FINAL REPORT

HIGH-SPEED TEXTURE MEASUREMENT OF PAVEMENTS

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ABSTRACT

This study was conducted to validate high-speed texture measuring equipment for use in highway applications. The evaluation included two high-speed systems and a new static referencing device. Tests were conducted on 22 runway and taxiway test sections from the National Aeronautics and Space Administration's Wallops Flight Facility and 7 surfaces from Virginia's Smart Road.

Texture estimates recorded with the high-speed (dynamic) equipment correlated extremely well with estimates made with static referencing methods. The system developed by International Cybernetics Corporation was very functional for most conventional highway surfaces. However, a better correlation may be achieved with the referencing methods by using a system (such as the MGPS surface system developed by the Federal Highway Administration) that produces the American Society for Testing and Materials' standard mean profile depth.

Finally, an analysis conducted using the CTMeter (circular track meter, a laser-based but static system) demonstrated an important advantage of combining indices produced from high-definition surface profiles. By comparing the mean profile depth with the root mean square data for a particular surface, it is possible to characterize more fully the shapes that contribute to a pavement's macrotexture.

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INTRODUCTION

The surface of a pavement can be thought of as consisting of various levels of texture. Tiny grains of fine aggregate and features that make up the surface of coarse aggregate provide what is known as the pavement microtexture. *Microtexture* describes those features of a pavement surface that are less than 0.5 mm in length. In functional terms, microtexture is the most significant contributor to low-speed skid resistance. Features of the pavement surface that range from approximately 0.5 mm to 50.0 mm in length are classified as macrotexture. Macrotexture was shown to be the primary component of high-speed, wet skid resistance (Mahone, 1975). Coincident with the issues concerning wet skid resistance are those of surface drainability and surface splash and spray characteristics. Texture also influences the production of noise at the tire/pavement interface, and certain patterns of macrotexture along a pavement surface have been related to mix segregation and the presence of other surface distresses (Stroup-Gardner and Brown, 2000).

Until recently, the most common test methods for determining macrotexture were labor intensive and time-consuming. New developments in high-resolution profiling have produced methods for estimating macrotexture depth at highway speeds. Specifically, high-powered, rapid-firing laser range finders coupled with precision electronic distance measuring equipment has been purported (Federal Highway Administration, 1997) to allow the characterization of pavement surfaces at a high degree of detail without interrupting traffic. The fundamental questions that need to be addressed are (1) how effectively does this equipment characterize pavement macrotexture and (2) how could this information be used if it were available?

PURPOSE AND SCOPE

This study was initiated to validate high-speed texture measuring equipment for use in highway applications. Two high-speed systems were evaluated over the course of this study: (1) the ICC system (manufactured by International Cybernetics Corporation) on the Virginia Transportation Research Council's (VTRC) inertial profiling vehicle, and (2) the MGPS system, the commercial outgrowth of the Federal Highway Administration's (FHWA) road surface analyzer (ROSAN) project conducted by the Turner-Fairbank Highway Research Center (see Table 1).

Table 1. Characteristics of the Texture Measuring Systems Included in Study

Type of System	Frequency of Measurement	Name	Background	Measures
High speed (dynamic)	Semi-continuous to continuous	ICC (International Cybernetics Corporation)	Developed by private company	Proprietary texture estimate
		MGPS	Developed by FHWA (commercial outcome of ROSAN project)	Mean profile depth (ASTM E1845)
Referencing device (static)	Discrete	Volumetric (sand patch)	Traditional	Mean texture depth (ASTM E965)
		CTMeter	Developed by Nippon Sangyo Co. of Japan	Mean profile depth and root mean square

METHODS

The high-speed systems were evaluated by collecting texture data on various airfield and highway surfaces and comparing them with data obtained using static referencing methods.

Test Sites

Researchers conducting this study were fortunate to have access to two facilities, each with an extensive array of pavement surface types and textures. The first facility, the Wallops Flight Facility (Wallops) on the Eastern Shore of Virginia, provides an assortment of conventional and non-conventional airfield surfaces. The second facility, Virginia's Smart Road test bed (Smart Road) in Blacksburg, Virginia, incorporates a series of contemporary highway surfaces.

Wallops Flight Facility

Wallops are an active airport owned and operated by the National Aeronautics and Space Administration (NASA). The test surfaces are distributed among three full-scale runways and numerous taxiways. These surfaces vary from grooved and non-grooved hot-mix asphalt (HMA) and portland cement concrete (PCC) to very smooth synthetic surfaces and numerous bituminous-based surface treatments. The test surfaces ranged in size from a dense-graded asphalt concrete test section 300 m (1,000 ft) long on a main runway to temporarily attached plates that were just over 1 m wide and less than 3 m long (4 by 8 ft). Table 2 is not a complete list of the surfaces available at Wallops but does include those that were relevant to this project.

Table 2. Test Surfaces at Wallops

Surface Code	Width (ft)	Length (ft)	Surface Description
A	15	107	Non-grooved canvas belt-finished PCC
B	15	107	Grooved 1x1/4x1/4-inch canvas belt-finished PCC
C	15	107	Grooved 1x1/4x1/4-inch burlap drag-finished PCC
D	15	107	Non-grooved burlap drag-finished PCC
E	15	305	Non-grooved small-aggregate HMA
F	15	107	Grooved 2x1/4x1/4-inch small aggregate HMA
S-1	4	61	Non-grooved PCC w/Skidabrader® light texture (1994)
S-2	4	61	Non-grooved PCC w/Skidabrader® medium texture (1994)
S-3	4	61	Non-grooved PCC w/Skidabrader® high texture (1994)
S-4	4	91	Non-grooved PCC w/Skidabrader® very high texture (1994)
S-5	4	274	Non-grooved PCC w/Skidabrader® medium texture (1995)
S-6	4	183	Non-grooved PCC w/Skidabrader® medium texture (1997)
R-1	3	91	Rejuvenated asphalt without sand
R-2	3	91	Small aggregate asphalt
R-3	3	91	Rejuvenated asphalt with sand
MS/0	3	91	Small aggregate asphalt (no overlay)
MS/1	3	91	MS/0 with slurry seal overlay (1995)
MS/2	3	91	MS/0 with microsurface, single overlay (1995)
MS/3	3	91	MS/0 with microsurface, double overlay (1995)
MS/4	3	91	MS/0 with anti-skid overlay (1999)
K0	3	85	Non-grooved float-finished PCC
K	3	85	Driveway sealer without sand on K0

Note: The Skidabrader® is a shot-blasting device used to restore texture to traveled surfaces. It is operated by Humble Equipment Corporation, Huntsville, Alabama.

Data were collected at Wallops in conjunction with NASA's Annual Tire/Runway Friction Workshop. Although the workshop facilitators made every effort to accommodate the static texture testing, this testing had to be scheduled alongside extensive high-speed friction testing. The fact that these surfaces are on active runways and taxiways further constrains access to most surfaces (necessarily). Consequently, little attempt was made to match precisely static and dynamic (high-speed) test measurement locations within a given section. The static texture values represent the average of three tests conducted within a homogeneous (nominally speaking) test surface. The dynamic texture values are an average of all the values in a "texture profile," which consists of a texture estimate for every 0.6 m (2 ft) longitudinally within a test surface.

Smart Road

The Smart Road contains, among many other things, 14 pavement test sections. Topping these test sections are 9 wearing surfaces. This assortment of pavement surfaces includes 5 Superpave® mixtures, a 12.5 mm stone mastic asphalt (SMA), a 19 mm SMA, a 12.5 mm maximum nominal aggregate size open-graded friction course (OGFC), and tined PCC. The Superpave mixtures were designed in accordance with the Virginia Department of Transportation's (VDOT) Special Provision for Superpave (VDOT, 1999). The PCC surfaces were placed in accordance with VDOT specifications, which require a finished texture exhibiting grooves/tines approximately 3 mm by 3 mm (1/8 in) at 20 mm (¾ in) spacing (VDOT, 1999). The SMA-12.5, SMA-19.0, and OGFC are experimental mixes. Although every effort was made to promote good quality control, two of the HMA mixes failed to meet specifications. The aggregate gradation of the SM-12.5D Superpave mix was finer than the design requires, and the OGFC was placed with 1% less asphalt than directed.

Although 9 wearing surface designs exist on the Smart Road, the similar aggregate gradations used on the Superpave surfaces led researchers to limit testing to only 7 surfaces (see Table 3).

Although the surfaces (and textures) available at the Smart Road were considerably fewer than at Wallops, the Smart Road permitted a much more thorough and sustained access. When static and dynamically based data from the Smart Road are compared, the two "samples" are taken (as nearly as possible) from the same location on the test surface.

Table 3. Test Surfaces at Smart Road

Section ID	Width (ft)	Length (ft)	Surface Description (VDOT Designation)
Loop	16	570	Stone Matrix Asphalt (SMA 19)
A	24	317	Dense-graded HMA (SM 12.5D)[1]
G	24	274	Dense-graded HMA (SM 9.5D)
J	24	280	Dense-graded HMA (SM 9.5D)
K	24	262	Open-Graded Friction Course (OGFC 12.5)
L	24	317	Stone Mastic Asphalt (SMA 12.5)
Concrete	24	250	Continuously Reinforced Portland Cement Concrete (Transversely Tined)

[1] The "placed" gradation failed designed mix properties.

Texture Measuring Systems

Dynamic (High-Speed) Systems

ICC System

The most extensively evaluated system was included as part of an ICC inertial road profiling system. The profiler uses the combination of a short-range laser range finder, an accelerometer, and a distance measuring transducer to measure and compute the roadway profile. The ICC texture measuring system applies the same equipment to estimate texture. The difference lies in the amount of data retained (profile detail) and the analysis of the additional data when statistics that relate to texture are computed. The specific algorithms used by ICC are proprietary and therefore not provided in this report.

MGPS System

The MGPS system is owned and operated by the FHWA's Eastern Federal Lands Office (FHWA, 1997). The MGPS system also uses a laser, an accelerometer, and distance-measuring equipment to collect a very detailed profile. The system then uses the profile to compute the standard mean profile depth (MPD) specified in ASTM E1845 (ASTM, 2002). The main "hardware" difference between this system and the ICC laser profiler is that the MGPS system uses a higher frequency laser (64 MHz) with a smaller imprint. The higher frequency allows it to measure the profile with definition down to 0.25 mm if the tests are conducted at slower speeds.

Static Systems

Sand Patch Test

The reference texture values for the various surfaces included in this study were also obtained using two techniques. The first and most traditional technique was the volumetric (or sand patch) method (ASTM E965) (ASTM, 2002). This traditional method (see Figure 1) is based on a volumetric test that uses either sand or glass spheres. The test is relatively simple to perform, but its results are operator dependent and therefore not very reproducible (Henry, 2000). Currently, the specifications in ASTM E965 recommend the use of readily available glass spheres because of the consistency of the particle shapes. However, in Virginia, the test is still performed using the traditional Ottawa sand. Results from tests using the Ottawa sand are adequate as long as the sand meets the required specifications.

Figure 1. Volumetric Method (Sand Patch Test) (ASTM E965)

Circular Track Texture Meter

The second technique for establishing reference texture values applies a device known as the CTMeter (circular track texture meter [CTM], Figure 2). The CTM, which was purchased by VTRC during this study, is operated in accordance with the newly established ASTM Standard E2157 (ASTM, 2002). The CTM has a laser displacement sensor mounted on an arm that rotates on a circumference and measures the texture with a sampling interval of approximately 0.9 mm. Previous studies have reported a good correlation between the MPD as measured by the CTM and the mean texture depth (MTD) measured by the volumetric method (sand patch test, ASTM E965) (Henry, 2000; Abe et al., 2000).

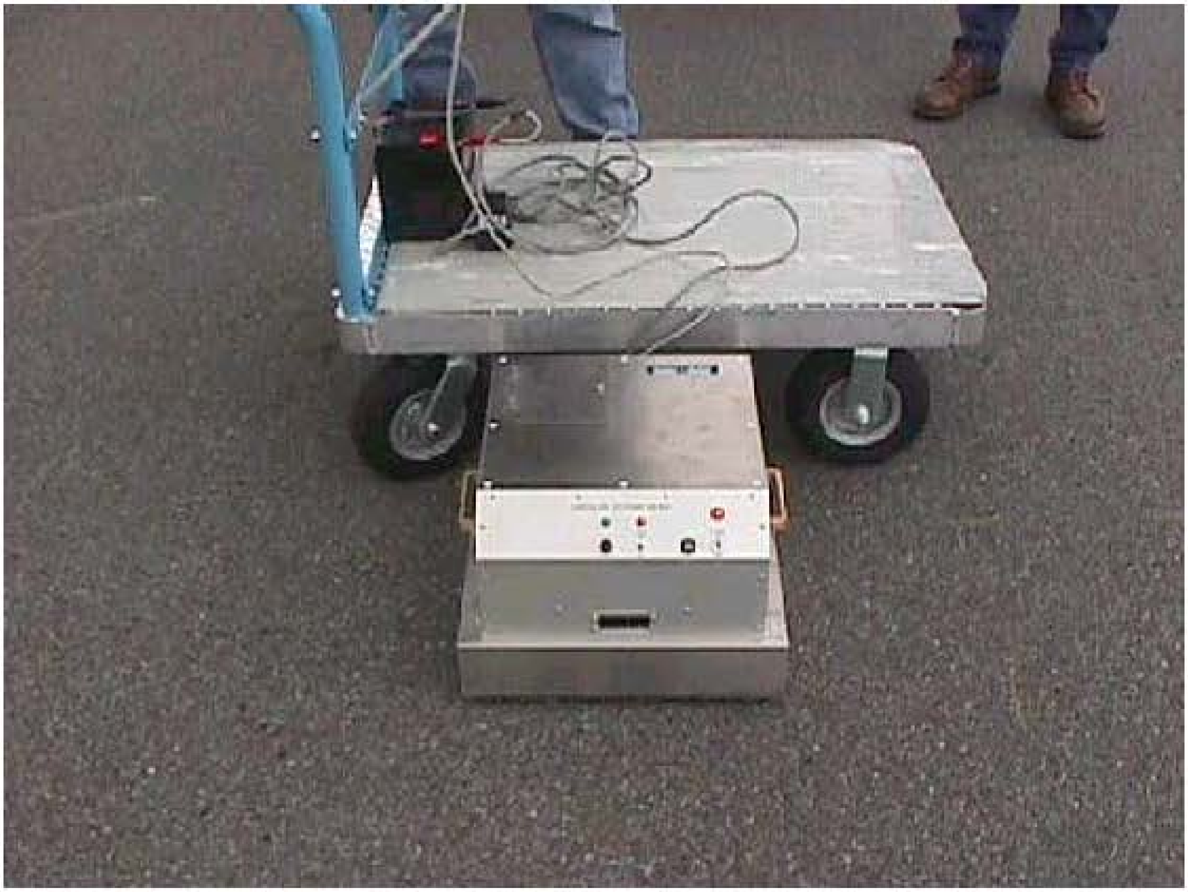


Figure 2. Circular Track Texture Meter

Comparison of Texture Measuring Systems

Static (Reference) Methods

This study provided an opportunity to confirm the agreement reported between the volumetric method (sand patch test) (ASTM E965) and the more contemporary CTM (Abe et al., 2000). A compilation of data from friction workshops at Wallops (Yager, 2000) provided texture values (including sand patch and CTM data) for 26 surfaces. In this compilation, the static texture values reported for each surface represented the average of three tests of each type. The sand patch tests were conducted by an experienced professional, and the CTM tests were conducted by scientists closely involved with the development of the CTM itself.

To supplement the data from the workshops at Wallops, another series of tests was conducted at the Smart Road. For these trials, the sand patch tests were performed by an experienced engineering technician from VTRC and the CTM tests were conducted by one of the authors. One notable difference between the two series of tests was that each pairing of tests from the Smart Road represents a single test (not an average of three tests within a section). Figure 3 illustrates a typical pattern employed to distribute static texture measurements within a test section. Tests were conducted either on the left wheel path or between wheel paths at approximately 23.6, 46.4, and 69.2 m from the beginning of the section. Where both tests were conducted, the sand patch test immediately followed the CTM tests in the center of the circular track used by the CTM. Through use of this approach and two rounds of tests (September 2000 and April 2002), 55 sand patch/CTM test pairs were added to the database from the Smart Road test sites.

A total of 81 pairs of static texture values were available from the two test sites (Wallops and the Smart Road).

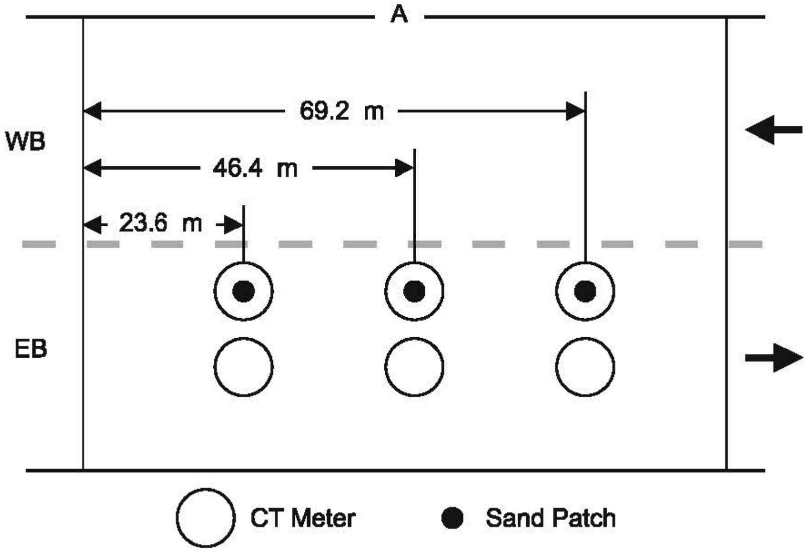


Figure 3. Example Test Configuration for Smart Road. WB = westbound direction, EB = eastbound direction, A = section designation.

High-Speed Systems

Cooperation from the FHWA's Eastern Federal Lands Office permitted a limited comparison of two high-speed texture measuring systems. The tests conducted in August 2000 at the Smart Road included high-speed runs with the ICC and MGPS systems. Obviously, these comparison tests were limited to the surfaces of the 14 Smart Road test sections. Fortunately, both systems supply essentially continuous profiles of texture. By carefully establishing a common starting point, it is possible to generate quickly thousands of texture pairings.

For this cursory comparison, the first set of observations used pairings that were established at 1.0-m intervals. The second set extracted average texture values for the locations that correspond to the static texture readings (the reference values). To obtain these average values (for both systems), the locations of static measurements were first identified within the respective "texture profiles." Then, average texture estimates for that position were generated by using approximately 0.75 m (2.5 ft) of texture readings from the profiles leading up to and away from that position (a total of 1.5 m of dynamic texture profile).

High-speed (Dynamic) versus Static Methods

The texture values provided by the extensive sand patch and CTM tests created an excellent reference against which to evaluate the higher speed, higher volume (or high-density) laser-based texture measurement systems. As discussed in the description of the test sites and test equipment, the static values from Wallops consisted of an average of three measurements within a homogeneous section. This representative value was paired with the overall average of all the high-speed system readings (available at 0.6-m intervals) within that section. For the Smart Road tests, each static measurement was isolated and paired with a representative high-speed estimate. Unfortunately, there were no MGPS data from Wallops available for this comparison.

Negative versus Positive Texture

In addition to the MPD, the analysis software supplied with the CTM produces a root mean square (RMS) value for the profile of the circular track. The RMS is a statistical value, which offers one measure of how much the actual data (measured profile) deviates from a best-fit (modeled profile) of the data. In this application, it also provides for an interesting comparison with the MPD. By reviewing both statistics together (the MPD and RMS), it is possible to make a judgment relating to the kinds of features supplying the texture.

To appreciate the comparison of MPD and RMS, it is important to describe more fully the calculation of the MPD. ASTM and the International Standards Organization (ISO) both describe the MPD calculation as follows:

> The measured profile is divided into segments having a length of 100mm (4 in.). The slope of each segment is suppressed by subtracting a linear regression of the segment. This also provides a zero mean profile, i.e., the area above the reference height is equal to the area below it. The segment is then divided in half and the height of the highest peak in each half segment is determined. The average of these two peak heights is the mean segment depth. The average value of the mean segment depths for all segments making up the measured profile is reported as the MPD (ASTM E1845 [ASTM, 2002]; ISO13473 [ISO, 1998]).

A graphical representation of the MPD calculation is also presented in Figure 4.

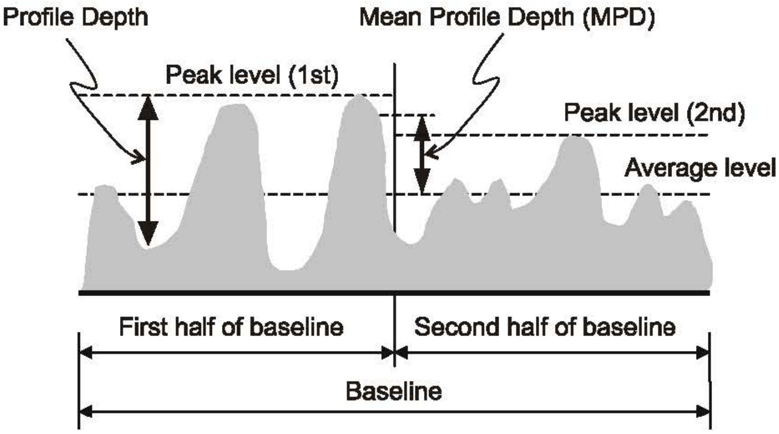
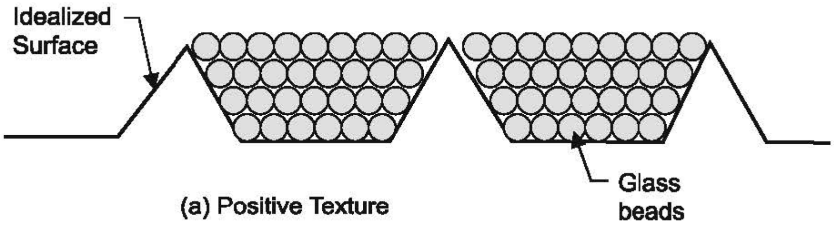
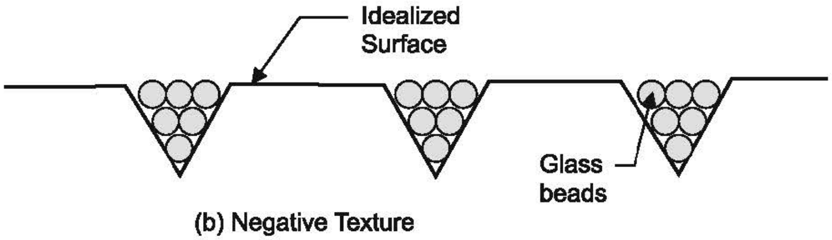


Figure 4. Calculation of Mean Profile Depth

To illustrate further the relationship between the two calculations, consider the idealized surfaces shown in Figure 5. One is simply a mirror image of the other. The RMS for these two lines (surfaces) would be identical. However, the MPD for Figure 5a would be much larger than for Figure 5b. To help visualize that concept, consider these two surfaces filled with glass beads (or Ottowa sand), as would be the practice with a volumetric method (ASTM E965) for measuring texture. The surface represented by Figure 5a exhibits what might be considered positive texture, whereas Figure 5b depicts negative texture. Examples of real-world pavement that provide extremes of positive and negative texture are shown in Figure 6. The chip seal (Figure 6a) delivers considerable "positive" texture. Conversely, the grooved PCC (Figure 6b) provides its macrotexture through a "negative" texture feature. Although no documentation has been provided, correspondence between the developer and the authors confirmed that the ICC system was based on the RMS calculation (personal correspondence from Robert Olenoski, Sr., International Cybernetics Corporation, Largo, FL, 1998).

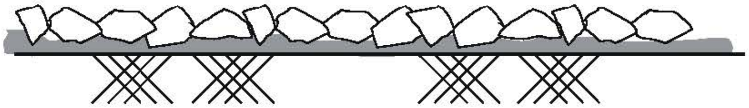


(a) Positive Texture

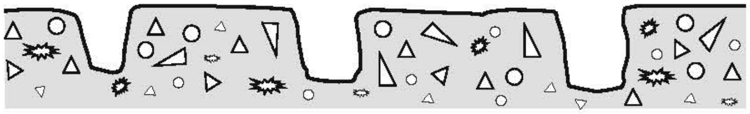


(b) Negative Texture

Figure 5. Positive and Negative Texture



(a) Chip Seal (Positive Texture)



(b) Grooved Concrete (Negative Texture)

Figure 6. Examples of Positive and Negative Texture

The previous discussion of positive versus negative texture demonstrates why it is important to assess critically the practical implications of this approach when considering conventional highway (and airfield) surfaces. To look at how the RMS basis might affect the system capability, a brief exercise was carried out using the CTM's ability to produce MPD and RMS. That exercise involved the following steps:

1. Using CTM data, subtract RMS from MPD for every surface.
2. Determine the magnitude of this difference relative to the RMS value (i.e., [MPD – RMS)/RMS] or TEXRATIO).
3. Sort the dataset by the magnitude (and sign) of TEXRATIO.
4. Assess the qualitative nature of the results (e.g., Do pavements that potentially exhibit negative texture generate relatively smaller MPD values?).
5. Stratify the dataset by the magnitude (and sign) of difference between MPD and RMS (i.e., separate negatively textured surfaces, positively textured surfaces, and neutral surfaces).
6. Add the corresponding texture estimates from the ICC system (within each texture stratification).
7. Model the ICC texture estimate as a function of MPD (from CTM) for each stratification.
8. Compare the correlation among the various stratifications.
9. Determine if the ICC texture correlate better with MPD when the RMS and MPD values are closer (i.e., neutral texture).

Texture Variability

The texture definition provided by these high-speed systems made it possible to conduct an assessment of the amount of variability in these various airfield and highway pavements. This task was not exhaustive and was conducted more as an attempt to put high-speed/high-definition texture data into perspective. Further, these results shed some light on the practical value of the various static (and highly discrete) texture measurements that have traditionally been used.

"Continuous" texture data were available for the ICC instrument from Wallops and the Smart Road. Strictly speaking, these "profiles" of texture were made up of texture estimates for every 0.6 m (2 ft) longitudinally for a test section. To conduct a texture variability assessment, texture profiles were assembled for a selection of test sections. Observations relating to variability were made based on some basic descriptive statistics for each of these representative texture profiles.

FINDINGS AND DISCUSSION

Comparison of Texture Measuring Systems

Because of the unavoidable basic differences between data collection at the Smart Road and Wallops, the comparison of various texture measuring techniques and systems is approached first by separating the results according to test site. If suggested by trends in the separated data, the datasets are brought together for further observation and discussion.

Static (Reference) Methods

Figures 7 through 9 pertain to the static methods of measuring macrotexture. The y-axis in each of these figures refers to the sand patch test results (MTD) (ASTM E965). The x-axis is

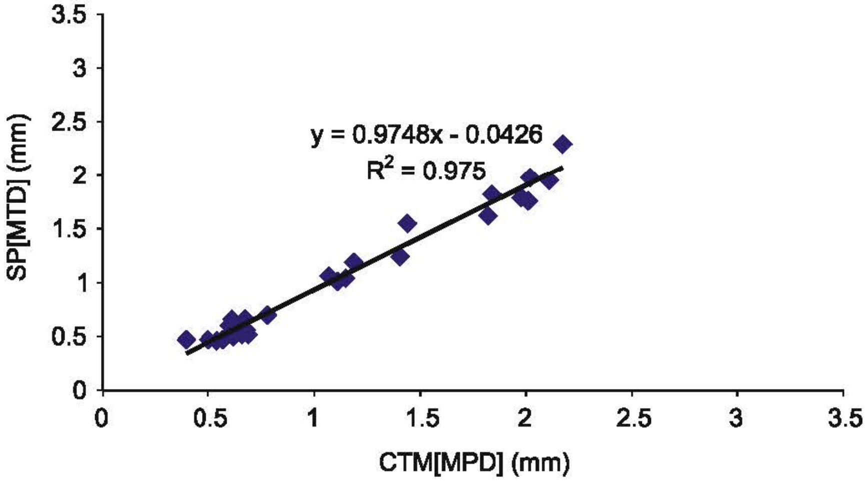


Figure 7. Wallops Static Texture

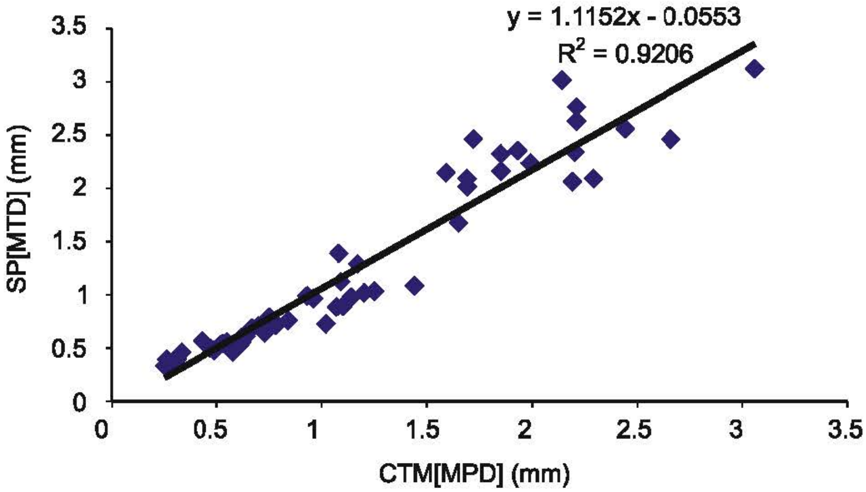


Figure 8. Smart Road Static Texture

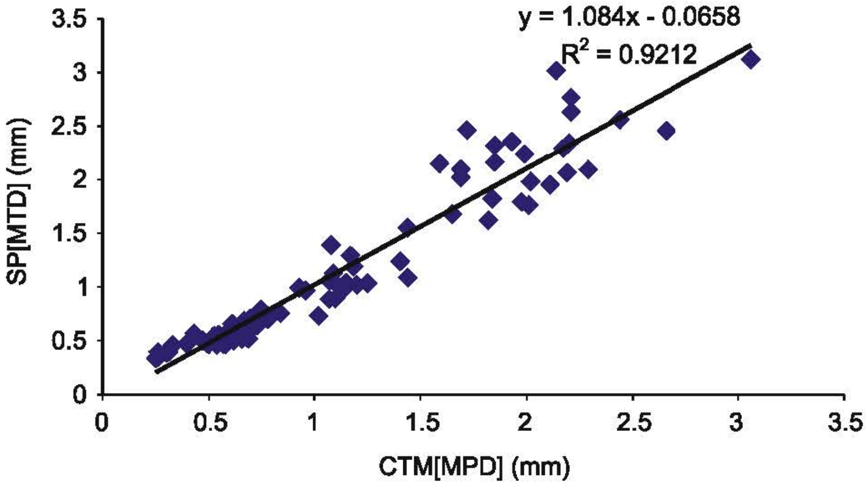


Figure 9. Combined Static Texture

the corresponding MPD as determined from data collected with the CTM. Clearly, noting the R^2 values from each combination of tests, the correlation between the MPD and MTD is quite good. Particularly considering the inherent operator dependence of the sand patch test and the amount of natural variability in surface texture (to be discussed more thoroughly later), it is really quite remarkable that the results of the two tests agreed so well. A combined goodness-of-fit statistic of 0.92 is also consistent with findings from an earlier comparison in which the R^2 was 0.97 (Abe et al., 2000). A y-intercept of less than 0.07 mm (on the combined model) is nearly small enough to ignore and suggests that a 1-to-1 relationship between MTD and MPD would not be an unreasonable approximation.

High-Speed Systems

Figures 10 and 11 reflect the comparison of the ICC estimated texture (ICCTEX) versus the MPD (ASTM E1845) as estimated by the MGPS system. For these tests, the MGPS system was sampling the elevation profile at every 1.0 mm of longitudinal distance along the test track. Although the plot in Figure 10 represents nearly 1,500 pairings, it reflects only texture measured in the center of the eastbound direction.

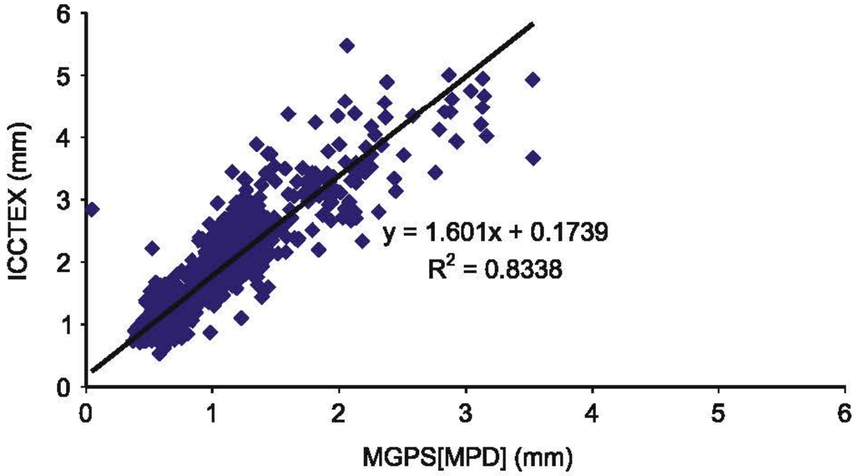


Figure 10. High-speed Comparison: Texture Profiles

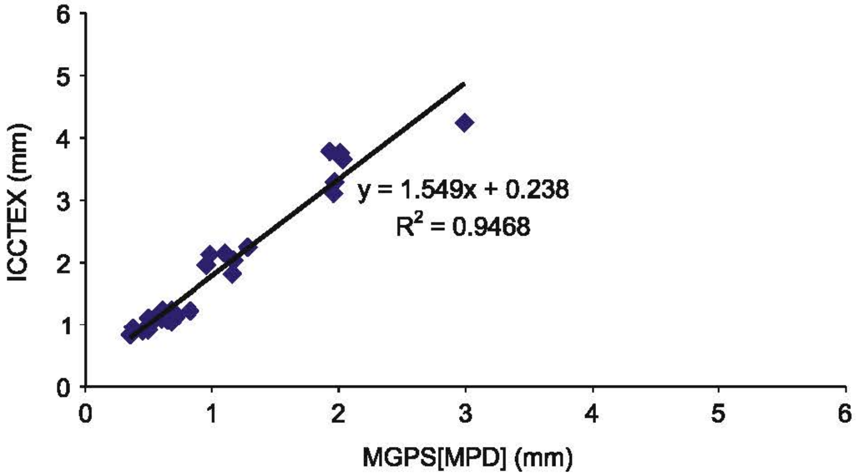


Figure 11. High-speed Comparison: Summary (Static Test) Locations

Figure 11 reports the textures estimated at locations that correspond with the data from the static readings. For these data, the texture values represent an average of all the texture estimates within the 1.5-m vicinity of the static readings. Instead of individual readings, as was the case in Figure 10, these values are averages of several readings. The result is a texture representative from each instrument that encompasses some of the inherent variability (at least longitudinally) of pavement texture. The resulting model produces a much better fit.

Both models exhibit good to exceptional correlation. The ICCTEX appears to relate to the MGPS[MPD] at a 1.5 to 1 ratio with a y-intercept of approximately 0.2 mm (nearly 0).

High-Speed versus Static Methods

Figure 12 brings together the sand patch (MTD) and ICC data for Wallops and the Smart Road. Clearly, the data from the two sites suggest two different relationships. It is important to remember that the sand patch tests at the two facilities were conducted by different individuals. The natural operator dependence of the sand patch test likely contributes to the differences in the predictive equation. As far as the discrepancy in goodness of fit, a primary culprit may be the difference in levels of control (see Test Site description under Methods). Finally, the differences in test surfaces at the two facilities may be the most likely influence on the R^2 and the equation coefficients for the two models. Grooved pavements, for example, are common at Wallops but are inherently difficult to characterize with the sand patch test.

Figure 13 provides a similar breakdown for statically determined MPD (from the CTM) versus the ICC estimated texture. Since the sand patch and CTM results had shown such good agreement earlier, it is of little surprise that the models shown in Figures 12 and 13 would also be fairly consistent. Once again, the data from the Smart Road produce the better fitting equation.

Notice that in both sets of data, there is a grouping of points from Wallops that appear to be outliers. In both cases, these data represent texture estimates on two grooved PCC sections. If these "outliers" are removed, the data from both test sites appear to belong together and provide

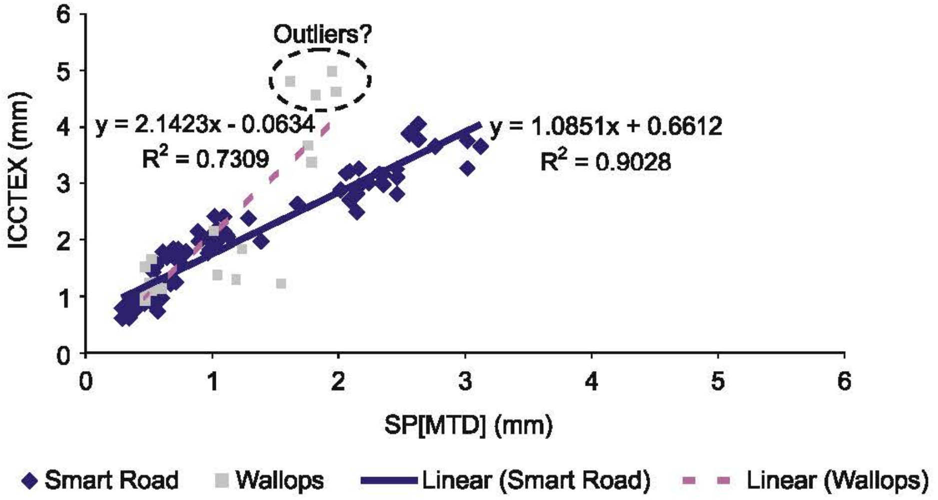


Figure 12. Comparison of Sand Patch (MTD) and ICCTEX Data

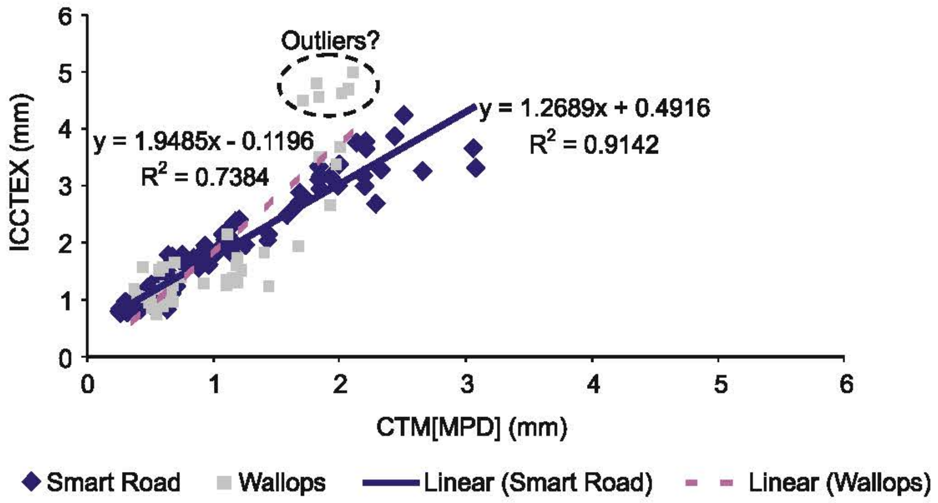


Figure 13. Comparison of CTM[MPD] and ICCTEX

very reasonable combined models, losing very little of the explanatory strength observed in the Smart Road models. The goodness-of-fit statistics for these expanded models are practically equivalent: R^2 = 0.870 for the SP[MTD] model and 0.869 for the CTM[MPD] model. It is interesting to note that the handful (six data points) of grooved PCC tests from the Smart Road did not indicate this "outlying" tendency. Still, good reason remains to suspect that there are issues left to resolve when it comes to measuring texture on grooved pavements.

Fortunately, there were enough data from the testing at the Smart Road to allow a review of the agreement between the MPD as calculated from the MGPS system and the CTM (Figure 14). The goodness of fit is consistent with all of the dynamic versus static texture models created from the Smart Road testing. For this particular model, also note the very small y-intercept value and the nearly 1-to-1 relationship between the high-speed and static methods for estimating the MPD.

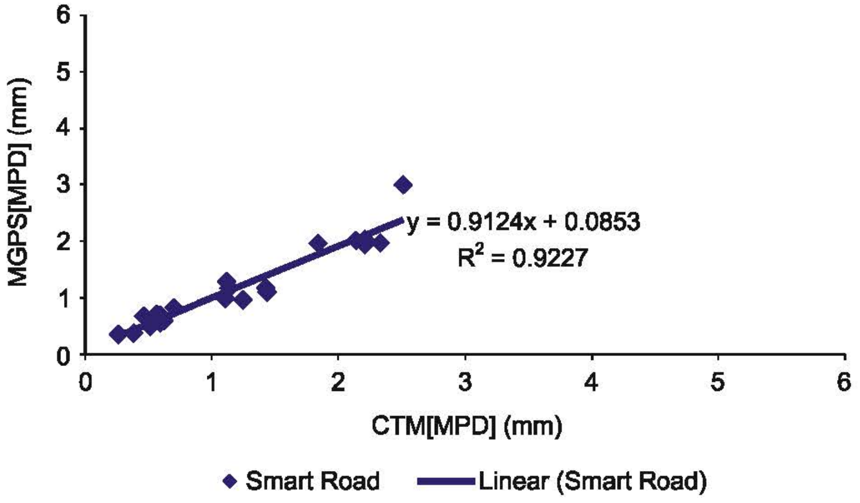


Figure 14. Comparison of CTM (MPD) and MGPS (MPD)

Negative versus Positive Texture

There were 124 texture pairings for which data were available from the CTM and the ICC equipment. Through use of the two indices that can be generated from the CTM data (the MPD and the RMS), the texture orientation (negative, positive, neutral) from each test location was approximated. For the purposes of stratifying the data, test locations for which the MPD was 5% or more than the RMS value were considered to be positively textured. Test locations for which the RMS was 5% or more than the MPD were considered to be negatively textured. For the remainder of the test locations (those for which the RMS and MPD were approximately equal), the surfaces were categorized as neutral in texture. Although there were a total of 28 test surfaces at the two facilities, the surfaces can be more generically grouped into 22 surface types. Table 4 presents these surface types, along with the number of individual test locations within each type found to exhibit positive, neutral, or negative texture.

Table 4. Surface Types and Texture Orientation

	Texture Orientation		
Surface Type/Description	**Positive**	**Neutral**	**Negative**
HMAC Surface, 9.5 mm	21	12	9
HMAC Surface, 12.5 mm	3	2	1
SMA, 12.5 mm	2	8	2
SMA, 19.0 mm	2	6	4
Open-Graded Friction Course	6	12	6
HMAC – Runway Surface (small aggregate.)	2	1	0
HMAC – Runway Surface (grooved)	0	1	0
Runway Anti-Skid (AC surface treatment)	1	0	0
Microsurfacing single (AC surface treatment)	1	0	0
Microsurfacing double (AC surface treatment)	1	0	0
Slurry Seal (AC surface treatment)	1	0	0
Rejuvenated HMAC without Sand	0	1	0
Rejuvenated HMAC with Sand	0	1	0
Driveway Sealer (over PCC)	0	0	1
Light-textured Skidabrader® (PCC)	0	0	1
Med-textured Skidabrader® (PCC)	0	2	1
High-textured Skidabrader® (PCC)	1	0	0
Very high-textured Skidabrader® (PCC)	1	0	0
Canvas Belt-Finished (PCC)	1	0	0
Burlap-Dragged (PCC)	1	0	0
Float Finished PCC	0	1	0
Grooved Concrete (broom, burlap, or belt)	0	0	8
Totals	**44**	**47**	**33**

Note: The Skidabrader® is a shot-blasting device used to restore texture to traveled surfaces. It is operated by Humble Equipment Corporation, Huntsville, Alabama.

Many of the test locations within the assortment of surface types had varying texture characteristics. In general, however, the conventional HMA concrete (HMAC) surface mixes, the surface treatments (runway and/or highway), and the high-textured to very high-textured Skidabrader® surfaces tended to be positively textured (gray shading). (The Skidabrader® is a shot-blasting device used to restore texture to traveled surfaces. It is operated by Humble Equipment Corporation, Huntsville, Alabama.)

The SMA, OGFC, medium-textured Skidabrader®, and rejuvenated HMAC surfaces all tended to be fairly neutral (shaded boxes). Finally, the grooved concrete surfaces provided the most consistent examples of negatively textured pavements (double boxes).

Given the strong reliance of the ICC system on the RMS calculation, it was important to compare the relative ability of the system to correlate with "ground truth" (i.e., reference) measurements within the various orientations of texture. Table 5 reports the best-fit linear model (ICCTEX as A function of CTM[MPD]) for each classification of texture.

As expected, the ICC system demonstrated its best correlation within the neutral texture regime, although the model for positively textured surfaces was also quite reasonable. Fortunately, the majority of the more common highway surfaces fall within the positively and neutrally textured categories (9.5 mm and 12.5 mm HMAC, SMA, OGFC, etc.). Of course, grooved hydraulic cement concrete surfaces are the exception.

Table 5. Estimating Texture Across Classifications

Orientation	Linear Model		Goodness of Fit, R^2
	Slope	**y-intercept**	
Positive	1.1567	0.4879	0.8591
Neutral	1.3671	0.4476	0.9268
Negative	1.3883	0.4114	0.7811

Texture Variability

To put texture and its variability into perspective, it is helpful to see a texture profile on a real-world scale. Figure 15 presents the texture profiles for the center of the eastbound lane of the first 700 m of the Smart Road test bed. The lower running profile represents data from the MGPS system, and the higher running profile is the ICC texture. Note that both systems respond fairly dramatically to the more aggressive textures of the SMA and the grooved surface of the bridge deck.

Figure 16 summarizes the variability on seven of the test sections. In this instance, the data are presented through a high-low-close chart on which the mean and range of measured values are presented. These seven surfaces were selected to cover the gamut of common surfaces that might be expected on typical highways and runways. The profiles from which these statistics were generated ranged in length from 60 to 150 m of texture.

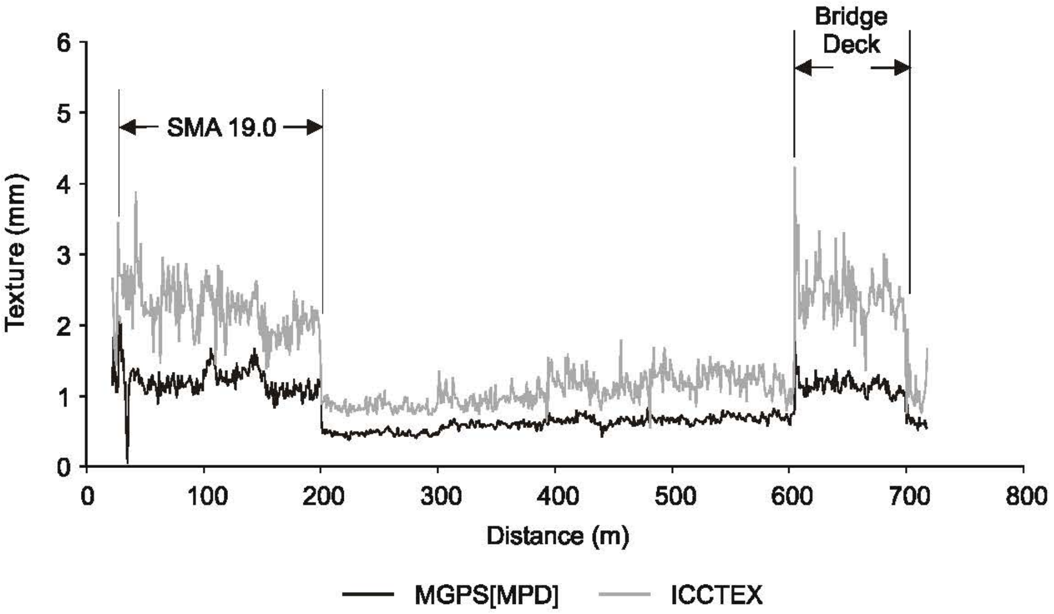


Figure 15. Smart Road Continuous Texture: Center of Eastbound Lane. MGPS(MPD) = mean profile depth via MGPS system, ICCTEX = ICC proprietary texture estimate.

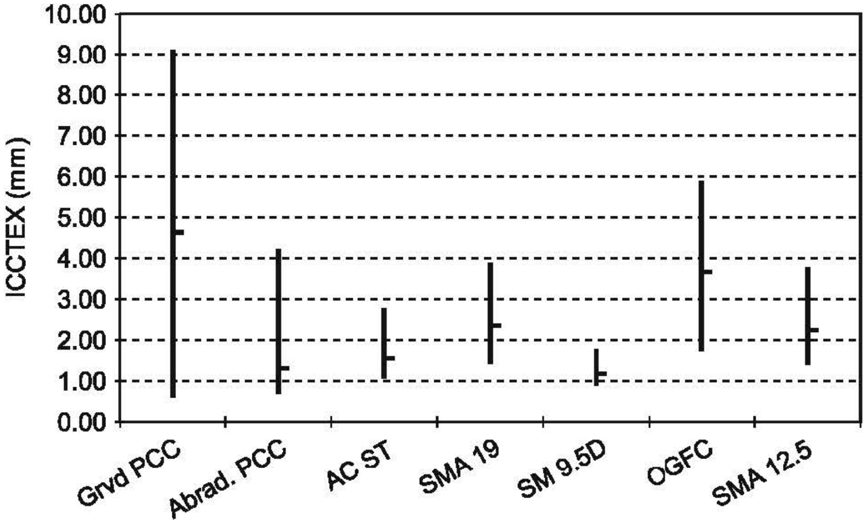


Figure 16. Texture Variability. Grvd PCC = grooved portland cement concrete, Abrad. PCC = Skidabrader® treated PCC, AC ST = asphalt cement surface treatment, SMA 19 = 19 mm stone matrix asphalt, SM 9.5 = 9.5 mm surface mix, OGFC = open-graded friction course, SMA 12.5 = 12.5 mm SMA.

The texture of the grooved concrete pavements fluctuated from approximately 0.6 mm to just over 9.0 mm of texture (as measured with the ICC system) in one 100-m test section. The more aggressively textured HMA surfaces (SMA and OGFC) also had high average textures and significant variability. The surface treatment and the 9.5 mm surface mix (SM 9.5D) had more stability throughout the section but still varied as much as 1 to 2 mm over fairly short distances (100 m).

On a closing note, Table 6 lists the mean texture readings from the ICC equipment and the average texture estimates supplied by one of the static methods (the MPD from the CTM). This table also includes a measure of the amount of range observed for texture over the length of each test section. The values reported for the static device represent only three measurements total, whereas the dynamic data represent a minimum of 99 readings per test section. It is important also to note out that the dynamic data came from purely longitudinally oriented measurements whereas the CTM data, by their nature, provide more of a three-dimensional view of the surface. By rotating through a full circle as it collects data, the CTM provides a texture estimate that is without directional bias (assuming that such bias might exist).

Table 6. Dynamic versus Static Variability

	Dynamic Data		**Static Data**	
Type	**Mean ICCTEX**	**Range (as % of mean)**	**Mean CTM[MPD]**	**Range (as % of mean)**
Grooved PCC	4.64	184	2.07	44
Skidabraded™ PCC	1.31	270	0.89	20
Surface treatment	1.56	110	1.16	4
SMA 19	2.35	105	1.11	8
SM 9.5D	1.18	77	0.53	15
OGFC	3.66	114	2.31	54
SMA 12.5	2.25	106	1.07	25

CONCLUSIONS

- *Results from the use of the CTM and the volumetric method (sand patch test, ASTM E965) showed remarkable agreement.* For all practical purposes, the output from the two static texture-measuring techniques is equivalent.

- *For the surfaces at the Smart Road, the ICC estimated texture and the MPD as measured with the MGPS system showed very good agreement (were highly correlated).* However, the ICC values were typically 50 percent larger than the dynamically determined MPD.

- *For the surfaces at the Smart Road, results with the high-speed texture measuring systems were highly correlated with those of the static referencing methods.* The very best agreement was between the MGPS system and the CTM (both systems were supplying MPD, one dynamically and the other statically). However, all of the comparison models demonstrated very high correlations.

- *With the exception of grooved PCC test sections, the data from Wallops suggested a good agreement between results obtained with reference texture-measuring methods and high-*

speed equipment. The data from the grooved concrete pavements suggest that some issues remain to be resolved, as discussed in "Suggestions for Further Research."

- *The ability to calculate MPD and RMS (as is possible with the CTM) offers the unique capability to assess the "orientation" of texture, which enables the engineer to determine what types of features are supplying the macrotexture (negatively, positively, or neutrally textured).*

- *The ICC system provides good estimates of macrotexture on positively textured surfaces* (e.g., most dense-graded HMAC mixes and surface treatments).

- *The ICC system provides excellent estimates of true texture on neutrally textured surfaces* (e.g., many dense-graded HMAC mixes, SMA mixes, and OGFCs).

- *The agreement between statically measured texture and the ICC texture measurement system is less impressive with negatively textured surfaces* (e.g., grooved PCC).

- *The "texture profiling" possible with dynamic texture measuring devices confirms that macrotexture on typical pavements has considerable fluctuations. Even the most advanced static testing methods will have difficulty characterizing the extent of that fluctuation.*

RECOMMENDATIONS

1. *VDOT's Pavement Evaluation Section as well as other researchers in this field should use the CTM to establish "ground truth" macrotexture estimates.* Although it comes at considerable relative expense, the speed, automation, and operator independence associated with the CTM make it the superior method for collecting reference macrotexture estimates.

2. *VDOT's Pavement Evaluation Section and Pavement Management Team should use high-speed texture measuring systems to survey the macrotexture on traveled surfaces.* Systems that provide a measure of MPD and RMS are particularly useful, since the combination of indices can provide a characterization of the features supplying the macrotexture (i.e., whether it is positively, negatively, or neutrally textured).

3. *VDOT's Pavement Evaluation Section and Asphalt Materials Section should use the ICC system for most dense- and gap-graded HMAC surfaces and most conventional bituminous-based surfaces treatments.*

4. *VDOT's Pavement Evaluation Section and Concrete Materials Section should use the ICC system on transversely grooved surfaces with caution until further research suggests otherwise.*

5. *VDOT's Asphalt Materials Section and State Specifications Engineer should apply high-speed texture measuring systems to characterize surface uniformity (variability) rapidly.*

SUGGESTIONS FOR FURTHER RESEARCH

Surface Uniformity

Since the inception of this project, high-speed texture measurement has been targeted as a potential tool for combating HMA mix segregation. In early 2002, preliminary findings from this study (and others) had demonstrated enough promise to prompt the initiation of a study designed to pursue just such an application. This ongoing project, entitled "Effect of HMA Mix Characteristics on Surface Macrotexture," is approaching this goal by first determining what characteristics of an HMA mix can be used to predict its ideal texture. The findings from this effort will form the basis of a VDOT special provision for mix uniformity (an "anti-segregation specification"). The fieldwork associated with this work was completed in late fall 2002, and a final report will be published in the spring of 2003.

Grooved/Tined Pavements

Not only are grooves and tines a popular macro-texturing technique for pavements and runways, they are also a required feature on VDOT's bridge decks. In theory, it should be possible to characterize these transverse "channels" with high-definition texture measurements that are taken along a longitudinal path (perpendicular to tine/groove). Unfortunately, the findings of this study suggested less success than expected, at least as compared with two very effective referencing systems. For the ICC equipment, this shortcoming may relate to its dependence on the RMS calculation. This argument was supported by the findings and discussion pertaining to negatively textured surfaces. It is also possible, however, that the less-impressive correlations for grooved/tined surfaces relate to an inability of the reference texture-measuring systems to reflect fully the very directional nature of the grooves. More work is required to determine exactly where the limitations exist and what steps may be taken to mitigate those limitations.

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