Pavement Texture: Its Significance and Development

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This paper discusses the influence of roadway surface textures on skid resistance, the skid resistance-speed gradient, accident rates on wet pavements, pavement wear, and the noise generated by tire-road interaction. The tendency of a vehicle to hydroplane is reduced by increasing the depth of the pavement texture. Appropriate textures are developed by using open-graded asphalt friction surface courses and by finishing portland cement concrete with steel tines or a vibrating float while the concrete is plastic. Hardened pavements can be textured by grooving with a diamond saw or by resurfacing with an overlay. More development is needed in techniques of texture measurement, especially in automating the stereophotographic interpretation method.

Water on the roadway is one of the major causes of highway accidents. It induces hydroplaning, reduces skid resistance, and adversely affects vehicle control (1). Modern high-speed traffic challenges the highway engineer to provide dynamic drainage at the tire-pavement interface and facilities for rapid removal of water from the pavement surface during precipitation. Construction of deep-textured surfaces can help in achieving these goals.

CLASSIFICATION OF SURFACE TEXTURES

The large-scale features of a pavement surface—known as the macrotexture—are commonly distinguished from the fine-scale features—the microtexture. Pavement surfaces can be analyzed in more detail by use of an American Society for Testing and Materials (ASTM) procedure, ASTM E 559. Four parameters are coded for the macrotexture: height, width, angularity, and density of the distribution of large projections. Two parameters describe the microtexture: harshness and the rugosity of the background. Kummer and Meyer (2) have classified the surface types as (a) smooth, (b) fine-textured and rounded, (c) fine-textured and gritty, (d) coarse-textured and rounded, and (e) coarse-textured and gritty.

MECHANISTIC ASPECTS OF TEXTURE

Effect of Texture on Friction and Speed Gradient

Figure 1 (3) shows the effects that road surfaces have on skid resistance and speed gradient. Both adhesion and hysteresis contribute to skid resistance. Adhesion is the shear force developed at the interface between the tire and the roadway, and hysteresis is the friction produced by damping losses in the rubber of the tire. Harsh or gritty pavement surfaces yield larger skid numbers (100 times the coefficient of friction) than rounded, polished, or smooth surfaces. This is true for both locked-wheel and peak braking. The sharp asperities of angular aggregates tend to penetrate the water film and grip the tires to provide better friction on wet pavements. The sharp, coarse texture is even more effective for peak braking than it is for locked-wheel braking.

The skid resistance-speed gradient (G) can be defined by

$$G_{(A-B)} = (SN_A - SN_B)/(B - A) \qquad (1)$$

in which A and B are the test speeds at which the skid numbers SN_A and SN_B are measured. The gradient is often steeper at higher levels of skid resistance; therefore, a percentage gradient, which can be defined as

$$PG = [G/SN_{0.5(A+B)}] \times 100 \qquad (2)$$

may correlate better with texture measurements (4) than does the speed gradient.

The speed gradient is not as steep for coarse surfaces as for fine-textured roadways because the large voids in coarse surfaces allow more rapid expulsion of water at the tire-road interface and because the coarse texture develops greater hysteretic effects in the tire, improving its friction characteristics. Skid resistance thus decreases more slowly with increasing speed. Open- or coarse-textured pavements are therefore excellent for safe, wet-weather travel at higher speeds. They decrease objectionable splash and spray, reduce hydroplaning, and diminish headlight glare by dispersing light (glare becomes intolerable at night when the roadway surface is smooth, wet, and reflective).

Gritty, fine-textured pavements usually yield larger skid numbers at lower speeds than do open-graded roadways. This makes them suitable for slow-speed traffic. Moyer (5) recognized the virtue of gritty, dense-graded surfaces many years ago. Surfaces of this type have been used successfully in Kentucky and Virginia and in other locations.

Influence of Texture Depth

Figure 2 shows significant increases in mean skid number with an increase in mean texture depth ("sand

Figure 1. Influence of different road surfaces on tire grip.

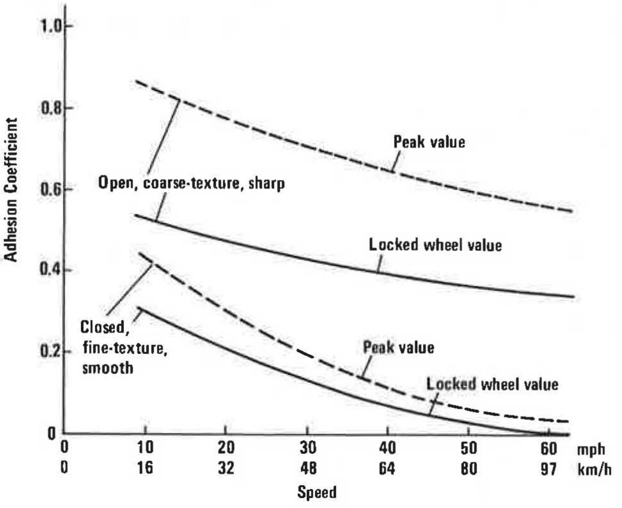
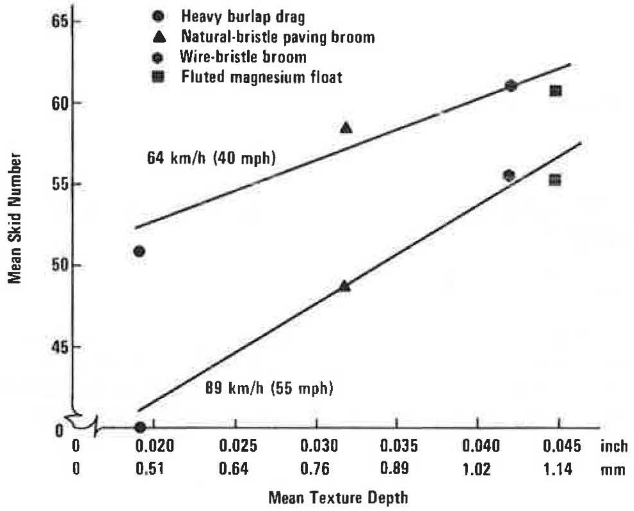


Figure 2. Effect of texturing methods on initial texture depth and skid resistance.



patch" method of texture measurement) on portland cement concrete (PCC) pavement in skid tests at 64 and 89 km/h (40 and 55 mph) (6). It should be noted that the slope is greater at the higher test speed. The coarse texture allows better drainage relief than the fine texture, particularly at the higher speed, and stimulates the hysteretic response of the tires.

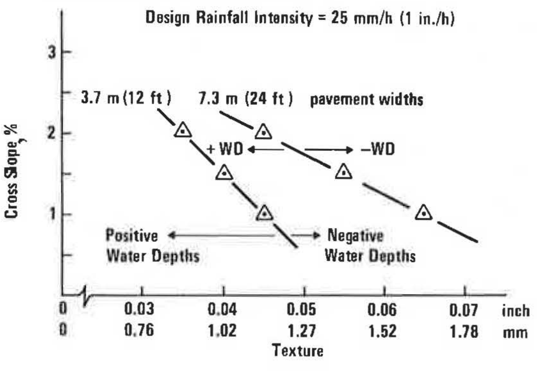
Similar results have been obtained by others (7,8). One investigator's experiments extended linearly to a texture depth of nearly 2.5 mm (0.1 in). Both the sand-patch and "putty impression" methods (6,7,9) were used for measurement.

In a study of hydroplaning (10), experiments yielded more than a 16-km/h (10-mph) difference in speed for the initiation of hydroplaning for textures between 0.46 and 3.68 mm (0.018 and 0.145 in); this was determined by using the putty impression method and a 10 percent spin-down of the hydroplaning wheel. The more shallow texture was obtained by using a burlap drag on PCC pavement and the deeper one by using a seal coat with large, round river gravel. The deeper texture may be coarser than that generally used on highways, but it demonstrates the influence of texture on hydroplaning.

When the water depth on a pavement surface is measured from the top of the asperities, the depth is expressed as negative when the asperities are exposed and positive when they are inundated.

In Figure 3, the putty impression method has been used to show the depths of texture required to prevent significant water depths for various cross slopes and for two pavement widths when a design rainfall intensity of 25 mm/h (1 in/h) reaches the steady state (11). It should be noted that the texture requirement increases as the width of the pavement increases and the cross slope decreases.

Figure 3. Combinations of cross slope and texture required to prevent significant water depths.



Skid Number Versus Accident Rate

Experimental results indicate that wet-pavement skid resistance usually increases with the depth of the pavement texture. Figure 4 shows that the wet-surface accident rate decreases as the skid number increases. These data were obtained from ASTM locked-wheel skid test measurements and from accident analysis on rural Interstate and parkway roads in Kentucky. Two analysis curves of similar shape are shown: one for roads with average daily traffic (ADT) of less than 3000 and one for roads with greater than 3000 ADT. The results are expressed in accidents per 161 million vehicle km (100 million vehicle miles).

Both curves reveal a significant decrease in the accident rate when the wet-pavement skid number is greater than 44. These data were obtained from an extensive analysis of wet-pavement accidents and a large number of highway skid tests conducted at 64 km/h (40 mph). Other analyses and tests conducted at a speed of 113 km/h (70 mph) show that a value of SN_{40} = 44 is equivalent to approximately SN_{70} = 27.

Open-Graded Asphalt Friction Courses

Western states recognized the merits of open-graded asphalt friction courses several years ago (12), and a number of these courses have been placed on roadways throughout the nation. Highway designers are recommending these surfaces to improve skid resistance and mitigate hydroplaning.

If quality aggregates are used, the skid resistance of open-graded courses is excellent when the plant-mix seals are new. In general, test results show improvement in friction characteristics as the bitumen wears and the harsh angular aggregates are exposed. The skid number decreases slightly with continued wear, but the surfaces continue to exhibit excellent skid resistance for several years.

The Louisiana Department of Highways has conducted tests on plant-mix seals with several different aggregates (13). A summary of test results on the performance of open-graded surfaces with time and traffic is given in Table 1. The test results indicate that the skid resistance of plant-mix seals is superior to that of a dense-graded hot-mix surface. The comparison would probably have favored plant-mix seals even more at higher speeds because the speed gradient of open-graded plant-mix seals is usually smaller than that of a dense-graded surface.

Smith, Rice, and Spelman (14) provide information on a new design method for open-graded asphalt friction courses, listing the following benefits for such courses:

1. Improved skid resistance at high speeds during wet weather,
2. Minimization of hydroplaning effects during wet weather,
3. Improved road smoothness [present serviceability index (PSI)],
4. Minimization of splash and spray during wet weather,
5. Minimization of wheel-path rutting,
6. Improved visibility of painted traffic markings,

7. Improved night visibility during wet weather (less glare),
8. Lower highway noise levels, and
9. Retardation of ice formation on the road surface.

These courses are desirable because their open texture provides channels for the escape of water from the surface. Air voids of 15 percent or greater are recommended in the design and construction of open-graded courses.

NOISE AND WEAR

Noise Produced by Tire-Road Interaction

The noise produced by tire-road interaction (15,16) increases with speed, depth of the pavement texture, and moisture, and it is the dominant traffic noise at higher vehicle speeds. It also increases with tire load and wear for many tire tread patterns. Tread vibration is a major source of tire-road noise. Irregularities in the road surface (asperities, texture, and roughness of the pavement) create an oscillation in the tread that emits sound waves. The modal responses of tires differ. At low frequencies most of the sound emanates from the contact area, whereas at higher frequencies carcass vibrations also contribute to the generation of sound.

Figure 5 (7) provides preliminary experimental highway data on sound pressure level versus texture depth for several finishing techniques at speeds of 64 and 97 km/h (40 and 60 mph). Noise was measured with a microphone near the left rear tire of a panel truck 1 m (3.3 ft) above the pavement. A conventional, worn highway tire was used as the test tire. Noise is expressed in decibels on the A scale, a measure of sound that is practical for modern highway vehicles and that correlates well with human evaluation of noise.

Notice that the sound level increases with texture depth for both speeds, but the noise is substantially greater at the higher speed. Steel comb or tine finishes for PCC pavements are rapidly gaining in favor, and this finishing technique has been used to develop the deeper textures.

Texture depth is not the only factor related to noise. The shape and the spacing of striations are other factors. Placing transverse grooves at irregular intervals in the road surface has prevented generation of a pure tone for concrete that was plastic grooved with a vibrating float (17). Random sizing of the discrete blocks or lugs of tire tread patterns is another way to reduce sound level. These methods diversify the sound frequencies developed and so decrease the intensity of individual tones.

Optimal tire performance and its relation to pavement texture, noise, polishing, and wear have been studied in England. Petrographic types of aggregates were subjected to polishing tests and then examined with a scanning electron microscope. A microtexture between 0.01 and 0.1 mm (0.0004 and 0.004 in) was recommended to penetrate a viscous water film and establish a harshness that is adequate for effective tire contact without excessive tire wear (18). Optimal macrotexture for sufficient bulk water drainage was provided by surface aggregates 6 to 12 mm (0.24 to 0.47 in) in diameter.

Another study suggests that a 0.4 ratio of groove to rib width for vehicle tires gives optimum tread drainage (19).

Wear of the Pavement Surface

Pavement surfaces wear by abrasion, degradation, and decomposition as a result of vehicle traffic and environ-

Table 1. Friction performance of open-graded surfaces (high traffic volume in exterior lane).

		Skid Number at 64 km/h			
Age (months)	Cumulative Traffic (000s)	Hot Mix	Gravel Plant-Mix Seal	Expanded Clay Plant-Mix Seal	Slag Plant-Mix Seal
0	0	36	42	60	52
4	0.68	37	47	60	56
12	2.11	42	46	59	51
18	3.90	39	45	55	51
32	5.83	46	46	57	51
40	6.83	44	44	56	50
48	7.83	41	43	52	52

Note: 1 km/h = 0.62 mph.

Figure 4. Skid number versus accident rate.

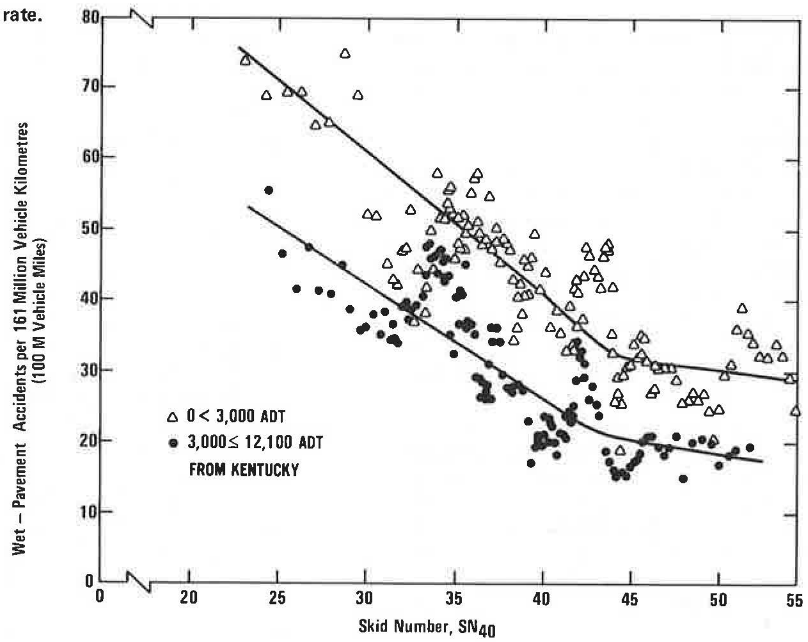


Figure 5. Effect of texture depth on sound pressure level.

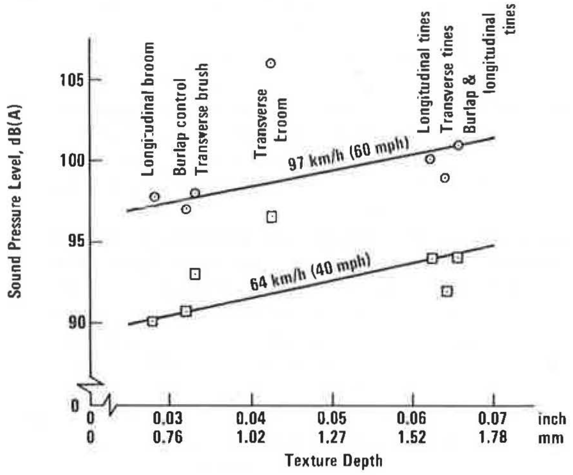
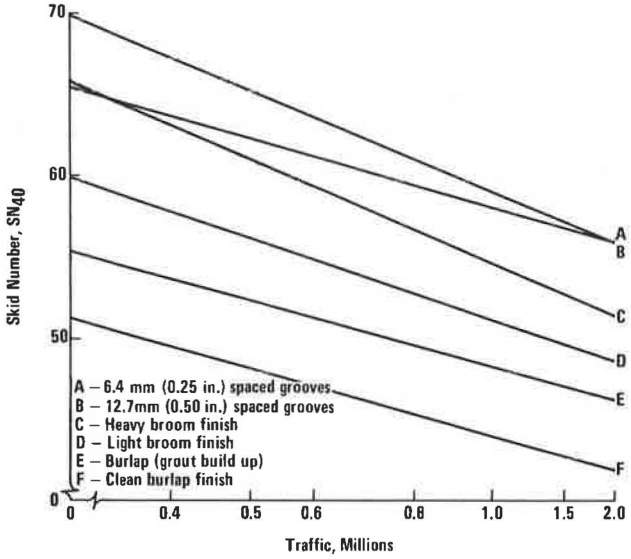


Figure 6. Skid resistance of various PCC pavement textures under traffic without studded tires.



mental change. The rubber tires react with the detritus on the roadway to abrade homogeneous exposed rocks, degrade laminated stones or those with zones of weakness, and disintegrate the bonding medium, which in turn releases surface aggregates. The polishing of a pavement by traffic impairs the microtexture, and further wear reduces the texture depth of the surface (the macrotexture), decreases the void space of open-graded seal coats by degradation and compaction, and reduces the channels that permit the expulsion of surface water. Continued wear and the infiltration of dust, mineral particles, abraded rubber, oil drippings, and other foreign materials tend to clog the void spaces over a period of time and gradually reduce texture and skid resistance.

The release of sand-size mineral particles is not always a disadvantage. Dense-graded asphalt pavements have been designed to retain surface rugosity by attrition and thus continue to provide a skid-resistant surface. Eventually, it becomes necessary to rehabilitate the surface. When the pavement is wet, however, the open-graded asphalt friction course is usually superior to the dense-graded surface for higher vehicle speeds.

Studded tires and chains rapidly destroy the texture of both PCC and bituminous pavements. Heavy use of studded tires soon causes depressions or ruts in the wheel paths. Use of high-quality pavements with hard, durable surface aggregates retards the processes of wear, rutting, wheel-path compaction, and deterioration of skid resistance.

It is essential to use polish-resistant aggregates in pavement surfaces to provide enduring texture and skid resistance. Aggregates and pavement specimens can be evaluated before construction by means of polishing tests (ASTM D 3319, E 451, and E 510), petrographic analysis (ASTM C 294 and C 295), and chemical tests (ASTM D 3042) (20,21). The hardness of the mineral aggregates can be rated on the Mohs scale. Several types of circular test tracks have also been used for preevaluating the endurance characteristics of pavement surfaces. However, accelerated polishing tests do not account for weathering effects.

The Georgia Department of Transportation has used ASTM locked-wheel skid measurements to compare the wear of PCC pavement textures under traffic without studded tires (8). These results are shown in Figure 6, plotted as skid number versus traffic in millions (log scale) for a maximum of 2 million passes. It can be seen that grooves produced by steel comb or tine finishes gave the highest skid resistance and that the rate of wear for the surface with grooves spaced 12.7 mm (0.5 in) apart is less than that of all other finishes except the burlap finish with grout buildup (which has much lower skid resistance).

The rate of wear may decrease as the number of traffic passes increases. But even if wear for the tined finish with 12.7-mm (0.05-in) groove spacing continues at the same rate, it will remain above SN_{40} = 50 after 6.7 million passes.

FORMATION, RESTORATION, AND MEASUREMENT OF TEXTURE

Development of Texture on PCC Pavements

During the past few years, it has been recognized that the texturing methods for PCC pavements have been inadequate for allowing proper drainage relief, mitigating hydroplaning, exciting sufficient rubber hysteresis, and providing sufficient skid resistance for high-speed traffic. As a result, finishing techniques are being modified, and new methods are being introduced (22). Limited success has resulted from experiments conducted with finishing tools such as nylon brooms; flexible, fine wire brushes; wire drags; and modified burlap drags.

Greater success is being achieved by steel combing or grooving plastic concrete. Experiments have also been conducted with a fluted magnesium float (6). The steel comb or the vibrating groover has been incorporated in texturing and curing machines as a part of the paving train. This is desirable for mass producing textures with uniform high quality.

The deeper textures produced by the steel comb or the vibrating groover provide larger channels for water expulsion and drainage. This improves skid resistance, prevents hydroplaning, decreases splash and spray, and reduces wet-pavement highway accidents. These finishing techniques (8,17) permit coarse aggregates to remain near the surface of the pavement or between the grooves and minimally disturb the surface mortar, resulting in stronger, more durable textures. An additional benefit is that these grooves are placed in the plastic concrete at the time of construction at a cost that is only a fraction of that for grooving hardened pavements. Grooving of hardened pavements, which is discussed below, can be very advantageous when surfaces have become slick as a result of wear by traffic or when they have an inadequate texture. It may be desirable to finish pavements with a burlap drag before grooving to produce a gritty texture between the grooves.

Recent research recommends a minimum macrotexture of 1.3 mm (0.05 in) for coarse-textured surfaces on high-speed highways (23). The texture can be measured by the sand patch or the silicone putty method.

Grooving Hardened Pavements

Grooving of hardened pavements to reduce wet-pavement accidents in locations that have high accident rates has increased rapidly in recent years. A before-and-after study on 55 lane-km (34 lane-miles) of grooved pavements in California has shown a 20 percent decrease in total accidents and a 70 percent reduction in wet-pavement accidents even with a 17 percent increase in traffic (24).

Transverse grooves furnish shorter escape routes for surface water, reduce splash and spray, and allow better wet-pavement braking distances than do longitudinal grooves. Presumably, longitudinal grooves increase the directional control and stability of vehicles because they improve lateral friction characteristics.

Because of the high cost of grooving hardened pavements, there is a tendency to minimize the grooving dimensions and increase the pitch or spacing. It is better to develop adequate pavement texture during construction and resurfacing—and thereby decrease the need for diamond sawing—than to groove hardened pavement. Grooving, however, is an effective means of reconditioning roadway surfaces that are smooth or worn from traffic.

Restoring or Retexturing Pavement Surfaces

Some common methods for restoring pavement surfaces are applying a seal coat, resurfacing, or placing a thin asphalt overlay (14,25). PCC pavements may be resurfaced with a PCC overlay (26) if the contractor is meticulous about resurfacing procedures. In any case, for the best results, the pavement should be structurally sound, patched, or repaired before resurfacing.

Pavements are often resurfaced to correct road roughness or to increase skid resistance. Adequate texture should be developed during resurfacing to obtain the best drainage relief and friction characteristics. Harsh, angular, properly graded aggregates are essential for these surface layers.

Measurement of Pavement Texture

Rose, Hutchinson, and Gallaway (9) summarize 26 methods for evaluating or measuring pavement texture. Of these, stereophotographic interpretation and the sand patch, silicone putty, and static drainage (outflow meter) methods or modifications of these procedures are most commonly used. Most of the measurements involve stationary procedures, but there is also a need to evaluate pavement texture from a vehicle moving at traffic speeds.

Pavement textures are complex, and many of the procedures measure only a single attribute such as depth, hydraulic radius, or drainage characteristics. This is why the correlation of skid resistance with texture measurements, which is commonly done today, is often imperfect.

RECOMMENDED TEXTURING METHODS

PCC pavement should be textured with a steel comb incorporated as a part of the paving train. The steel tines should be spaced 13 to 20 mm (0.5 to 0.8 in) apart center to center, and for high-speed roadways the average depth of the striations should be 5 mm (0.2 in). When pavements become worn or slick, they should be retextured by grooving with a diamond saw or resurfaced with an overlay that has a deep texture. The open-graded asphalt friction course—constructed from quality aggregates in accordance with procedures given by Smith, Rice, and Spelman—is recommended as a surface for new or hardened pavements.

CONCLUSIONS

Open-graded or coarse-textured roadway surfaces are advisable for high-speed, wet-weather traffic. They provide drainage relief at the tire-pavement interface, reduce the steepness of the speed gradient, decrease the likelihood of hydroplaning, minimize splash and spray, reduce the glare from wet pavements, and improve high-speed skid resistance. The skid number increases as the texture depth increases, and the wet-pavement accident rate diminishes as the skid number increases (the lowest rate occurring for values of 44 and greater).

Texture wear and tire-pavement noise usually become greater as the depth of the texture increases, but these factors depend on jaggedness, the contour of the surface, and the method used in finishing the pavements. The open-graded asphalt friction course is an exception. It is less noisy than many other surfaces. Adequate texture can be obtained by plastic grooving fresh concrete with a vibrating float or a steel comb. The surface is more durable when the grooves are spaced 13 mm (0.5 in) or more apart center to center. When it is well-designed and properly constructed, the open-graded asphalt friction course produces an excellent surface. Texture can be provided on hardened pavements by grooving or resurfacing. Polish-resistant aggregates must be used in resurfacing if durable textures are to be obtained. Harsh, angular aggregates give good results.

Pavement texture can be characterized by stereophotographic interpretation. Texture depths of 1.3 mm (0.05 in) or greater, measured by the sand patch method, are advocated for high-speed roads; however, measurements of this nature do not fully evaluate the characteristics of the texture. Textural requirements should probably be varied with the geometrics of the highway and with traffic demands. Deeper texture is needed in geographic locations where rainfall intensities are greater and vehicle speeds are faster.

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This paper is a staff report condensation of research conducted for the Federal Highway Administration. The contents reflect my views, and I am responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

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