Effects of Pavement Contaminants on Skid Resistance

ROGER B. SHAKELY, JOHN JEWETT HENRY, AND ROBERT J. HEINSOHN

It is known from previous research that skid resistance can vary significantly on a daily basis. The cause of this short-term variation may be attributed to external factors such as amount and intensity of rainfall and contamination effects of debris on the road surface. For this study, daily skid-resistance measurements were taken on the road surface according to ASTM E274-77 and a sample of dust and debris was collected from the road surface and analyzed for size distribution. It was found that the major factor that influenced the short-term skid resistance was dust particles in a certain range of sizes found on the road.

Road-surface friction characteristics vary throughout the year due to factors such as pavement polishing or wear, amount of precipitation, and road-surface contamination (1). Each of these factors separately plays an important part in determining the skid resistance of a road surface, but there is also a strong interaction among them that affects pavement friction characteristics.

Pavement polishing increases with traffic density for a given pavement. Polishing alone will lower skid resistance of pavements due to the overall effect of wearing down of the pavement texture. The grinding action between the tire and the road surface creates a very fine abrasive compound made up of tire and road-surface compounds together with ground-up particles of wind-blown soil and debris. These particles may adhere to tires, become airborne as fugitive dust emissions, or remain on the road surface. The particles that remain on the road and in the tire path affect the skid resistance by filling in some of the small asperities. The small asperities that are smaller than 500 μm are defined as the pavement microtexture; those larger than 500 μm are defined as the macrotexture (2). The greater the particle loading in the tire path, the lower the skid resistance at low tire slip speeds. The size of these particles is in the microtexture range of the pavement and they provide a crude form of lubrication on the road surface by preventing good contact between the tire and the pavement at the microtexture level. This is an important factor in skid resistance at tire slip speeds less than 16 km/h (10 miles/h).

The effect of rain on pavement skid resistance has received more attention than the effect of contaminants. The amount of water between the tire and the pavement and how easily it is channeled away has a very significant effect on skid resistance. The action of channeling the water from the tire-pavement contact will produce a cleansing effect on the road surface. This cleansing effect, which washes away the fine aggregate created by the road polishing, will increase the skid resistance of the road surface. It also provides for maximum contact between the tire and actual pavement surface and results in a maximum skid resistance for the road surface.

The objective of this research is to study the effect that unbonded material that lies on the road surface has on the short-term variation of skid resistance and polishing. This research included the design and construction of a device that can be mounted on a moving vehicle that is traveling at a speed of 16 km/h and can remove, collect, and separate according to size unbonded material on the road surface.

SKID-RESISTANCE MEASUREMENTS

The skid resistance of the pavement tested in this study was measured in accordance with ASTM E274-77. This method of test measures the friction force of a vertically loaded test tire that is sliding over the pavement at a constant velocity. The immediate results are expressed as locked-wheel skid numbers (SNs), defined as follows:

$$SN_v = [\text{locked-wheel friction force at velocity (v)/normal load}] \times 100 \qquad (1)$$

A skidding velocity of v = 64 km/h (40 miles/h) is normally used for these tests, and the SN is expressed as SN_{40}. The microtexture of a pavement affects the skid resistance at low tire slip speeds (3). In order to obtain information about the microtexture, it would be necessary to run locked-wheel skid tests at very low speeds, which can create traffic hazards. The method chosen to obtain microtexture information for this study was to measure the skid resistance as the test tire was locked; the resulting slip range was 0 to 64 km/h. The transient portion of the tire lock-up contains the same skid data as would be obtained if separate locked-wheel skid tests were run at specific speeds between 0 and 64 km/h (3). Therefore, the SNs at 16, 32, 48, and 64 km/h were obtained from one transient slip test at 64 km/h. These data points are recorded in Table 1, and a statistical regression analysis was performed on each day of recorded data. The regression program computed a least-squares fit of the four pairs of data points (SN and slip speed) to an exponential function of the following form:

$$SN_v = SN_0 \exp(bV) \qquad (2)$$

where

SN_v = SN at slip speed v,
SN_0 = SN intercept determined by the regression analysis,
b = -PNG/100 percent SN gradient determined by the regression analysis (PNG = percentage of normalized gradient), and
V = slip speed of the test tire.

This is the Pennsylvania State University model (2) for skid resistance; it is used here to determine SN_0, the SN intercept. SN_0 characterizes the skid resistance at low speeds. The correlation coefficient for this curve fit was consistently more than 95 percent. From these results, SN_0 was used to represent the condition of the microtexture of the pavement.

EFFECT OF CONTAMINANTS ON ROAD SURFACE

Contamination of the road surface does have a major effect on skid resistance. The dust and debris that have settled on the pavement change the microtexture by filling the small asperities and thus affect the tire-pavement interaction. The type of contaminants in this size range (known as traffic or surface film) include dust, sand, oil, grease, organic debris, rubber particles, mud, and chemical treatments. All these will affect the condition of the microtexture. A case in point, which further

Table 1. Transient skid-resistance data.

Date	SN_0	SN_{16}	SN_{32}	SN_{48}	SN_{64}	PNG	R^2 (%)
9-21-77	58.7	51.5	45.5	41.0	35.0	1.26	99
9-29-77	53.2	48.6	39.5	35.5	33.0	1.27	97
9-30-77	58.8	51.5	43.0	35.5	33.0	1.53	98
10-3-77	58.5	52.0	43.0	37.0	34.0	1.42	99
10-4-77	53.6	48.0	38.0	34.0	30.5	1.47	98
10-5-77	54.6	48.5	42.5	38.0	33.5	1.22	99
10-7-77	58.6	51.5	46.0	42.0	35.5	1.21	99
10-10-77	53.2	47.0	43.0	39.5	33.5	1.10	99
10-11-77	60.6	53.0	44.5	39.5	34.0	1.45	99
10-12-77	52.5	47.5	41.5	37.0	34.0	1.12	99
10-13-77	52.2	48.5	40.0	37.0	34.5	1.10	97
10-14-77	60.3	54.0	43.0	37.5	34.5	1.48	98
10-17-77	61.4	55.6	47.5	43.0	39.0	1.16	99
10-18-77	59.7	54.5	45.0	40.0	37.5	1.24	97
10-21-77	55.9	51.0	45.0	41.5	37.5	1.00	99
10-24-77	54.5	49.6	47.0	41.5	39.0	0.85	99
10-25-77	54.2	50.0	44.0	39.0	37.5	0.98	98
10-26-77	53.5	50.0	43.0	38.5	37.5	0.97	96
10-28-77	56.7	53.0	44.0	42.0	38.5	1.00	96
10-31-77	56.2	51.0	45.0	41.5	37.0	1.04	99
11-2-77	60.1	55.5	44.5	40.0	38.0	1.24	96
11-14-77	53.7	49.5	43.0	38.5	36.5	1.02	98

demonstrates the effect of debris on the road surface, was noted during the course of this study. Work crews were removing the painted lines on the road by grinding away the painted surface. This grinding action created large quantitites of small particles that spread over the road surface. Results of skid tests at this location gave lower results by 11 SNs compared with results from the rest of the sites on the same road.

The effect of rain observed in this study was to increase the skid resistance of pavements by removing all or portions of the contaminants on the road surface. Road contamination that results from traffic film can significantly reduce the SN of a pavement that has fine asperities only. For example, Kummer and Meyer reported a rise in the SN from 11 to 20 for tests made just before and after a rain preceded by a long dry period (4). Skid tests were made on concrete pavements after a 15.4-mm (0.6-in) rain that was preceded by 20 days with no measurable precipitation. The data showed that the SN_{40} values had increased by a greater percentage on pavements that had the lower values prior to the rain. In general, the SNs obtained after the rain increased from 6 to 18 percent; the 18 percent increase occurred on a pavement that had an initial value of 40 and the 6 percent increase was for pavement that had an initial value of 60 (5). If there is no heavy rainfall to cleanse the road surface, it can become slippery when slightly wet due to the lubricating slurry of the water and dust debris (6).

The amount and frequency of the rain has a great influence on the accumulation of the traffic film, since rain is instrumental in washing it away. Hence, the degree to which the traffic film lowers the antiskid properties of a pavement depends on the period between rainfalls. The shorter the period, the shorter the time the film has to significantly accumulate on the road surface (6).

Dust generation and hence aggregate polishing are caused by tires rolling over the pavement. Motion takes place between the tread rubber and pavement as the tire deforms in the contact patch. In the presence of particles, this leads to the wear and polishing of the pavement. The pavement (particularly exposed aggregate) may become smoother or rougher than it was before, depending on the size and characteristics of the particles. The dust on the road most frequently originates from the pavement itself but may also be blown in from the shoulders or elsewhere.

ROAD VACUUM DEVICE

The design considerations for a vehicle-mounted road-dust collection device were as follows:

1. The vacuum system must be able to pick up unbonded road dust and particles in the wheel track of the road;
2. The system must be mounted on the front of a moving vehicle in order to assure minimum disturbance of the dust in the wheel track, which would otherwise occur if the vehicle were to pass over it;
3. The transportation of the dust particles must be for as short a distance as possible and with a minimum number of turns to reduce settling and impaction;
4. The method of particle collection should enable a quick and accurate analysis of the size distribution of the dust (otherwise the determination of particle size and distribution would have to be performed optically and would consume a considerable amount of time).

These design parameters were considered in the construction of the system shown in Figures 1 and 2.

The dust collector is attached to the front bumper of the Pennsylvania Transportation Institute (PTI) Mark 3 pavement skid tester. A beam hinged at the truck bumper extends down toward the pavement and attaches rigidly to a carriage mechanism. A two-wheeled carriage is used to support the vacuum hood in order to allow the hood to follow the road surface with much greater accuracy than would a system rigidly mounted on the truck. The front of the vacuum hood is attached to the carriage by a system of hinges and the back is supported by a cable that extends down from the beam. The hinges on the front of the hood and the cable in the rear allow the hood to swing up and back in order to prevent damage to the system if it comes in contact with a large stone or other obstacle on the road.

Suction at the hood is provided by a fan connected to the back of the Anderson 2000 high-volume cascade impactor, which serves as the filtration and separation system. The volumetric air-flow rate through the system is regulated by adjusting a Variac connected to the fan. The flow rate is read in the truck by using a rotameter designed for use with the cascade impactor.

The power for the fan is supplied by a 120-V AC generator carried in the back of the truck bed. Compressed air used in the operation of the vacuum hood is supplied by a compressor, which fills a supply tank in the front of the truck. The compressed air is used to aid in the dislodging of particles from the road surface by incorporating an air knife into the design of the hood.

The dust collection was carried out on a daily basis (weather permitting) between September 24 and November 14, 1977. The collections were made in the early afternoon on the same inside wheel track on a 545-m (1800-ft) section of dense-graded asphalt concrete pavement that contained limestone coarse aggregate. By collecting dust at two skid sites daily, the average road dust and skid resistance for the section of road was determined.

EXPERIMENTAL RESULTS AND INTERPRETATION

Location of Test Site

The location of the 545-m test site was a rural road. The dust accumulation on it should be representative of that generated solely by traffic. The area that surrounded the test section was covered with vegetation, and there was little exposed soil that could be blown onto the road by wind erosion. The amount of road dust collected is given in Table 2. Figure 3 gives the rainfall and skid-resistance data that were recorded from April 20 through December 1, 1977. Road-dust collection was carried out between September 24 and November 24, 1977. The average daily traffic count on PA-45 during this time was 775 cars.

Figure 1. Skid tester and dust-collection system.

Figure 2. Dust-collection system.

Correlation Between Road Dust and Skid Resistance

The pavement friction of the test site varied on a daily basis. The reason for this variation can be explained to some degree by the quantity of dust in the tire path. The values used to represent the pavement skid resistance are the SN_0 values, which characterize the skid resistance at low speeds. SN_0 is an indicator of the condition of the microtexture of the pavement, since the low-speed skid resistance is dependent on the microtexture of the pavement (2). The mass mean diameter of all the particles collected, except those in the preseparator (which collected particles larger than 50 μm) is 5 μm. This would affect the microtexture of the pavement (asperities smaller than 500 μm) more than the macrotexture (asperities larger than 500 μm).

Dust loading of the sample that contained particles 7.0-50.0 μm in size and SN_0 versus the date of collection is illustrated in Figure 4. This plot gives an indication of the interaction between the dust on the road and skid resistance on a daily basis. This interaction is an inverse relationship between the amount of dust and the SN. A linear regression analysis was conducted to determine the correlation between the amount of dust in the wheel track and the skid resistance. Different combinations of dust size and quantity were regressed against the SN_0 value for each day. The particles collected in the preseparator were not included in the analysis because of their large size and small amount. Table 3 gives the results of this analysis.

The highest correlation between road dust and skid resistance was found for particles in the size range 7.0-50.0 μm. The linear regression equation that relates SN_0 to grams per square meter of the dust sample of 7.0-50.0 μm from the test section is as follows:

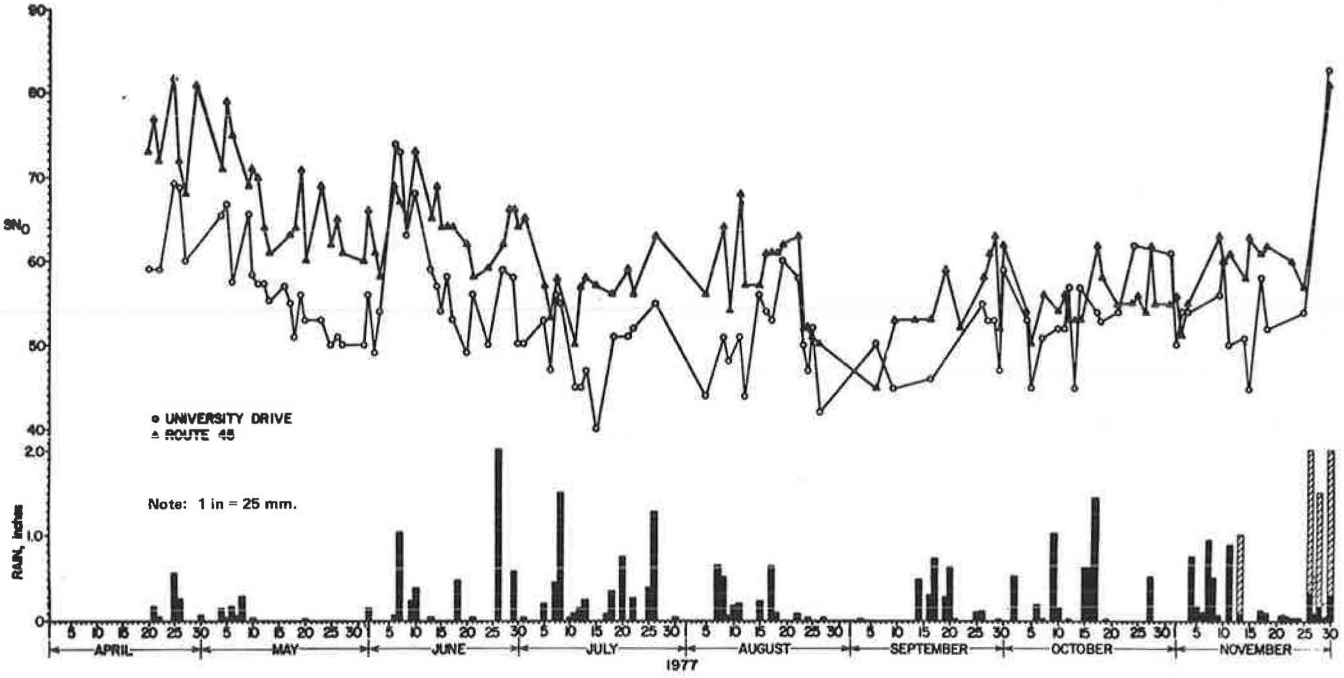
$$SN_0 = 60.99 - 951.0M1 \qquad (3)$$

where M1 is the dust loading in grams per square meter of the 7.0- to 50.0-μm dust sample collected at the test site. This equation results in a correlation coefficient of 60.1 percent.

Table 2. Mass loading per square meter for various sizes of dust particles collected along test section.

	Mass Loading (mg/m²) by Particle Size					
Date	Larger than 50 μm	7.0-50.0 μm	3.3-7.0 μm	2.0-3.3 μm	1.1-2.0 μm	Smaller than 1.1 μm
9-21-77	0.00	3.11	1.07	0.987	0.251	0.746
9-29-77	0.00	5.27	1.77	1.22	0.248	2.190
9-30-77	0.00	4.13	2.01	1.20	0.377	1.260
10-3-77	9.69	3.63	1.17	0.890	0.240	0.990
10-4-77	18.60	5.01	1.72	0.908	0.309	1.550
10-5-77	11.20	4.38	1.29	0.807	0.262	0.983
10-7-77	18.80	3.73	1.19	0.753	0.208	1.050
10-10-77	55.40	6.80	1.66	1.380	0.344	1.480
10-11-77	17.60	1.75	8.79	0.513	0.118	0.563
10-12-77	53.10	6.48	1.92	0.954	0.330	1.350
10-13-77	25.00	5.51	1.88	1.190	0.488	1.030
10-14-77	6.75	2.38	9.66	0.786	0.319	0.398
10-17-77	11.50	1.79	1.14	0.585	0.258	0.879
10-18-77	16.20	1.84	1.07	0.653	0.488	0.825
10-21-77	21.60	4.52	5.42	1.190	0.366	1.170
10-24-77	36.40	8.56	2.97	1.880	1.170	2.090
10-25-77	28.10	9.10	2.88	1.790	0.535	1.850
10-26-77	17.40	7.65	2.63	1.630	0.380	1.140
10-28-77	8.93	2.95	1.14	0.657	0.240	0.474
10-31-77	7.00	3.90	1.76	0.807	0.337	0.527
11-2-77	7.57	3.24	7.82	0.470	0.097	0.377
11-14-77	16.90	10.60	3.26	1.730	0.484	1.830

Figure 3. SN_0 for PA-45 and University Drive versus date and rainfall.



Note: 1 in = 25 mm.

Figure 4. Dust loading of dust sample 7.0-50.0 μm and SN_0 versus date of collection.

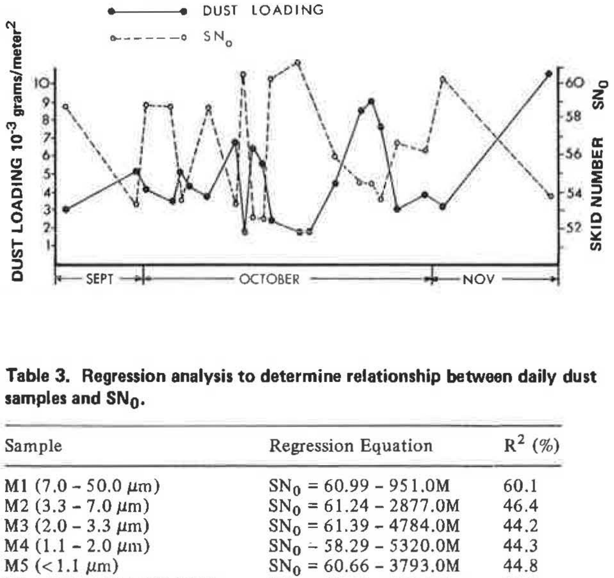


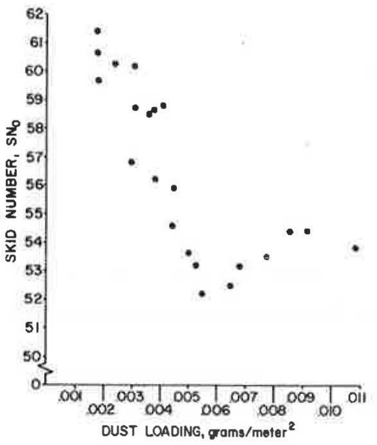
Table 3. Regression analysis to determine relationship between daily dust samples and SN_0.

Sample	Regression Equation	R^2 (%)
M1 (7.0 - 50.0 μm)	$SN_0 = 60.99 - 951.0M$	60.1
M2 (3.3 - 7.0 μm)	$SN_0 = 61.24 - 2877.0M$	46.4
M3 (2.0 - 3.3 μm)	$SN_0 = 61.39 - 4784.0M$	44.2
M4 (1.1 - 2.0 μm)	$SN_0 = 58.29 - 5320.0M$	44.3
M5 (<1.1 μm)	$SN_0 = 60.66 - 3793.0M$	44.8
M1 + M2 + M3 + M4 + M5	$SN_0 = 61.45 - 558.0M$	57.6
M1 + M2 + M3 + M4	$SN_0 = 61.29 - 619.0M$	56.4
M1 + M2 + M3	$SN_0 = 61.30 - 649.0M$	57.4
M1 + M2	$SN_0 = 61.18 - 735.0M$	58.2

Notes: 1 km/h = 0.6 mile/h.
SN_0 = SN at 0 km/h as determined by an exponential curve fit to a transient SN analysis.
M = dust loading in grams per square meter of dust collected in a particular size range.

A plot of SN_0 versus the loading of the dust sample of 7.0- to 50.0-μm collected between September and November is shown in Figure 5. It is interesting to note the maximum loadings of dust collected on the test section, which are in the range of 0.007-0.011 g/m². In this range, the straight-line relationship changes for loadings greater than 0.007 g/m². This could be due to an effective saturation of the microtexture by the dust. That is, increased dust loadings may have no significant effect on the SN_0 values of the pavement. Examination of the SN_0 data from August through November indicates that only once did the SN_0 value for the test site drop below 50. This may indicate that other factors that limit SN_0 begin to take effect and dust loading loses its effect.

Figure 5. SN_0 versus dust loading of dust samples 7.0-50.0 μm.



A regression analysis performed on the loadings of dust collected in the 7.0- to 50.0-μm range (leaving out the four points whose loadings are larger than 0.007 g/m²) results in an equation that fits the remaining data with an 82 percent correlation coefficient:

$$SN_0 = 64.21 - 1862.0M1 \quad (4)$$

From this study and a review of the 1977 SN_0

Table 4. BPN values from pavement before and after cleaning.

		BPN Values							
		Contaminated Pavement				Cleaned Pavement			
Location	Test No.	Trial 1	Trial 2	Trial 3	Avg	Trial 1	Trial 2	Trial 3	Avg
Asphalt parking lot	1	83	83	83	83.0	86	87	86	86.3
	2	69	69	69	69.0	73	72	72	72.3
	3	69	67	67	67.7	70	72	70	70.7
Avg					73.2				76.43
PA-45	1	57	57	57	57.0	61	60	60	60.3
	2	60	61	61	60.7	65	64	62	63.7
	3	67	67	68	67.3	75	74	74	74.3
	4	71	71	70	70.6	76	78	76	76.7
	5	61	61	60	60.6	67	67	66	66.7
	6	64	63	63	63.3	65	66	65	65.3
Avg					63.3				67.8

Figure 6. BPN values from surfaces before and after cleaning.

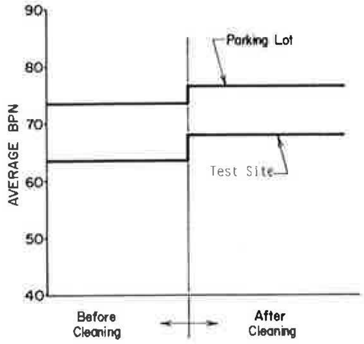
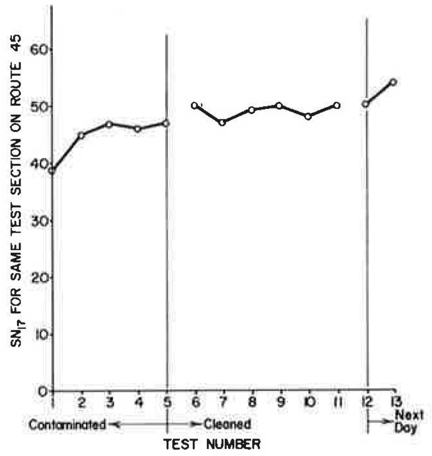


Figure 7. SN_{17} from contaminated and cleaned section of the test site.



data in Table 1, it appears that a dust loading greater than 0.007 g/m² will result in no further effect on the SN_0 value for the test section.

Verification of Interaction Between Dust and Low-Speed Skid Resistance

It has been postulated that one cause of daily variation of skid resistance at low speeds is the changing contamination levels on the road surface. An attempt was made to verify this by conducting a series of tests to specifically verify interaction between low-speed skid resistance and dust loading on a pavement surface.

The first of these tests used a British pendulum tester, which measures the low-speed skid resistance. The procedure followed the one specified in ASTM E303 except that the pavement surface was not cleaned for the first portion of the test. British pendulum tests were run on the contaminated pavement and the British-pendulum-number (BPN) values for the three trials were recorded. Next, the same location on the pavement was scrubbed to remove the contaminants, and the BPN values for the three trials were recorded. The results of these tests indicated an average rise in the BPN values of 3.2 for the three tests in the asphalt parking lot and an average increase of 4.5 in BPN values for the six tests taken on PA-45. BPN values before and after cleaning are shown in Figure 6 and Table 4. Both groups of tests show a significant and consistant increase in the low-speed skid resistance of the surfaces.

A second test was run at the test site with the PTI Mark 3 skid tester. A series of five skid tests was run at the same location at the test site at a speed of 27 km/h (17 miles/h). After these five skid tests, that section of pavement was scrubbed three times by using water and a stiff broom in order to remove the contaminants in the wheel track. Six more 27-km/h skid tests were run on the cleaned section of road to check for any change in skid resistance. Two more 27-km/h skid tests were run the next morning after a heavy rain that occurred the evening of the day the road was scrubbed.

The results of this test also indicate a significant rise in SN_{17}. An average rise in SN_{17} of 2.8 resulted in the data taken before and after scrubbing. A plot of SN_{17} on pavement before and after it was scrubbed is shown in Figure 7. SN_{17} is a less-sensitive indicator of low-speed skid resistance than SN_0, but it clearly indicates that the cleaning of dirt from the wheel track will result in increasing the track's low-speed skid resistance.

CONCLUSIONS

The skid resistance of a surface will vary due to many factors. These include the type of surface being tested, the contaminants on the surface, and the speed at which the test takes place. This study was limited to one road surface. It resulted in a straight-line relationship between SN_0 and dust loading up to a point at which it appears that the further increase in dust loading has no further effect on the reduction of the SN_0 values.

That dust has an effect on low-speed skid resistance was proved by the British pendulum tests made on several contaminated and cleaned surfaces.

Skid tests on contaminated and cleaned sections of pavement also verified these results.

Particles smaller than 7 μm appear to have no significant effect on the SN_0 values for the surfaces used in this study. A collection system that separates particles out in stages from 10 μm to 500 μm would be more useful in determining relationships between SN_0 and dust loadings.

REFERENCES

1. J. M. Rice. Seasonal Variation in Pavement Skid Resistance. Public Roads, Vol. 40, March 1977.
2. M. C. Leu. The Relationship Between Skidding Resistance and Pavement Texture. Pennsylvania State Univ., University Park, Automotive Res. Program Rept. S78, 1977.
3. V. Shah. Relationship of Locked-Wheel Friction to That of Other Test Modes. Pennsylvania State Univ., University Park, Pennsylvania Department of Transportation Project 72-7, Final Rept., 1977.
4. H. W. Kummer and W. E. Meyer. Rubber and Tire Friction. Department of Mechanical Engineering, Pennsylvania State Univ., Automotive Safety Project, Engineering Res. Bull. B-80, 1960.
5. B. E. Colley, A. P. Christensen, and W. V. Nowlen. Factors Affecting Skid Resistance and Safety of Concrete Pavements. HRB, Special Rept. 101, 1969.
6. K. C. Ludema. An Analysis of the Literature on Tire-Road Skid Resistance. Mechanical Engineering Department, Univ. of Michigan, Ann Arbor, 1973.

Recent Developments in Pavement Texture Research

G. G. BALMER AND R. R. HEGMON

This paper summarizes the state of the art of research on pavement texture, which has intensified during the last few years. The importance of texture for increased safety on wet roads has been established. The distinct contributions of microtexture and macrotexture to friction between tire and pavement are shown, and methods being developed for providing and maintaining adequate texture are discussed. Research now in progress both on improving methods of texture measurement and on developing models for predicting skid resistance and gradients of skid resistance and speed from texture measurements is described.

Effective pavement texture is essential for safer wet-weather highway travel. The fine features (microtexture) furnish a gritty surface to penetrate the thin water films and produce skid resistance through good adhesion between the tire and pavement surfaces. The coarse features (macrotexture) provide drainage channels for water expulsion between the tire and the roadway. This allows better tire contact with the pavement to improve skid resistance and mitigate hydroplaning (1,2). It yields a flatter gradient of wet-pavement skid resistance and speed that helps sustain good friction for high-speed traffic, because the water can escape faster through a coarser texture. A knobby or coarse-textured surface also causes larger rubber deformations, which result in hysteresis losses in the tire. These increase the tire friction characteristics.

Furthermore, it has been shown that the wet-pavement accident rate decreases as skid resistance increases (3). Thus, effective pavement texture is an important factor in traffic safety.

TEXTURE CLASSES AND FUNCTIONS

The fine features of a pavement surface are distinguished from the coarse features because of the different influences of these parameters on interactions between tire and pavement.

The microtexture contributes to skid resistance at all speeds, and it is the prevailing influence at speeds less than 50 km/h (31 miles/h). In contrast, the macrotexture is less important at low speeds, but a coarse macrotexture is essential for safer high-speed travel on wet pavements. Average texture depths of 0.5 mm (0.02 in) and less can be classified as microtexture and those larger as macrotexture.

TEXTURE CHARACTERISTICS

The pavement microtexture develops skid resistance through adhesion between the tire and the roadway. The sharp, fine particles (asperities) in the surface penetrate the thin water films and thus permit an intimate contact between the tire and the roadway. Microtexture depends largely on the mineral composition and the rugosity of the aggregates. The fine, hard grains in the coarse aggregates or fine aggregates bonded in the surface of the pavement provide the microtexture.

Ideally, aggregates for bituminous concrete should be composed of hard, coarse, angular minerals well bonded into a softer matrix so that gradual differential wear will occur (4).

Pavement macrotexture can be obtained by controlling the gradation (5,6) of the surface aggregates in a bituminous mixture such as the open-graded asphalt friction course. The surface aggregates must not polish readily if enduring skid resistance is to be maintained. Figure 1 (from the Texas Transportation Institute) is a photograph of a newly placed open-graded asphalt friction course. The coarse texture is visible in the foreground. Chip-seal surface treatments also produce a coarse macrotexture; however, these surfaces have a limited life because of the rapid erosion of the surface aggregates by traffic and weathering.

The macrotexture for portland cement concrete (PCC) pavement is produced by the finishing techniques (1). Excellent texture can be obtained by using steel tines (Figure 2). (Figures 2-4 are from experimentation by the Georgia State Department of Transportation.) In this photograph alternate tines have been bent upward to increase the spacing between tines. Steel tines (rakes or combs, as they are sometimes called) can be incorporated into the paving train to produce striations in the plastic