-mile) break-in produces results that are in excellent agreement with those of the E524 tire. Such a tire will not have a long useful life but will serve as an interim tire for research until demand for the blank tire increases.

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Seasonal Variations in the Skid Resistance of Pavements in Kentucky

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Frequent measurements of skid resistance were made on 20 pavements in common use in Kentucky from November 1969 through 1973. Principal analysis involved relating changes in skid resistance to day of the year and relating skid resistance to temperature at the time of test, to average antecedent temperatures, and to average rainfall. Seasonal variations exhibited an annual sinusoidal cycle. The changes in sand-asphalt and bituminous concrete surfaces under high volumes of traffic were about 12 skid numbers (SNs). The changes in portland cement concrete (PCC) and bituminous concrete under low volumes of traffic were about 5 SNs. The lowest SN values occurred in early to mid-August for PCC and sand-asphalt pavements and in late August to early September for bituminous concrete. Correlations between changes in SN and temperature were best for ambient air temperature averaged over four- and eight-week periods prior to date of test. However, correlations between changes in SN and temperature were not so good as correlations between SN and day of the year. On the other hand, combining traffic volumes in the form of deviations from yearly average daily traffic with temperature yielded correlations with SN that were as good as correlations between SN and the day of the year. It was concluded that skid-resistance measurements in Kentucky should be conducted between the first of July and the middle of November to assure detection of significant differences in SN. However, frequent testing of reference sections is recommended to define more specifically each year the beginning and ending dates of the testing season.

Laboratory studies of wear and frictional characteristics of aggregates in Kentucky began in 1956, and field testing of pavement surfaces began in 1958. Many variables associated with testing devices, procedures, and methods of test were investigated and led eventually to standardization. From 1958 to 1969, field tests were conducted with an automobile in several modes (1). Testing then was confined mostly to a six-month period from mid-May through mid-November. Also, the greater