

# Macrotexture Measurements and Related Skid Resistance at Speeds From 20 to 60 Miles per Hour

JERRY G. ROSE and BOB M. GALLAWAY, Texas Transportation Institute,  
Texas A&M University; and  
KENNETH D. HANKINS, Texas Highway Department

The role of macrotexture in imparting friction capabilities to pavement surfaces is of major concern to researchers. Macrotexture is but one of the many variables affecting the interaction at the tire-pavement interface; however, at present its relative importance is questioned. Friction tests obtained at 20, 40, and 60 mph with the Texas Highway Department research skid trailer and macrotexture tests utilizing 4 different methods were conducted on 41 pavement surfaces. These surfaces exhibited widely different friction levels, friction-speed gradients, drainage capabilities, mineralogical properties, and texture classifications. Macrotexture values obtained with the 4 methods are compared. The effects of macrotexture types and magnitudes on friction numbers and friction-speed gradients are analyzed. Statistical analyses and typical plots are given. Brief descriptions of several macrotexture measurement methods that have or are being used by various agencies in the United States and other countries are presented. For the treaded-tire and 0.020-in. water-film thicknesses used in this study, macrotexture was found to have little effect on friction level, but did appreciably influence the percentage decrease in friction with speed.

• **FRICITION** properties of pavement surfaces have become factors of major importance to the overall traffic safety problem. Although friction measurements of the tire-pavement combination are considered acceptable for evaluating the skid-resistant properties of pavement surfaces, attempts are being made to characterize the skid-resistant properties in qualitative manners, such as macrotexture, drainage characteristics of the surface and aggregate size, shape, microtexture, and mineralogy. Most of these qualitative tests are not convenient survey measures; however, a basic understanding of the relative effects of the measured factors on pavement friction is a necessity in order to more fully understand the interaction at the tire-pavement interface and, thus, to enable the designer to understand the need for these desirable properties in the pavement surface.

Several researchers have indicated that the type and magnitude of texture are important characteristics of pavement surfaces with respect to friction properties (12, 13, 22, 23). Pavement-surface texture refers to the distribution and the geometrical configuration of the individual surface aggregates. There is not sufficient agreement among the various researchers to adopt a standard nomenclature for discussing textural parameters. However, general practice today favors the use of the terms (a) macroscopic texture (macrotexture) to refer to that part of the pavement surface as a whole or the large-scale texture caused by the size and shape of the surface aggregate and (b) microscopic texture (microtexture) to refer to the fine-scaled roughness contributed by individual small asperities on the individual aggregate particles.

The researchers have conflicting claims on the relative merits of macrotexture and microtexture. Some contend that a high level of macrotexture is essential to provide the pavement drainage at high speeds (24), whereas microtexture is the main texture contributor for a given friction level. Still others believe that a combination of both macrotexture and microtexture is most desirable (13, 21).

Kummer and Meyer (13) proposed the classification shown in Figure 1, which delineates the 2 roughness types that affect the friction of pavement surfaces. Although 5 surface types are classified, only 3 levels of macrotexture, i.e., smooth, fine, and coarse, are identified because types 2 and 3 and types 4 and 5 respectively are the same as far as macrotexture level is concerned. Thus, a given level of macrotexture as measured by the majority of existing test methods does not appear to adequately assess the degree of roundness or grittiness the individual aggregates possess. It is the authors' opinions that this fact is the main contributor to the low coefficients of correlation between friction parameters and macrotexture obtained in this study.

Macrotexture and microtexture respectively provide for gross surface drainage and subsequent puncturing of the water film. Another factor that acts in combination with macrotexture and microtexture is internal drainage of the pavement surface itself. Goodwin (19), Hutchinson (20), and Gallaway (21), among others, have postulated that high void content surfaces, porous pavements, or vesicular aggregates would provide internal escape paths for water under a tire and thus lessen hydrodynamic pressure buildup. This would result in better tire-gripping capability and increased traction, particularly at higher speeds, while decreasing the need of macrotexture for providing initial, gross drainage. Research directed toward measuring dynamic drainage capabilities of pavement surfaces is in the development stage (20). The authors believe that the combined effects of macrotexture and microtexture and internal drainage largely

determine the friction levels of pavement surfaces. In this paper only the effects of macrotexture are examined.

Various agencies in the United States and other countries are engaged in developing methods for measuring pavement-surface macrotexture in order to more fully evaluate its role in vehicle braking, cornering, and accelerating maneuvers.

Methods that have been or are being used include the sand patch (1), NASA grease (2), drainage meter (3), foil piercing (4), linear traverse (5), stereophotographic (6), casting or molding (7), impression (8), centrifuge kerosene equivalent (9), wear and roughness meter (10), mineralogical studies and profilograph (11), and photo interpretation (12). Descriptions of 4 additional methods used in this research are given in the equipment discussion.

The phase of the research reported here had the following 3 objectives:

1. Analyze and compare different methods for measuring pavement surface macrotexture (both volumetric and mechanical roughness detector methods were used for assessing macrotexture levels);

2. Determine effects of macrotexture types and magnitudes on friction numbers and friction-speed gradients of various pavement surface types; and

3. Survey normal range of macrotexture existing on Texas pavements for use in a

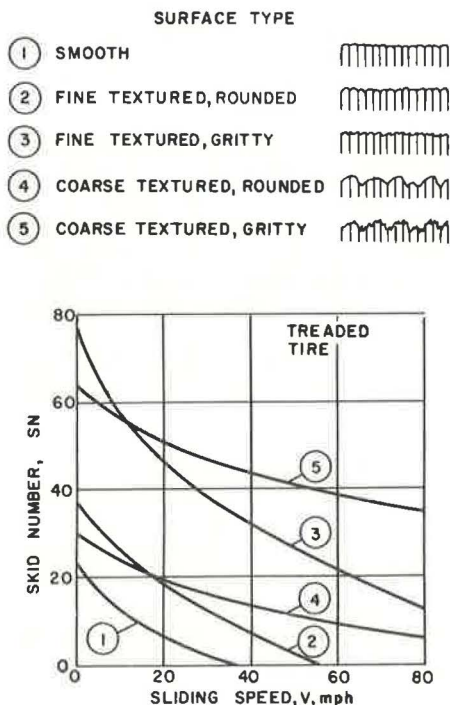


Figure 1. Classification of pavement surfaces according to their friction and drainage properties (13).



subsequent study of the effects of variable macrotexture on water depth buildup for various levels of pavement cross slopes and rainfall intensities.

### TEST EQUIPMENT

#### Skid Test Trailer

The friction measurements reported here were obtained with the Texas Highway Department research skid trailer that conforms substantially to ASTM standards and utilizes E-17 treaded tires inflated to 24 psi. The drag forces were measured with strain gages, and the self-watering system utilized a centrifugal pump that applied a water film approximately 0.020 in. in thickness to the pavement surface. The development and calibration of the trailer may be reviewed in an earlier research report (14). Figure 2 shows the trailer under test conditions.

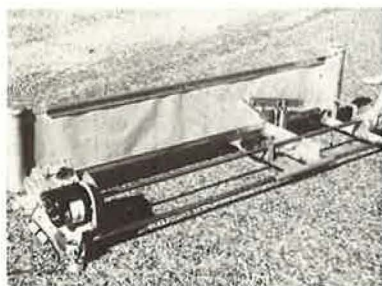


Figure 2. Texas Highway Department research skid trailer.

#### Macrotexture Measurements

Four methods were used to obtain 5 measures of macrotexture. Equipment used for these are shown in Figure 3. Two measures of average peak height and 2 measures of average texture depth were obtained, and these measurements were reduced to equivalent units. Also, one measure of accumulative peak height was obtained. Information on the methods is given in Table 1, and each is briefly described in the following.

**Profilograph**—The instrument used for this test was developed by the Texas Highway Department (15). It is designed to scribe a magnified profile of the surface texture as a probe is drawn across the surface. That is, the probe is placed on the pavement



profilograph



texturemeter



modified sand patch



putty impression

Figure 3. Equipment used for macrotexture tests.

surface and, as the probe is drawn over the surface irregularities, the vertical movement of the probe is magnified through a linkage system. The probe and linkage system are attached to a carriage that is forced to move in a horizontal manner parallel to the pavement surface by a framework with adjustable legs. The vertical and horizontal movement results in a duplicated (but magnified) texture profile that is scribed on a chart. Average peak height can then be determined. Also, the upward vertical excursions are recorded on a counter of which the counter reading, at any time, is the cumulative vertical peak heights (referenced to a median line in the surface) of the texture through the length traversed by the probe.

**Texturemeter**—The instrument, developed at the Texas Transportation Institute (16) and used previously for macrotexture tests (17), consists essentially of a series of evenly spaced, parallel rods mounted in a frame. The rods can be moved vertically, independently of one another, against spring pressure. At either end of the series of movable rods is a fixed rod rigidly attached to the frame. Each movable rod is pierced by a hole through which passes a taut string, one end of which is fixed to the frame and the other to the spring-loaded stem of a 0.001-in. dial gage mounted on the frame. When the instrument is in use, the rods are held in a vertical position with their ends resting against the pavement surface. If the surface is smooth, the string will form a straight line and the dial will read zero. Any irregularities in the surface will cause the string to form a zig-zag line and will result in a dial reading; the coarser the pavement texture is, the larger the dial reading will be. Average peak height can be calculated from the dial reading. The readings given by an instrument of this kind are affected by the size and spacing of the rods and the distance spanned by these rods. For the texturemeter used, the rods are spaced at  $\frac{5}{8}$  in., and the instrument spans a distance of 10 in. between fixed supports.

**Modified Sand Patch**—This method was modified slightly from that developed by the British (1). Equipment consists of (a) a 6.15- by 4.60-in. rectangular metal plate  $\frac{1}{8}$  in. thick with a 4.35- by 2.90-in. center hole and a 2-in. wide  $\frac{1}{16}$ -in. thick collar or free board; (b) 100 grams of a fine-grained sand; and (c) a 4-in. long straightedge. The technique involves determining the increase in the volume of sand required to fill the metal plate cavity when placed on a textured surface above the volume required to fill the cavity when placed on a nontextured surface. If the plate is placed on a textured surface, the bottom of the plate will rest on the upper aggregate asperities. The more irregular the surface texture is, the larger the resulting weight of sand required to fill the cavity will be. The average texture depth is defined as the ratio of the increased volume of sand to the area of the patch.

**Putty Impression**—This method was initially developed as a means of providing surface texture correction factors for nuclear density measurements (18). Equipment consists of (a) a 6-in. wide by 1-in. thick metal plate with a 4-in. wide by  $\frac{1}{16}$ -in. deep recess machined into one side, and (b) a 15.90-gram ball of silicone putty. When placed on a smooth surface, 15.90 grams of putty will smooth out to a circle 4 in. wide by  $\frac{1}{16}$  in. deep, thus completely filling the recess. The silicone putty is formed into an approximate sphere and placed on the pavement surface. The recess in the plate is centered over the putty, and the plate is pressed down in firm contact with the road surface. The more irregular the surface texture is (the higher the macrotexture), the smaller the resulting putty diameter will be because more material is required to fill the surface texture. Average texture depth, based on volume per unit area, is calculated from an average of 4 diameter measurements.

TABLE 1  
METHODS USED FOR MACROTEXTURE TESTS

Method	Measure (in.)
Profilograph	Average peak height
Profilograph	Accumulative peak height
Texturemeter	Average peak height
Modified sand patch	Average texture depth
Putty impression	Average texture depth

## SURFACE TYPES

Forty-one pavement surfaces were tested including 21 hot-mix asphalt concrete surfaces, 9 portland cement concrete surfaces, 9 surface treatments, and 2 seal coats.



The term surface as used in this paper is defined as a section of pavement on which the wearing course is essentially identical over the entire length under study. These test surfaces were selected with regard to level of service, degree of polish, and traffic volume. In addition, it was planned for the test sample to include at least 10 surfaces from each major service category of the Texas Highway System. The array of surface types selected included the various configurations of mineralogical types and aggregate sizes commonly used in Texas. Tests were also made on new surface designs, which are not widely used at present but for which increased use is envisioned for the future. Information and summary data for the surfaces are given in Tables 2 and 3. Skid number-speed curves are shown in Figures 4, 5, and 6. Differences in skid numbers found on the 41 pavements are evident from these data. The surfaces were classified with respect to the type of coarse aggregate contained. Lightweight aggregate implies an expanded clay or shale.

### TEST PROCEDURE

A series of 20-, 40-, and 60-mph skid tests were conducted at 4 locations on each test surface. Ten texture measurements were taken at each location for a total of 40 measurements per surface. All measurements were made in the outer wheelpath.

Average skid numbers at 20, 40, and 60 mph respectively with appropriate temperature corrections were calculated for each test surface. In addition, for use in subsequent comparisons, average skid numbers between 20 and 60 mph were calculated. Provided abrupt slope changes in the skid number-speed curve do not occur, the average skid number is very nearly equal to the skid number at 40 mph. Calculations are shown in Figure 7.

Gradients (denoted by  $G$ ) of the skid number-speed curve between 20 and 60 mph and between 20 and 40 mph were calculated. These have been used in previous reports. In addition, in order to reflect the relative position of the curve, percentage gradients were calculated. Curves of a given gradient positioned low on the graph would have higher percentage gradients than curves with the same gradient positioned high on the graph. Thus,

TABLE 2  
CLASSIFICATION OF TEST SURFACES

Surface and Aggregate	Number Tested
Hot-mix asphalt concrete	21
Lignite boiler slag aggregate	3
Rounded siliceous gravel	4
Crushed limestone aggregate	4
Crushed siliceous gravel	4
Crushed sandstone aggregate	3
Lightweight aggregate	3
Portland cement concrete	9
Rounded siliceous gravel	5
Crushed limestone aggregate	3
Rounded siliceous gravel and crushed sandstone aggregate mixture	1
Surface treatment and seal coat	11
Rounded siliceous gravel	2
Crushed limestone aggregate	4
Lightweight aggregate	3
Flushed bituminous seal	2

TABLE 3  
SKID NUMBER AND MACROTEXTURE VALUES

Surface	Number Tested	Skid Number Range at 40 mph	Macrotexture Range (in.)
Hot-mix asphalt concrete	21	29-59	0.01-0.04
Portland cement concrete	9	36-45	0.01-0.04
Surface treatment	9	29-65	0.02-0.07
Seal coat	2	18-27	0.00-0.01

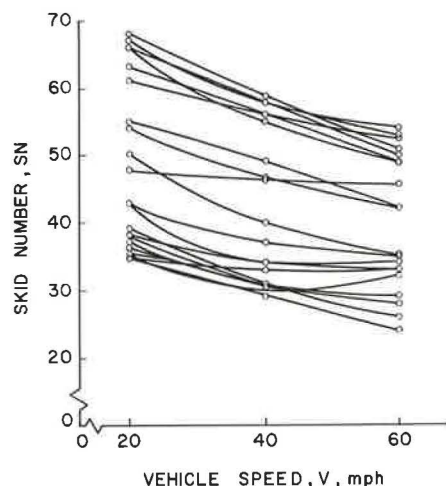


Figure 4. Skid number-speed relationships for hot-mix asphalt concrete surfaces.

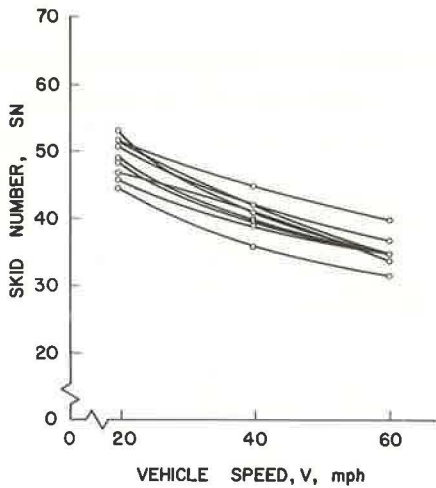


Figure 5. Skid number-speed relationships for portland cement concrete surfaces.

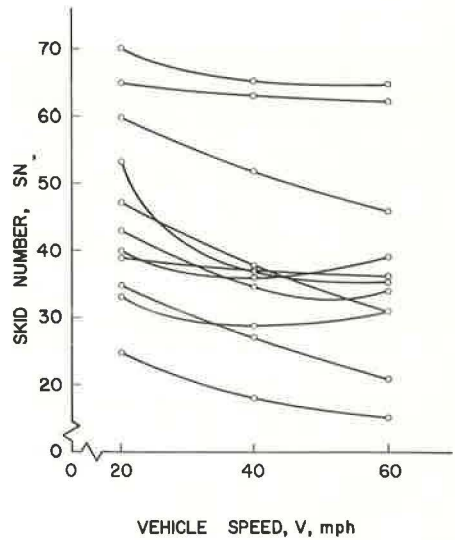
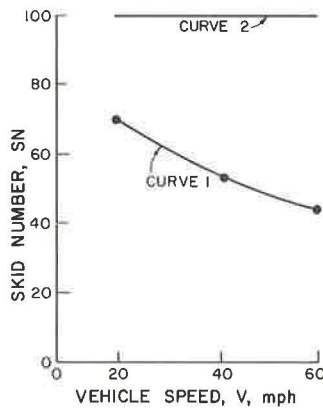


Figure 6. Skid number-speed relationships for surface treatments and seal coats.

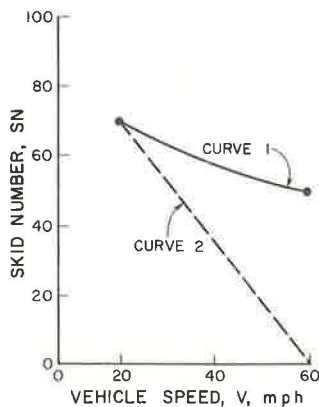


$$\text{AVERAGE SKID NUMBER } A_V \text{SN} = \frac{\text{AREA UNDER CURVE 1 (A}_1\text{)}}{\text{AREA UNDER CURVE 2 (A}_2\text{)}} \times 100$$

$$A_V \text{SN}_{20-60} \approx \text{SN}_{40}$$

NOTE:  $A_2$  IS CONSTANT = 4000 UNITS

Figure 7. Average skid number calculation.



$$\text{GRADIENT (G)} = \frac{\text{SN}_{20} - \text{SN}_{60}}{40}$$

$$\text{GRADIENT (G}_2\text{)} = \frac{\text{SN}_{20} - 0}{40}$$

PERCENTAGE GRADIENT (PG) =

$$\frac{G}{G_2} \times 100 = \frac{\text{SN}_{20} - \text{SN}_{60}}{\text{SN}_{20}} \times 100$$

Figure 8. Gradient and percentage gradient calculations.

percentage gradient is defined as the percentage of the gradient, obtained under test conditions, to a theoretical gradient if the skid number at the higher speed were zero. Calculations are shown in Figure 8.

### DISCUSSION OF RESULTS

Statistical analyses were conducted to determine correlation coefficients, coefficient of determination, and regression lines for the comparisons established in this study. Results are given in Tables 4 through 7. Table 8 gives detailed macrotexture and friction values.

TABLE 4  
STATISTICAL CORRELATION OF MACROTEXTURE TEST METHODS

No.	Variables		Regression Line	Correlation Coefficient	Coefficient of Determination	Standard Deviation
	Y	X				
1	TDS	TDP	$Y = -0.00 + 1.41 X$	0.93	0.86	0.009
2	TDS	APHP	$Y = 0.02 + 0.03 X$	0.86	0.74	0.012
3	TDS	PHP	$Y = -0.01 + 1.80 X$	0.81	0.66	0.014
4	TDS	PHTM	$Y = 0.00 + 1.75 X$	0.86	0.74	0.012
5	TDP	APHP	$Y = 0.02 + 0.02 X$	0.78	0.61	0.009
6	TDP	PHP	$Y = -0.00 + 1.11 X$	0.77	0.59	0.010
7	TDP	PHTM	$Y = 0.01 + 1.08 X$	0.81	0.65	0.009
8	APHP	PHP	$Y = -1.01 + 68.64 X$	0.92	0.85	0.306
9	APHP	PHTM	$Y = -0.42 + 63.30 X$	0.92	0.85	0.307
10	PHP	PHTM	$Y = 0.01 + 0.76 X$	0.83	0.68	0.006

Note: TDS = average texture depth, sand method; TDP = average texture depth, putty method; APHP = accumulative peak height, profilograph method; PHP = average peak height, profilograph method; and PHTM = average peak height, texturemeter method.

TABLE 5  
STATISTICAL CORRELATION OF SKID NUMBER AND MACROTEXTURE

No.	Variables		Regression Line	Correlation Coefficient	Coefficient of Determination	Standard Deviation
	Y	X				
1	SN <sub>20</sub>	TDS	$Y = 48.35 + 13.18 X$	0.03	0.00	11.79
2	SN <sub>20</sub>	TDP	$Y = 45.09 + 140.37 X$	0.18	0.03	11.60
3	SN <sub>20</sub>	APHP	$Y = 47.54 + 1.87 X$	0.12	0.02	11.70
4	SN <sub>20</sub>	PHP	$Y = 44.23 + 186.81 X$	0.17	0.03	11.63
5	SN <sub>20</sub>	PHTM	$Y = 47.56 + 71.59 X$	0.07	0.00	11.77
6	SN <sub>40</sub>	TDS	$Y = 40.09 + 46.58 X$	0.10	0.01	11.26
7	SN <sub>40</sub>	TDP	$Y = 37.01 + 175.08 X$	0.24	0.06	10.99
8	SN <sub>40</sub>	APHP	$Y = 39.17 + 3.67 X$	0.25	0.06	10.94
9	SN <sub>40</sub>	PHP	$Y = 33.87 + 317.44 X$	0.30	0.09	10.81
10	SN <sub>40</sub>	PHTM	$Y = 38.51 + 181.39 X$	0.18	0.03	11.12
11	SN <sub>60</sub>	TDS	$Y = 34.37 + 110.84 X$	0.24	0.06	10.43
12	SN <sub>60</sub>	TDP	$Y = 31.44 + 250.00 X$	0.35	0.13	10.04
13	SN <sub>60</sub>	APHP	$Y = 34.26 + 5.63 X$	0.41	0.17	9.79
14	SN <sub>60</sub>	PHP	$Y = 26.36 + 477.12 X$	0.47	0.22	9.49
15	SN <sub>60</sub>	PHTM	$Y = 32.73 + 307.97 X$	0.33	0.11	10.15
16	ASN	TDS	$Y = 40.74 + 49.63 X$	0.10	0.01	11.03
17	ASN	TDP	$Y = 37.65 + 179.60 X$	0.25	0.06	10.75
18	ASN	APHP	$Y = 39.97 + 3.60 X$	0.25	0.06	10.73
19	ASN	PHP	$Y = 34.64 + 316.77 X$	0.30	0.09	10.58
20	ASN	PHTM	$Y = 39.26 + 181.42 X$	0.19	0.03	10.90

Note: SN = skid number, subscript indicating speed in mph; ASN = average skid number between 20 and 60 mph; TDS = average texture depth, sand method; TDP = average texture depth, putty method; APHP = accumulative peak height, profilograph method; PHP = average peak height, profilograph method; and PHTM = average peak height, texturemeter method.

TABLE 6  
STATISTICAL CORRELATION OF GRADIENT AND MACROTEXTURE

No.	Variables		Regression Line	Correlation Coefficient	Coefficient of Determination	Standard Deviation
	Y	X				
1	G <sub>20-40</sub>	TDS	$Y = 0.41 - 1.67 X$	-0.27	0.07	0.140
2	G <sub>20-40</sub>	TDP	$Y = 0.40 - 1.74 X$	-0.18	0.03	0.143
3	G <sub>20-40</sub>	APHP	$Y = 0.42 - 0.09 X$	-0.48	0.23	0.127
4	G <sub>20-40</sub>	PHP	$Y = 0.52 - 6.53 X$	-0.47	0.22	0.128
5	G <sub>20-40</sub>	PHTM	$Y = 0.45 - 5.50 X$	-0.43	0.19	0.131
6	G <sub>20-40</sub>	ln TDS	$Y = 0.31 - 0.01 \ln X$	-0.08	0.01	0.145
7	G <sub>20-40</sub>	ln TDP	$Y = 0.27 - 0.02 \ln X$	-0.11	0.01	0.145
8	G <sub>20-40</sub>	ln APHP	$Y = 0.33 - 0.02 \ln X$	-0.24	0.06	0.141
9	G <sub>20-40</sub>	ln PHP	$Y = -0.09 - 0.12 \ln X$	-0.35	0.13	0.136
10	G <sub>20-40</sub>	ln PHTM	$Y = 0.32 - 0.01 \ln X$	-0.07	0.01	0.145
11	G <sub>20-60</sub>	TDS	$Y = 0.35 - 2.44 X$	-0.44	0.20	0.115
12	G <sub>20-60</sub>	TDP	$Y = 0.34 - 2.75 X$	-0.33	0.11	0.121
13	G <sub>20-60</sub>	APHP	$Y = 0.33 - 0.09 X$	-0.57	0.33	0.105
14	G <sub>20-60</sub>	PHP	$Y = 0.45 - 7.24 X$	-0.59	0.35	0.103
15	G <sub>20-60</sub>	PHTM	$Y = 0.37 - 5.91 X$	-0.53	0.28	0.109
16	G <sub>20-60</sub>	ln TDS	$Y = 0.15 - 0.03 \ln X$	-0.22	0.05	0.125
17	G <sub>20-60</sub>	ln TDP	$Y = 0.12 - 0.04 \ln X$	-0.23	0.05	0.125
18	G <sub>20-60</sub>	ln APHP	$Y = 0.24 - 0.03 \ln X$	-0.33	0.11	0.121
19	G <sub>20-60</sub>	ln PHP	$Y = -0.27 - 0.14 \ln X$	-0.48	0.23	0.112
20	G <sub>20-60</sub>	ln PHTM	$Y = 0.21 - 0.01 \ln X$	-0.15	0.02	0.127

Note: G = gradient (slope) of the friction-speed curve, subscript indicating speed range in mph; TDS = average texture depth, sand method; TDP = average texture depth, putty method; APHP = accumulative peak height, profilograph method; PHP = average peak height, profilograph method; and PHTM = average peak height, texturemeter method.

TABLE 7  
STATISTICAL CORRELATION OF PERCENTAGE GRADIENT AND MACROTEXTURE

No.	Variables		Regression Line	Correlation Coefficient	Coefficient of Determination	Standard Deviation
	Y	X				
1	PG <sub>20-40</sub>	TDS	$Y = 17.7 - 81.0 X$	-0.31	0.09	5.77
2	PG <sub>20-40</sub>	TDP	$Y = 18.3 - 122.3 X$	-0.31	0.09	5.77
3	PG <sub>20-40</sub>	APHP	$Y = 17.9 - 4.2 X$	-0.54	0.30	5.09
4	PG <sub>20-40</sub>	PHP	$Y = 22.9 - 321.4 X$	-0.56	0.31	5.04
5	PG <sub>20-40</sub>	PHTM	$Y = 19.3 - 249.0 X$	-0.47	0.22	5.36
6	PG <sub>20-40</sub>	ln TDS	$Y = 9.6 - 1.5 \ln X$	-0.21	0.05	5.93
7	PG <sub>20-40</sub>	ln TDP	$Y = 3.1 - 3.1 \ln X$	-0.37	0.14	5.63
8	PG <sub>20-40</sub>	ln APHP	$Y = 13.0 - 1.9 \ln X$	-0.45	0.20	5.42
9	PG <sub>20-40</sub>	ln PHP	$Y = -10.7 - 6.8 \ln X$	-0.49	0.24	5.31
10	PG <sub>20-40</sub>	ln PHTM	$Y = 12.1 - 0.7 \ln X$	-0.14	0.02	6.01
11	PG <sub>20-60</sub>	TDS	$Y = 29.6 - 225.1 X$	-0.53	0.28	8.44
12	PG <sub>20-60</sub>	TDP	$Y = 30.1 - 301.7 X$	-0.46	0.21	8.80
13	PG <sub>20-60</sub>	APHP	$Y = 28.0 - 8.7 X$	-0.69	0.47	7.21
14	PG <sub>20-60</sub>	PHP	$Y = 38.8 - 680.3 X$	-0.72	0.52	6.88
15	PG <sub>20-60</sub>	PHTM	$Y = 31.5 - 545.7 X$	-0.63	0.39	7.74
16	PG <sub>20-60</sub>	ln TDS	$Y = 7.2 - 4.0 \ln X$	-0.36	0.13	9.27
17	PG <sub>20-60</sub>	ln TDP	$Y = 2.6 - 6.5 \ln X$	-0.47	0.22	8.75
18	PG <sub>20-60</sub>	ln APH	$Y = 17.9 - 3.8 \ln X$	-0.56	0.31	8.23
19	PG <sub>20-60</sub>	ln PHP	$Y = -33.7 - 14.7 \ln X$	-0.64	0.41	7.60
20	PG <sub>20-60</sub>	ln PHTM	$Y = 14.2 - 1.8 \ln X$	-0.24	0.06	9.65

Note: PG = percentage gradient of the friction-speed curve, subscript indicating speed range in mph; TDS = average texture depth, sand method; TDP = average texture depth, putty method; APHP = accumulative peak height, profilograph method; PHP = average peak height, profilograph method; and PHTM = average peak height, texturemeter method.



TABLE 8  
MACROTEXTURE AND FRICTION VALUES

Surface and Aggregate	Number Tested	Macrotexture					Friction				
		Profilegraph		Texture-meter Avg. Peak Height (in.)	Modified Sand Patch Avg. Texture Depth <sup>a</sup> (in.)	Putty Impression Texture Depth <sup>a</sup> (in.)	Skid Number		Gradient		Percentage Gradient
		Avg. Peak Height (in.)	Accum. Height (in.)				20 mph	40 mph	60 mph	20-40 mph	20-60 mph
Hot-mix asphalt concrete											
Lignite boiler slag aggregate	3	0.0184	0.023	0.0021	0.0078	0.0079	47	41	37	0.30	0.24
Rounded siliceous gravel	4	0.0252	0.741	0.0215	0.0317	0.0276	44 <sup>b</sup>	39 <sup>b</sup>	37 <sup>b</sup>	0.25 <sup>b</sup>	0.18 <sup>b</sup>
Crushed limestone aggregate	4	0.0177	0.308	0.0123	0.0205	0.0175	49 <sup>b</sup>	40 <sup>b</sup>	36 <sup>b</sup>	0.45 <sup>b</sup>	0.31 <sup>b</sup>
Crushed siliceous gravel	4	0.0227	0.589	0.0179	0.0308	0.0276	47 <sup>b</sup>	41 <sup>b</sup>	39 <sup>b</sup>	0.30 <sup>b</sup>	0.21 <sup>b</sup>
Crushed sandstone aggregate	3	0.0215	0.299	0.0142	0.0159	0.0212	68	60	56	0.40	0.29
Open-graded lightweight aggregate	3	0.0262	1.107	0.0264	0.0406	0.0324	64	55	49	0.45	0.38
Average	21	0.0219	0.516	0.0159	0.0250	0.0226	52	45	42	0.35	0.26
Portland cement concrete											
Rounded siliceous gravel	5	0.0210	0.239	0.0095	0.0230	0.0202	52	44	39	0.40	0.35
Crushed limestone aggregate	3	0.0188	0.128	0.0074	0.0195	0.0170	51	42	36	0.45	0.37
Rounded siliceous gravel and crushed sandstone aggregate	1	0.0203	0.355	0.0140	0.0535	0.0308	52	43	38	0.45	0.35
Average	9	0.0202	0.215	0.0093	0.0252	0.0203	52	43	38	0.45	0.36
Surface treatment											
Rounded siliceous gravel	2	0.0463	2.527	0.0425	0.0794	0.0464	42	39	40	0.15	0.06
Crushed limestone aggregate	4	0.0267	0.879	0.0226	0.0569	0.0450	46	37	35	0.45	0.30
Lightweight aggregate	3	0.0425	1.943	0.0295	0.0649	0.0470	67	62	60	0.25	0.19
Average	9	0.0363	1.800	0.0293	0.0646	0.0460	52	46	44	0.30	0.21
Flushed bituminous seal	2	0.0154	0.035	0.0094	0.0049	0.0030	33	25	21	0.40	0.29
Average	2	0.0154	0.035	0.0094	0.0049	0.0030	33	25	21	0.40	0.29

<sup>a</sup>These are comparable values even though the descriptive terms differ.

<sup>b</sup>Includes data from 1 test surface at Annex that increases friction averages.

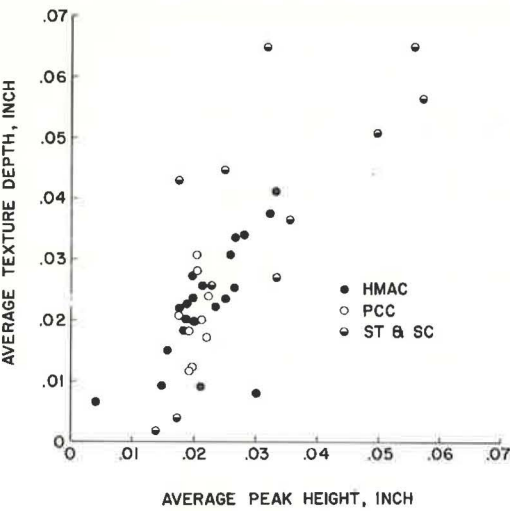


Figure 9. Putty impression versus profilograph methods.

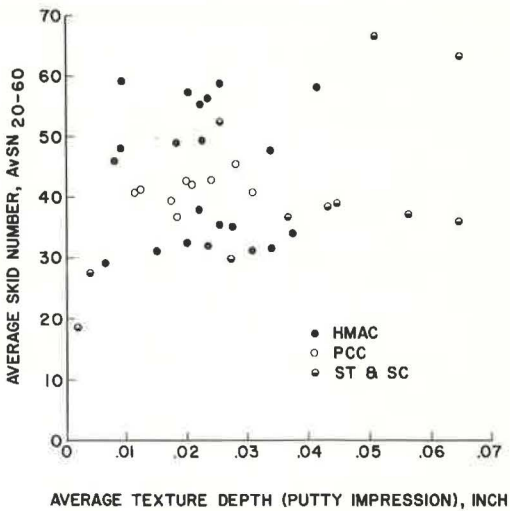


Figure 10. Average skid number versus macrotexture.

Comparison of Macrotexture Test Methods

Statistical correlation of the 5 macrotexture measures obtained on the 41 surfaces are given in Table 4. The relationships indicate a fairly high degree of correlation. A typical plot of one relationship is shown in Figure 9. The most diverse data scatter was obtained at the extremities of the texture levels.

Comparison of Skid Number and Macrotexture

Statistical correlation of skid numbers with macrotexture measures obtained on the 41 surfaces are given in Table 5. Correlation coefficients were extremely low for all speed levels, but the relative magnitudes increased with higher speeds. Textures obtained with the profilograph consistently correlated better with skid numbers. A typical plot of one relationship is shown in Figure 10. A slight trend is noticeable.

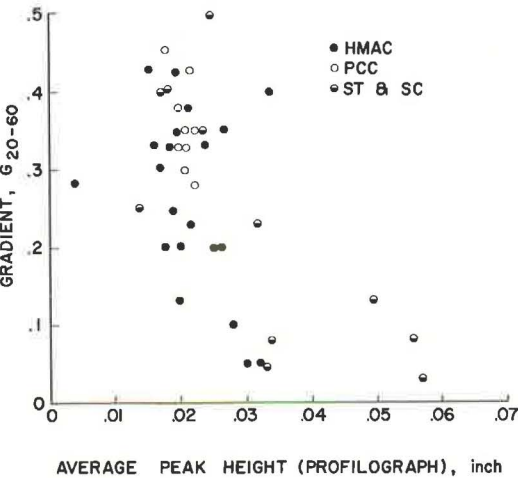


Figure 11. Gradient versus macrotexture.

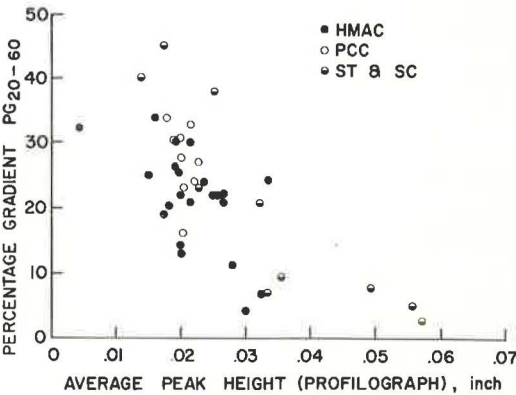


Figure 12. Percentage gradient versus macrotexture.

### Comparison of Gradient and Macrotexture

Statistical correlation of friction-speed gradients obtained from 20-40 mph and from 20-60 mph with macrotexture measures obtained on the 41 surfaces are given in Table 6. Correlation coefficients were fairly low, particularly for the logarithmic relationships. Gradient computations from 20-60 mph resulted in higher coefficients than those from 20-40 mph. Also, the mechanical roughness detector instruments (profilograph and texturemeter) gave higher coefficients than the volumetric measures (putty and sand). A typical plot is shown in Figure 11.

### Comparison of Percentage Gradient and Macrotexture

Statistical correlation of friction-speed percentage gradients obtained from 20-40 mph and from 20-60 mph with macrotexture measures obtained on the 41 surfaces are given in Table 7. Relative trends were the same as those for corresponding gradient comparisons; however, magnitudes in each case were greater, indicating better correlation. Again, as was evident from the gradient comparisons presented previously, macrotexture effects on friction increased with higher speeds. A typical plot is shown in Figure 12.

### Comparison of Gradient and Skid Number

Friction-speed gradients and average skid numbers from 20-60 mph for the 41 pavements are shown in Figure 13. A relationship does not exist.

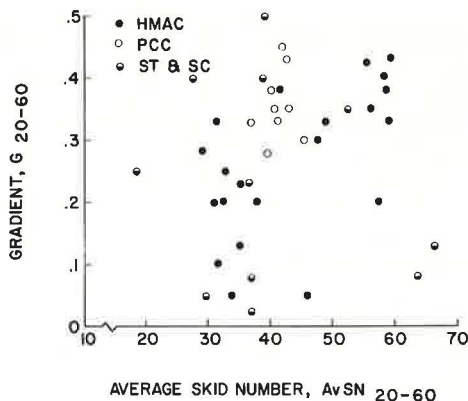


Figure 13. Gradient versus average skid number.

## CONCLUSIONS

Based on the specific test conditions, equipment limitations, and pavement surface types utilized in this study, the following general conclusions appear to be warranted.

Pavement surface macrotexture measurement may be affected by any one of several different methods, and the units of such measurements may be the same; however, the contribution of such macrotexture to the frictional drag of a given tire-pavement system is not easily evaluated. A primary reason for the difficulty is that, for any selected method of macrotexture measurement, there are numerous possible combinations of pavement surface rugosity that will yield similar texture values. It may be further stated that, for given equipment and environmental conditions, pavements with approximately equal macrotexture values may very well have widely different skid numbers where such numbers are obtained by methods currently listed by Committee E-17 in ASTM Standards.

A primary function of macrotexture is water drainage from the tire-pavement interface. This drainage becomes more important as (a) vehicle speed increases, (b) tire tread depth decreases, and (c) water depth increases. In addition, macrotexture causes tire wrinkling, and this texture acts as an energy absorber in rolling, slipping, and skidding. This action brings into play the hysteresis properties of the tire rubber. The energy absorption caused by the hysteresis of the tire rubber increases with vehicle speed.

The study further shows that, of the means investigated, the profilograph method is the most convenient way to measure macrotexture; however, statistically, a rather poor correlation between macrotexture and skid resistance was shown. One explanation for this finding is that macrotexture of the aggregate was disregarded, and a second reason is quite likely lodged in the limited variation in water-film thickness studied.



The range of macrotexture found on the pavements included in the study covered, in reasonable fashion, the range one might encounter across the entire United States. Of the 41 pavements tested, texture values ranged from 0.0+ to about 0.07 in. A pavement with a macrotexture value higher than about 0.10 would be noisy and, if composed of sharp textured gritty particles, would create excessive tire wear without offsetting benefits in vehicle control.

As already indicated, water-film thickness and tire-tread depth are important parameters affecting the impact of a given macrotexture on frictional drag. A study of the relative magnitudes of these effects is under way, and definitive results will be available within a matter of months.

Drainage of the tire-pavement interface may be effected into the pavement as well as between the tire and the pavement. Open-graded, lightweight aggregate asphalt concrete has been designed and placed into service, and these pavements appear to offer important bonuses in this area. Three such pavements were included in this study. This design would offer partial solutions to drainage problems in transitions from tangents to superelevated curves on 2-lane facilities and on compound curves.

### SUMMARY

1. The 4 methods used to evaluate pavement surface macrotexture provide acceptable data, and texture values obtained by the different methods compared favorably.
  2. The profilograph method for measurement of macrotexture is preferred because of its simplicity, reproducibility, and better correlation with friction parameters. However, statistically, even results obtained with the profilograph do not relate favorably with friction parameters.
  3. Macrotexture was found to range from 0.00 to 0.07 in. on a random sample of 41 Texas highways. The larger values were associated with surface treatments composed almost entirely of aggregate; whereas, the smaller values were associated with "flushed" seals. The majority of the surfaces were in the 0.015- to 0.035-in. range, which included most of the hot-mix asphalt concrete and portland cement concrete pavements.
  4. The effect of the aggregate microtexture is included in many of the measurements made in the study, but the magnitude of the effect remains unknown. A clear understanding of the total problem hinges, at least in part, on the magnitude of the effect of microtexture.
- (The following summary statements are predicated on the existence of a reasonably constant water-film thickness of 0.02 in. for all surfaces that were tested.)
5. No correlation was found between 20-, 40-, and 60-mph skid numbers and macrotexture. Macrotexture effects accounted for a maximum of 3 percent at the variation in skid numbers at 20 mph, 9 percent at 40 mph, and 22 percent at 60 mph.
  6. Poor correlation was found between gradients of the friction-speed curve and macrotexture. A maximum of 23 percent at the variations in 20- to 40-mph gradients was explained by macrotexture effects, whereas 35 percent of the variations in 20- to 60-mph gradients was explained.
  7. A fair correlation was found between percentage gradients of the friction-speed curve and macrotexture. In these cases maximums of 31 and 52 percents of the variations in 20- to 40- and 20- to 60-mph percentage gradients respectively were explained by macrotexture effects.
  8. A relationship between gradient and skid number was not obtained.
  9. The existence of a high macrotexture level as measured by the 4 methods does not ensure a high coefficient of friction.
  10. The existence of extremely large-scale macrotexture ( $>0.035$  in.) ensures a relatively flat friction-speed gradient; however, macrotexture ( $\leq 0.035$  in.) does not ensure a flat friction-speed gradient.
  11. Water depth on the pavement surface was held reasonably constant in the study; so, the effect of varying this factor was not investigated. Skid numbers are largely affected by microtexture and macrotexture on the surface and internal drainage into the surface as well as pavement water depth and vehicle speed.

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