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The activities discussed in this report represent the next step in the process of understanding the relationship between the uniformity and surface characteristics of hot-mix asphalt. The study documents the typical "texture profile" for Virginia's most common surface mixes. It revisits the texture-fluctuation provision proposed in the earlier project and delves into an expanded use of elevation profiles for promoting uniformity.

Although the major findings and conclusions from this work do not specifically support a texture-based "segregation specification," the study does advocate continued dedication to material and construction uniformity. Alternatives to a texture-based specification include quality measures that recognize variability of traditional quality characteristics (such as percent defective and percent within limits specifications) and a new approach to reporting and using ride quality data, i.e., "roughness profiles."

Whether specifically required or used voluntarily to comply with provisions that have stringent variability components (e.g., ride, texture, density), a properly functioning and operated material transfer vehicle is a proven contributor to good hot-mix uniformity. If the vehicle (at $900/mile) eliminates an estimated $3,000 per lane-mile loss in service life due to low-level segregation, the benefit-to-cost ratio is greater than 3.

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FINAL REPORT

TEXTURE, RIDE QUALITY, AND THE UNIFORMITY OF HOT-MIX ASPHALT PAVEMENTS

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Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
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the University of Virginia)

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DISCLAIMER

ABSTRACT

Two years ago, the author completed a study with researchers at Virginia Tech that was designed to develop a tool to measure and control segregation of hot-mix asphalt pavements. This earlier work focused on the application of high-speed texture measurements and ultimately proposed an approach that would discourage segregation by establishing limits on allowable fluctuation of pavement macrotexture. Rather than emphasize segregation detection and measurement, the proposed special provision promoted new-surface uniformity.

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INTRODUCTION

Two years ago, the author completed a study with researchers at Virginia Tech that was designed to develop a tool to measure and control segregation of hot-mix asphalt (HMA) pavements (McGhee, Flintsch, and Izeppi, 2003). The work focused on the application of high-speed texture measurements and ultimately proposed an approach that would discourage segregation by establishing limits on allowable fluctuation of surface macrotexture. Rather than emphasize segregation detection and measurement, the proposed special provision promoted new-surface uniformity.

Relating Texture to Placed Mix Properties (Interim Activity)

The earlier work was constructed around a series of field investigations that targeted properties of segregated (or non-uniform) HMA pavement sections (McGhee et al., 2003). These investigations involved four general mix classifications: dense-graded 9.5 mm and 12.5 mm surface mixes, 19.0 mm surface and/or intermediate mixes, and 25.0 mm base mixes. The field investigations are explained in detail in the earlier report but basically involved a 120- to 150-foot test section at each of eight sites. Within each test section, extensive non-destructive density and texture measurements were made, followed by the extraction of actual material samples (via coring). The primary function of the cored material was to allow a comparison/verification of the mix characteristics observed visually.

The author revisited the data from the 2003 study (McGhee et al., 2003) to explore the use of “texture profiles” to augment more conventional quality measurements (McGhee, 2004). This follow-up work involved a formal attempt to relate surface texture data and in-place asphalt concrete (AC) content and void level. Figures 1 and 2 summarize the results of a simple correlation analysis. Note the negative correlations between texture and asphalt content (AC %) and the consistent positive correlation with void level (the converse of density). For most mixes and measures of texture, the correlations are significant (greater than 0.4). The correlation with void level is much better than for AC content. As discussed in the earlier report, the weaker correlation with AC content is likely tied to temperature segregation. That is, although the mix itself may arrive with its constituents well blended (liquid AC was relatively consistent), temperature differentials prevented uniform compaction and resulted in areas of insufficient compaction.

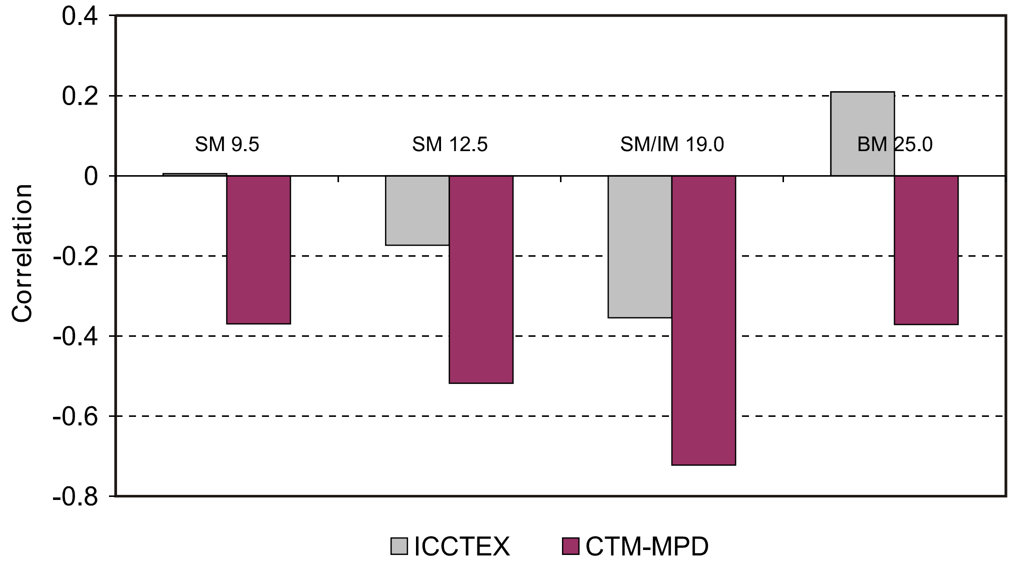


Figure 1. Correlation of AC Content (P_b%) with Texture, All Mixes. SM 9.5 = surface mix with 9.5 mm nominal maximum aggregate size (NMS). SM 12.5 = surface mix with 12.5 mm NMS. SM/IM 19.0 = surface/intermediate mix with 19.0 mm NMS. BM 25.0 = base mix with 25.0 mm NMS. CTM = circular track texture meter (ASTM E2157); CTM-MPD = CTM-based mean profile depth (MPD – ASTM E1845); ICCTEX = texture estimate from proprietary system developed by International Cybernetics Corporation.

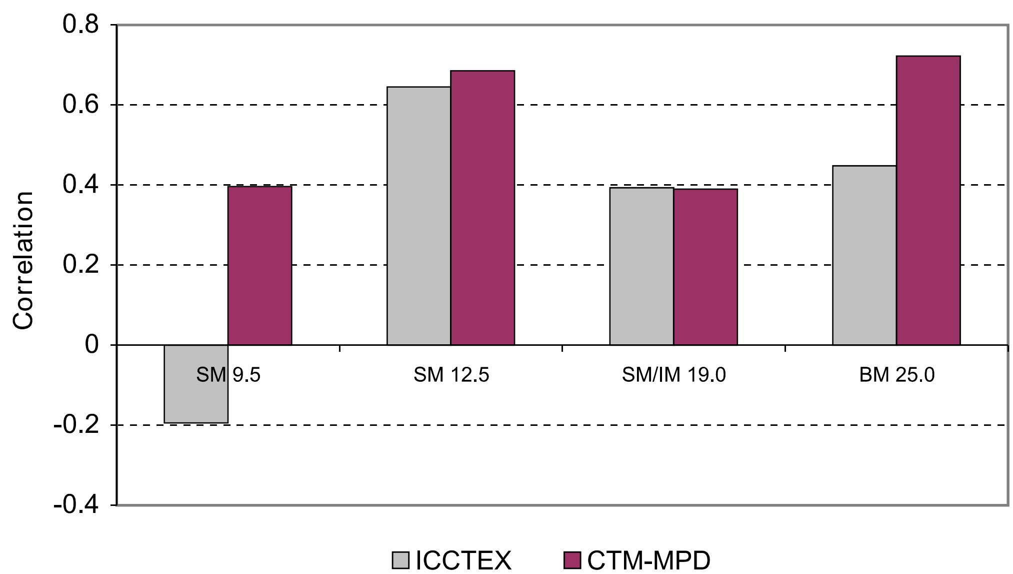


Figure 2. Correlation of Air Voids (V_a from cores) with Texture, All Mixes.

It is also worth noting that there is practically no correlation between high-speed texture (ICCTEX) and either quality characteristic (AC or void level) for the smaller-stone mixes. There are likely several reasons for this. First, it is difficult to match exactly the dynamically collected data (collected at 35 mph) to the core locations. Second, even if the high-speed tests were shown to pass precisely over the static testing (and coring) locations, the dynamic test is only a linear

(2-D) representation of the three-dimensional characteristics of texture. Third, the International Cybernetics Corporation (ICC) texture-estimating system used for this work employs height-sensing equipment that was originally designed for elevation profile measurement, not texture measurement. Although the system has been shown to provide reasonable texture estimates on surfaces with moderate to aggressive textures (McGhee and Flintsch, 2003), the less-pronounced texture of most smaller-stoned (9.5 mm) mixtures may well be approaching the lower threshold of the equipment. Finally, traditional segregation is simply less of an issue with the smaller-stoned, dense-graded mixes.

Continuously Reported Smoothness Data

Although most contemporary high-speed profiling systems do not simultaneously capture texture data, the information they do collect can be relevant to traveled surface uniformity. How much an elevation profile can reveal about surface uniformity depends on how the profile is analyzed and what is reported from the analysis.

One of the more promising tools for assessing uniformity through elevation profile data is the roughness profile, a concept first introduced 15 years ago by researchers at the University of Michigan's Transportation Research Institute (Sayers, 1990). A roughness profile, as distinguished from a simple elevation profile, consists of a line-plot produced from a series of roughness index values (e.g., International Roughness Index, or IRI). Recently, the Federal Highway Administration released software that, among other things, makes working with roughness profiles very easy. This software, known as ProVAL and available at http://www.roadprofile.com/, provides for continuously reported roughness indices (i.e., roughness profiles). It further permits an analyst to establish target roughness ranges with which the software can critically assess any profiled surface with a fine degree of scrutiny.

Advances in Hot-Mix Asphalt Technology Applied in Virginia

Since the first segregation study was completed, the use of stone matrix asphalt (SMA) in Virginia has increased from approximately 14 thousand tons in 1999 to a projected 450 thousand tons in 2005 (Bailey, 2004). SMA is by design a coarse, sticky, and all-around more complicated material to produce and place. Using traditional production and placement techniques, SMA would be a natural "segregator." Fortunately, the hot-mix community (to include the industry and VDOT) recognizes that successful SMA is not possible with traditional processes. Contractors have gone to great lengths to acquire and use high-quality aggregates. Additional checks are in place at the plants to ensure uniform blending at the higher temperatures required by the premium binders. During placement, a material transfer vehicle (MTV) is required, and many contractors are using oversized hoppers to ensure an even delivery of material to the paver. Finally, several contractors are using the heavier double tamping-bar paver to give themselves every advantage in attempting to achieve adequate and uniform compaction.

PROBLEM STATEMENT

The equipment used in the earlier work (McGhee et al., 2003) does not appear to be sensitive to texture fluctuation in fine mixes (e.g., dense-graded 9.5 mm Superpave® mixes). For that matter, the finer mixes used in Virginia generally do not pose a significant threat to segregation. At the same time, the much coarser SMA is rapidly emerging as the surface of choice for the most heavily traveled facilities in Virginia. Although steps are taken to mitigate the potential for segregation, these mixes have some impressive, but as yet undocumented, texture characteristics. Finally, recent advances in elevation profile analysis suggest that it may be time to revisit the potential of conventional profilers for maximizing new surface uniformity.

PURPOSE AND SCOPE

This project explored the relationship between the uniformity of hot-mix asphalt and measurable surface characteristics. The study documents the typical texture profiles for Virginia's most common surface mixes. It revisits the texture-fluctuation tool for ensuring uniformity proposed in McGhee et al. (2003) and delves into an expanded use of elevation profiles for promoting HMA uniformity.

METHODS

Field Investigation

Mix Selection

Test sections (projects) were selected to represent the most typical HMA surfaces in Virginia. Given the issues discussed in the "Introduction" regarding the finer dense-graded mixes, more emphasis was given to selecting and testing the SM 12.5 mm (i.e., Superpave) mixes. Since the use of SMA has grown dramatically in recent construction seasons (and is showing no sign of slowing down), a special effort was made to gather data on a good cross-section of SMA surface mixes.

Profile and Texture Measurement

Once the candidate surfaces had been selected, they were tested with a conventional inertial road profiling system equipped with a high-speed texture-estimating system. For the purposes of this research, the term *texture* refers to an estimated *macrotexture*. This estimated macrotexture comes from an algorithm based on root mean square (RMS) developed by the fabricator of the profiler, ICC. Strictly speaking, this RMS-based index is insufficient for representing real surface macrotexture since it cannot distinguish between positive and negative components of surface texture. For that reason, the texture estimates are generally labeled as ICCTEX values, and no attempt was made to relate them to standard measures of texture (e.g., as described in ASTM E1845 and ASTM E965). A more complete discussion of pavement texture and texture-measuring devices can be found elsewhere (Henry, 2000; McGhee and Flintsch, 2003).

As originally proposed, the profile and texture surveys were to be conducted in concert with VDOT's rideability program for maintenance resurfacing. This program annually administers a smoothness provision to approximately 700 miles of new surface (Reid and Clark, 2004). Unfortunately, the fabricator of VDOT's inertial profilers was unable to supply a compatible texture-estimating system for the profiler that performs most of the rideability testing. Consequently, testing for this research project used an earlier generation profiler, one that had originally been requisitioned by the Virginia Transportation Research Council (VTRC) to experiment with high-speed texture measurement. This system was still functional but not routinely used for ride quality testing. Having to resort to an alternate profiling unit not only limited the available dataset but also resulted in a significant delay in acquiring sufficient data and additional costs for the added operator and profiler time.

Once data collection finally began, elevation and texture profiles were collected for the length of each selected resurfacing project. The elevation profiles provided an elevation point at 3-inch (approximate) intervals for the left and right wheelpaths. The texture estimates (ICCTEX) were recorded at 1-foot intervals and represent the left wheelpath and a point exactly between the two wheelpaths (i.e., the lane center).

Data Reduction

Texture Data

Although texture was sampled at 1-foot intervals longitudinally, it was reported at a 2-foot interval to supply a texture profile. These texture profiles were used to characterize section texture using two approaches. The first involved producing simple descriptive statistics for the length of each project. Using these descriptive statistics, the following summary data were produced:

- ICCTEX averages and standard deviations (SD) by project
- ICCTEX averages and SDs by mix classification.

To represent the texture characteristics on a typical pay lot of surface better, 10 samples of approximately 52 feet each were selected from within each project-long texture profile. The length of these pay lots was set to correspond with that used with VDOT's Special Provision for Rideability. The following summary data were produced using only data from the 10 pay lot samples:

- ICCTEX averages and SDs (project by project)
- ICCTEX averages and SDs by mix classification
- frequency distributions for texture
- frequency distributions for texture fluctuation (texture SDs).

The frequency distributions for texture SD were prepared to contrast typically observed fluctuation with the targets set forth in the previously proposed Special Provision for Uniformity (McGhee et al., 2003). For the two types of surface mixes tested previously, the targets are repeated in Table 1. These targets provide typical "bin" values for the frequency distribution analysis.

Table 1. Proposed Targets for Texture Fluctuation

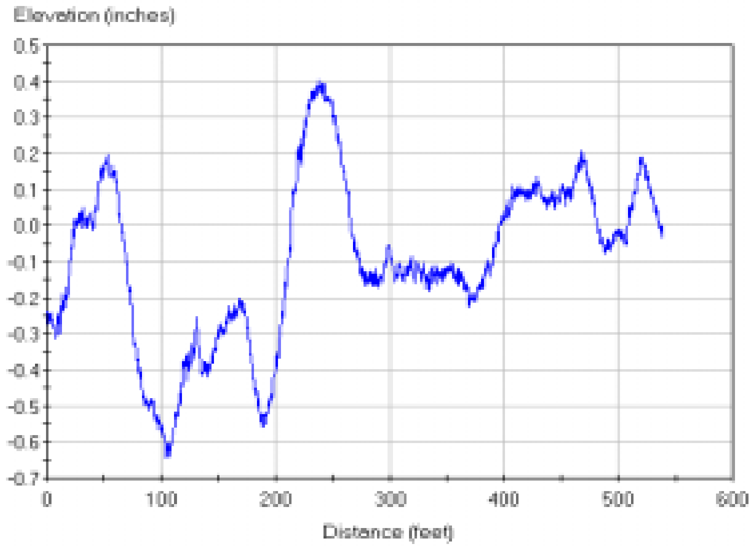
Standard Deviation of Texture		**Price Adjustment (% Unit Price)**
SM 9.5	**SM 12.5**	
0.05 and under	0.10 and under	105
0.06 to 0.10	0.11 to .20	103
0.11 to 0.15	0.21 to 0.25	100
0.16 to 0.20	0.26 to 0.30	90
0.20 to 0.25	0.31 to 0.35	80
Over 0.25	Over 0.35	Remove and replace

Profile Data

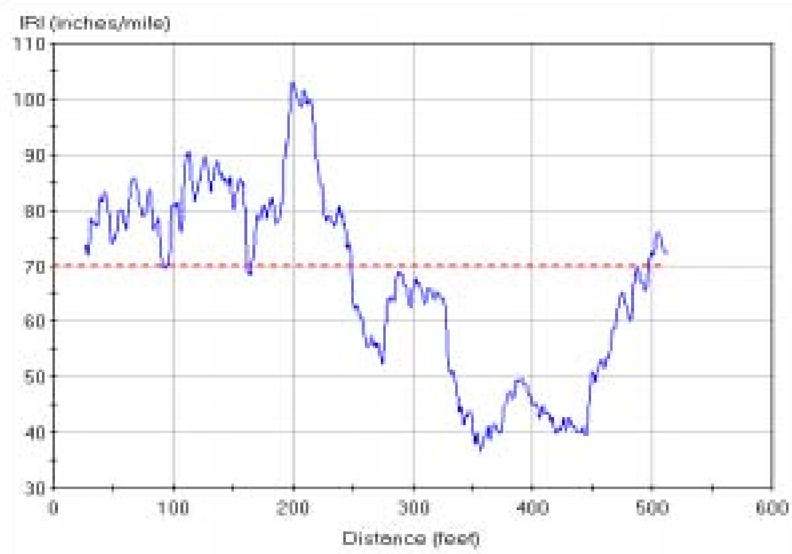
The elevation profile data were used to characterize ride quality. Using the standard analysis and reporting software supplied by ICC, IRI values were generated to represent each wheelpath and the average of the two wheelpaths for each project and each pay lot sample. IRI values for each pay lot were summarized for comparison with texture fluctuation.

The elevation profiles were also exported into ProVal where continuously reported IRI (a.k.a. roughness profiles) were produced and analyzed. These roughness profiles applied the same base length as the standard VDOT pay lot for smoothness, approximately 52 feet. The difference is that VDOT's conventional pay lot uses a discrete 52 feet of elevation profile with one IRI value representing the entire lot. With the roughness profile, this 52-foot base length slides forward one elevation point at a time, producing a continuous series of IRI values, each representing 26 feet before and after any given point along the project. Figure 3 illustrates the difference between the standard "discrete" reporting and the continuously reported IRI with the sliding 52-foot base. Note that Figures 3b and 3c are in general agreement as to which portions of the profile exhibit higher IRI values. Note also that the continuously reported IRI reveals considerably higher localized roughness. Instead of one number to represent all the roughness activity within a 52-foot pay lot, the continuously reported IRI provides one number for every elevation sample. For the example shown in Figure 3, the 540-foot-long project would be entirely represented by just 10 IRI values using the traditional approach. With continuously reported IRI and an elevation sample every 3 inches, the same project would be defined by a practically continuous stream of 2,160 IRI points.

ProVal was used to characterize ride quality as viewed through the continuously reported IRI (Figure 3b). Table 2 is an example of the very simple distribution that summarizes the ride character for the short profile from Figure 3a. Using this feature of ProVal, along with a similar breakdown for the IRI statistics by traditional pay lot, it was fairly easy to contrast the relative discriminating power of the traditional pay lot and the continuously reported IRI.



(a)



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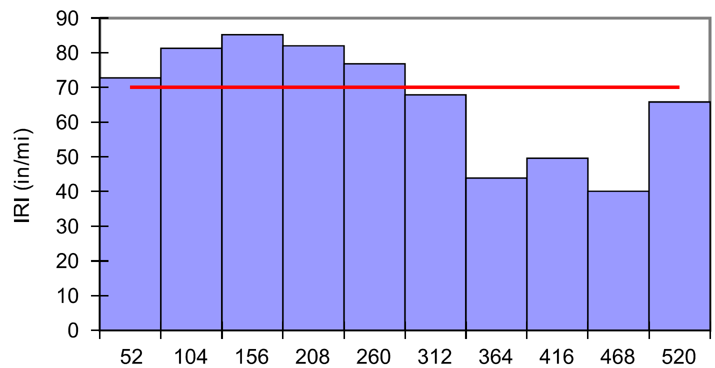

(c)

Figure 3. (a) Elevation profile; (b) corresponding roughness profile generated within ProVal (note 70 in/mi upper limit for IRI); (c) corresponding IRI for traditional pay lots (note 70 in/mi upper limit for IRI).

Table 2. Histogram of IRI from Continuously Reported IRI in Figure 3

Roughness Range (in/mi)	Percent of Pavement
Below 0.0	0.0
0.0 to 10.0	0.0
10.0 to 20.0	0.0
20.0 to 30.0	0.0
30.0 to 40.0	3.9
40.0 to 50.0	20.1
50.0 to 60.0	9.2
60.0 to 70.0	19.4
70.0 to 80.0	21.6
80.0 to 90.0	20.2
90.0 to 100.0	3.8
100.0 to 110.0	1.8
110.0 to 120.0	0.0
Above 120.0	0.0

FINDINGS

Test Matrix

Table 3 summarizes the test matrix that serves as the foundation for this study. These projects represent typical paving activity from any construction season. The research team was unaware of any major segregation issues in surface mixes during the 2004 season and made no attempt to target projects with segregation issues. The relative number of projects (and mileage) tested reflects the emphasis placed on the larger stone Superpave mixes (SM 12.5) and SMA. The 9.5 mm SMA projects also appear to have received less attention, although it is important to point out that the smaller stone SMA has to date seen much less application. The dataset shown here represents a substantial portion of the smaller stone SMA that was placed last season. Texture estimates are discussed in more detail later, but the relatively minor overall texture difference between the two Superpave mixes (SM 9.5 and SM 12.5) can be noted.

Table 3. General Statistics from Field Investigation

Mix Classification	No. Projects Tested	Total Length Tested (mi)	Average IRI (in/mi)	Average ICCTEX (mm)
SM 9.5	3	15.4	71.3	1.30
SM 12.5	12	67.8	68.4	1.32
SMA 9.5	4	35.3	60.5	2.01
SMA 12.5	13	90.4	67.1	2.43
Totals	32	209		

IRI = International Roughness Index, ICCTEX = texture estimate from ICC system.

Characteristics of Estimated Texture

Project-long Data

Table 4 provides statistics drawn from project-long texture profiles. Included are texture SD and coefficient of variation (COV) for the left wheelpath and lane center. Consistent with observations made in the first study (McGhee et al., 2003), texture appeared to fluctuate less with the SM 9.5 mixes, even though overall texture (wheelpath or lane center) was essentially equal to that measured on the SM 12.5 mm mixes.

Although 15 miles of surface (as tested for the SM 9.5 mixes) is far too short to allow general conclusions regarding exhibited texture, it is important to point out that the observed texture levels for these mixes is consistent with those in the previous study (McGhee et al., 2003). These relative texture levels were also observed in a study of high-speed texture measurement (McGhee and Flintsch, 2003) and were informally documented in a friction database developed in VDOT's Material Division (Hughes, 2004).

The consistent difference in texture between the wheelpath and the lane center is also worth noting. There are likely two primary contributors to this phenomenon. The first involves the feed of material around the auger gearbox typically located under the center of the paver. If the material level at the augers runs low, the point where the left and right augers meet will be deficient of material and a coarseness at the mat center will result (AASHTO, 1997). The second contributor is simply any additional consolidation of the new mat under traffic.

Experience from the earlier segregation study (McGhee et al., 2003) suggests that this consolidation effect may be the more prominent of the factors producing this texture difference. In the earlier work, the texture difference between wheelpath and lane center was not consistent with the lower-level mixes (intermediate and base). Although the materials (surface, intermediate, and base) were assumed to be placed with similar equipment and practices, the intermediate and base mixes had not seen traffic, whereas all the surface mixes had been open to traffic for some time.

Table 4. Texture Characteristics from Project-long Texture Profiles

Mix Classification	Left Wheelpath			Lane Center		
	ICCTEX	SD	COV	ICCTEX	SD	COV
SM 9.5	1.19	0.18	15%	1.40	0.22	15%
SM 12.5	1.22	0.23	19%	1.43	0.27	19%
SMA 9.5	1.87	0.40	22%	2.14	0.43	20%
SMA 12.5	2.16	0.48	22%	2.70	0.55	20%

SD = Standard deviation of ICCTEX, COV = coefficient of variation for ICCTEX.

Pay Lot Samples

The analysis presented by Table 5 focuses on activity at the pay lot level. It summarizes much of the same information as in Table 4, but only for the 10 pay lot samples that were extracted from each project. Rather than reflecting the fluctuation (via texture SD) over an entire length of a project, these descriptive statistics relate to much shorter segments of activity. The samples exclude any peculiarities that may occur very early or very late in a pavement project. In that respect, the data are "cleaner" than those used to produce Table 4.

Table 5. Texture Characteristics from Pay Lot Samples

Mix Classification	Left Wheelpath			Lane Center		
	ICCTEX	SD	IRI	ICCTEX	SD	MRI
SM 9.5	1.21	0.16	68	1.41	0.20	76
SM 12.5	1.20	0.19	69	1.48	0.23	70
SMA 9.5	1.84	0.33	77	2.06	0.35	77
SMA 12.5	2.25	0.42	67	2.74	0.49	68

MRI = two-wheelpath IRI average.

Figure 4 provides frequency distribution charts for estimated texture of the 10 pay lot samples. These distributions encompass every pay lot sampled for every mix classification. For the SM 9.5 mixes, for example, each distribution represents measured texture for 60 pay lots of surface (10 samples of six lanes on three projects).

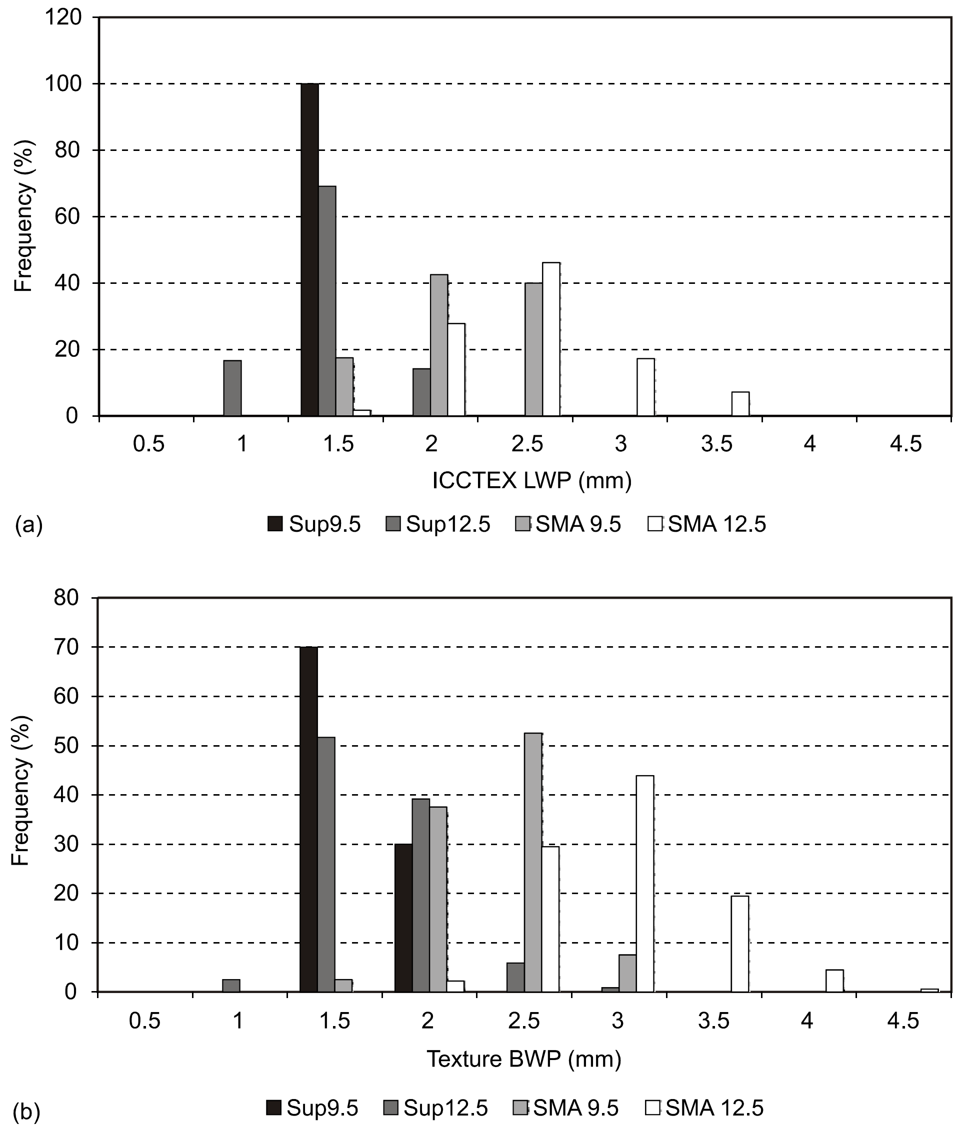

Figure 4. (a) Frequency distribution for estimated texture in left wheelpath (LWP) (Sup9.5 = Superpave designed SM 9.5 mix. Sup12.5 = Superpave designed SM 12.5 mix); (b) frequency distribution for estimated texture in center of the lane (BWP).

These distributions vividly illustrate the range of texture exhibited by Virginia's typical surface mixes. Once again, the SM 9.5 mixes demonstrate very consistent textures, whereas the SM 12.5 surfaces tend to drift higher and lower. The texture of SMA surfaces tends to be much higher. Unlike the Superpave examples, however, the relationship between the texture exhibited by the larger- and smaller-stone mixes is more rational. That is, the smaller-stone (9.5 mm SMA) mixes consistently provide the lower textures, and the larger-stone mixes offer the most exaggerated (or aggressive) textures.

Table 6 compares the SD of texture for the two Superpave mixes to targets previously proposed (see "Methods"). Assuming that the texture measured at the lane center is the most representative of the originally placed material, the distribution analysis necessary to provide the "measured" values in Table 6 was performed only on data from the lane center. Although there were no reports (or observation) of significant segregation among the mixes tested for this project, the uniformity as measured and reported in Table 6 is assumed to be at an acceptable quality level. Assuming that to be the case, more pay lots should have fallen within the 100% pay range. Clearly, the originally proposed targets were too stringent for the SM 9.5 mixes and perhaps too lenient for the 12.5 mm mixes.

Since SMA was not among the more common mixes used in Virginia in the late 1990s, there were no uniformity (i.e., SD) targets established for them in the earlier study (McGhee et al., 2003). Figure 5 illustrates the frequency distributions for texture SD for each of the four surface mix types tested in support of this project. Clearly, the targets established for dense-graded mixes (i.e., Superpave) are far from appropriate when considering SMA.

Of course, texture fluctuates more dramatically with SMA, but the fluctuation is among much higher levels of texture. To gain a fairer perspective of texture uniformity, Table 7 reports the average texture, SD of texture, and COV of texture for the dataset represented in Figure 5. Viewed through COV, texture fluctuation appears to increase more reasonably from mix to mix. In that sense, COV may be a better statistic through which to pursue new targets for HMA uniformity.

Table 6. Proposed Target versus Measured Uniformity

SD of Texture, 9.5 mm Superpave		SD of Texture, 12.5 mm Superpave		Price Adjustment (% Unit Price)
Targets	**Measured (BWP)**	**Targets**	**Measured (BWP)**	**Proposed**
0.05 and under	0%	0.10 and under	0%	105
0.06 to 0.10	3%	0.11 to .20	40%	103
0.11 to 0.15	25%	0.21 to 0.25	26%	100
0.16 to 0.20	27%	0.26 to 0.30	18%	90
0.20 to 0.25	17%	0.31 to 0.35	10%	80
Over 0.25	28%	Over 0.35	7%	Remove and replace

Table 7. Texture Characteristics for Pay Lot Samples: Lane Center Only

Mix Classification	Lane Center		
	ICCTEX	SD	COV
SM 9.5	1.41	0.20	14%
SM 12.5	1.48	0.23	15%
SMA 9.5	2.06	0.35	17%
SMA 12.5	2.74	0.49	18%

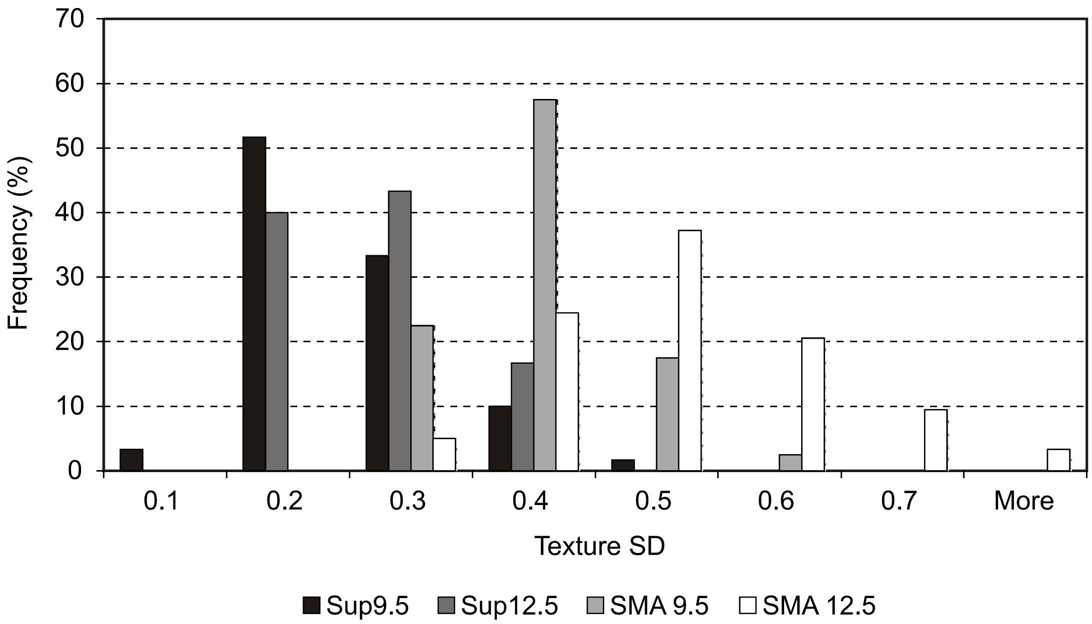

Figure 5. Frequency distribution for texture fluctuation in the center of the lane.

Characteristics of Elevation Profile

Comparison of Texture and IRI

To explore whether there was any measurable relationship between IRI and texture fluctuation, a correlation analysis was conducted using the data from the pay lot samples. For this analysis, the measured fluctuation in left wheelpath texture (LWP) was compared with the IRI from the left wheelpath. Likewise, the fluctuation in the lane center (BWP) was coupled with the two-wheelpath average IRI (or MRI). The results are summarized in Table 8. Clearly, with the exception of 9.5 mm SMA mixes, there appears to be no consistent relationship between texture fluctuation and IRI.

Table 8. General Statistics from Field Investigation

Mix Classification	Correlation (SD ICCTEX and IRI/MRI)	
	LWP	BWP
SM 9.5	0.12	0.22
SM 12.5	0.20	-0.01
SMA 9.5	0.42	-0.22
SMA 12.5	0.13	0.05

Uniformity of IRI

The lack of a relationship between texture fluctuation and IRI does not mean that IRI cannot be effectively applied to promote uniformity. Tables 9 and 10 condense the observed ride quality for most of the projects used in the study. They do this in two ways. The first is the percentage of traditional pay lots (52 feet of lane length) that fell within each IRI band. The second approach looks exactly the same, and in fact also uses a 52-foot base length. Instead of dissecting a project into discrete pay lots, however, this second approach reflects continuous IRI generated from a sliding 52-foot of elevation profile.

Generally speaking, the continuous roughness and fixed pay lot distributions are similar. This similarity is primarily because Virginia uses very short pay lots (nationally, a 528-foot pay lot is more common). For both tables, the typical target ranges for 100% payment (50 to 80 in/mi) are shaded. Notice that within these target ranges the percentages from the continuous roughness reports are slightly lower. The remaining percentages show up in higher and lower roughness ranges. This should be expected and is further indication of the heightened discriminating power of the continuous IRI.

Table 9. Ride Quality Summary: Superpave Mixes

Roughness Range (in/mi)	SM 9.5		SM 12.5mm	
	Continuous % Pavement	Fixed % Pavement	Continuous % Pavement	Fixed % Pavement
0.0 to 10.0	0.0	0.0	0.0	0.0
10.0 to 20.0	0.0	0.0	0.0	0.0
20.0 to 30.0	0.2	0.0	0.9	0.4
30.0 to 40.0	1.5	0.3	7.9	6.2
40.0 to 50.0	6.4	4.5	15.9	16.1
50.0 to 60.0	12.9	11.1	18.5	20.7
60.0 to 70.0	17.8	18.0	17.0	19.0
70.0 to 80.0	17.4	21.5	13.5	16.8
80.0 to 90.0	15.2	15.8	9.2	10.0
90.0 to 100.0	10.4	12.5	6.3	5.4
100.0 to 110.0	6.9	7.0	3.9	3.4
110.0 to 120.0	4.3	3.4	2.3	2.3
Above 120.0	7.2	5.9	4.6	4.3

Note: The typical target ranges for 100% payment (50 to 80 in/mi) are shaded.

Table 10. Ride Quality Summary: SMA Mixes.

Roughness Range (in/mi)	SMA 9.5		SMA 12.5	
	Continuous % Pavement	Fixed % Pavement	Continuous % Pavement	Fixed % Pavement
0.0 to 10.0	0.0	0.0	0.0	0.0
10.0 to 20.0	0.0	0.0	0.0	0.0
20.0 to 30.0	0.0	0.0	0.3	0.1
30.0 to 40.0	0.3	0.1	5.6	3.3
40.0 to 50.0	1.8	0.5	17.0	17.0
50.0 to 60.0	5.7	4.1	21.1	21.7
60.0 to 70.0	10.3	8.1	17.6	19.9
70.0 to 80.0	12.0	13.6	13.0	13.5
80.0 to 90.0	12.3	13.4	8.6	9.2
90.0 to 100.0	10.7	13.0	5.4	5.0
100.0 to 110.0	9.3	10.5	3.2	3.2
110.0 to 120.0	8.0	7.9	1.9	1.4
Above 120.0	29.7	28.7	6.4	5.9

Note: The typical target ranges for 100% payment (50 to 80 in/mi) are shaded.

Another attractive feature of the continuously reported IRI is that it coordinates well with percent within limits specifications and would conform well to a multi-characteristic performance-related specification (Weed, 2003). Reduction of rideability data from continuous reports permits the use of any lot size, from 52 feet to the entire project. In that respect, working with continuous roughness reports will facilitate combined or composite pay factors as long as all quality characteristics can be associated with some length of placed material.

Update on Texture-Measuring Capabilities

As discussed under "Methods," the high-speed texture-estimating system used by VDOT does not adhere to published standards for texture measurement. In the spring of 2005, this system was "retired" and various components were salvaged for a new inertial profiling system with high-speed texture measuring capabilities. The new system is expected to conform to the requirements of ASTM E1845 (ASTM, Inc., 2004), the prevailing standard for laser-based texture measurement.

CONCLUSIONS

- There is little functional basis upon which to select a Superpave 12.5 mm dense-graded mix in lieu of a 9.5 mm dense-graded mix. Although the texture fluctuates more dramatically with the 12.5 mm mixes, the average achieved texture is not significantly higher.

- The dense-graded 9.5 mm mixes (Superpave) placed in Virginia exhibit relatively uniform textures and do not typically exhibit serious segregation problems.

- The dense-graded 12.5 mm mixes (Superpave) exhibit much more varied textures on average and should be monitored for potential segregation issues.

- SMA mixes exhibit a much more exaggerated texture (and texture fluctuation) than Virginia's dense-graded mixes. The SMA textures do, however, vary rationally (i.e., go up with increasing nominal maximum aggregate size).

- Previously offered texture fluctuation targets (using texture standard deviation) do not appear to "fit" the general variety of SM 9.5 and SM 12.5 mixes. Texture fluctuation targets for SMA mixes would need to be much broader than those for Virginia's dense-graded mixes.

- Continuously reported IRI is more sensitive (than discrete lots) to extremes in achieved smoothness (and roughness).

RECOMMENDATIONS

- VDOT's Materials Division and VTRC should investigate the loss of texture in the wheelpath and determine whether it is indicative of significant under-compaction, excessive flow of mortar, or reorientation of stone under traffic.

- VDOT's pavement engineers should use SMA mixtures in lieu of larger nominally sized dense-graded surface mixes if enhanced texture is desired.

- VDOT's pavement engineers should apply continuously reported IRI to discourage localized roughness (and promote uniform ride quality). Virginia's current use of a relatively short pay lot will permit a fairly easy transition, especially for quality levels of reasonable consistency.

- Upon delivery of the anticipated high-speed texture-measuring system, VDOT's Pavement Design and Evaluation Section should conduct a series of tests to verify that the new system is providing the ASTM standard measure of texture. The test surfaces at the Virginia Smart Road should provide an adequate test matrix.

- VDOT's Materials Division and VTRC should discontinue development of a texture-based uniformity specification until a standard and proven high-speed texture-measuring system has been deployed operationally.

- VDOT's Materials Division and VTRC should promote uniformity through specifications that emphasize the average test results and the variability associated with performance-related quality characteristics. An ongoing study (Hughes, McGhee, and Maupin, 2005) is directly addressing this recommendation.

COSTS AND BENEFITS ASSESSMENT

Identifying and discouraging segregation are more optimistically about promoting uniformity. Although the major findings and conclusions of this work do not specifically support a “segregation specification,” the hot-mix community should maintain its dedication to material and construction uniformity. Quality measures that recognize variability, including percent defective and percent within limits specifications, are one very fundamental approach for promoting good uniformity in construction. Unfortunately, an earlier attempt to implement a percent within limits specification for HMA (Hughes, 1997; Schreck, 2005) was unsuccessful in part because it required “too much additional testing” and was consequently considered “too expensive.”

During a recent conversation with a respected representative of the asphalt industry, the author learned that the additional testing required to administer the pilot statistical quality assurance specification cost $1 to $2 per ton of hot mix (Schreck, 2005). For what it cost to conduct this additional testing, VDOT could require the material transfer vehicle (MTV) for every ton of hot mix placed (Wells, 2005). Whether specifically required or used voluntarily to comply with provisions that have stringent variability components (e.g., ride, texture, density), a properly functioning and operated MTV is a proven contributor to good hot-mix uniformity (Mahoney et al., 2003; Wilson, 2000).

Continuously reported IRI, variability specifications, and the use of an MTV show promise for improving uniformity. The costs for the improvement are comparable. At 165 pounds per square yard (1½-in thickness), it takes approximately 586 tons of hot mix to cover 1 lane-mile. At approximately $1.50 per ton (VDOT, 2005), it therefore costs VDOT approximately $900 per lane-mile for the MTV. A conservative estimate assigned a $3,000 per lane-mile loss to low levels of segregation (McGhee et al., 2003). If the MTV (at $900/mile) eliminates this $3,000 per lane-mile loss in service life, the benefit-to-cost ratio is greater than 3. This ratio assumes no additional benefit (beyond material uniformity) from use of the MTV.

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