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Supplementary Notes				

Abstract

In 2004, the Virginia Department of Transportation (VDOT) began examining the effects of allowing a 2-inch drop-off, rather than the specified 1.5-inch drop-off, between adjacent lanes. VDOT implemented a pilot program in its Northern Virginia District that gave paving contractors the option of not squaring up at the end of each shift on limited access roadways. This type of operation allowed the contractor to leave a milled section open to the traveling public and also to place an overlay in one lane but not the adjacent lane. The maximum allowable drop-off of the pavement in these instances was 2 inches.

The purpose of this study was twofold. The first was to develop a functional performance specification for the milled surface exposed to traffic during paving operations on limited access roadways. This was done by measuring the milled surfaces on the roadways in the VDOT pilot program. The practices of other states regarding edge drop-offs were also investigated.

The second and more important purpose was to investigate specific factors affecting paving and milling operations: safety, quality, productivity, and efficiency. The safety issues addressed included the effects of drop-offs created by milling or a straight overlay, loose debris created by raveling and "scabbing," windshield damage and accidents, and lane closure exposure time of the milling and paving crews. The condition of the milled surface was investigated to determine quality. To determine productivity and efficiency, three operations were investigated and compared: performance planing, mill and fill, and straight overlays. These investigations were conducted on particular limited access roadways in VDOT's Northern Virginia, Fredericksburg, and Salem districts.

The results were as follows:

- The sand patch test was adopted to calculate the mean texture depth of milled surfaces, and a maximum average mean texture depth of 2 millimeters was validated for milled surfaces exposed to traffic on limited access roadways.
- The use of a 2-inch milling depth, as well as the use of the micro-milling operation, helps reduce scabbing. A 2-inch drop-off also works well.
- Performance planing increases paving production by 32 percent and milling production by 49 percent over those of mill and fill.

By using a performance planing operation, rather than a mill and fill operation, VDOT could save $103,500 per year in traffic control costs and $522,000 per year in labor and equipment costs. Further, the use of performance planning would reduce both the exposure time of paving and milling workers to lane closures and user delays.

FINAL REPORT

HOT-MIX ASPHALT PLACEMENT: VIRGINIA'S MOVE TO A TWO-INCH DROP-OFF

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(A Cooperative Organization Sponsored Jointly by the
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ABSTRACT

In 2004, the Virginia Department of Transportation (VDOT) began examining the effects of allowing a 2-inch drop-off, rather than the specified 1.5-inch drop-off, between adjacent lanes. VDOT implemented a pilot program in its Northern Virginia District that gave paving contractors the option of not squaring up at the end of each shift on limited access roadways. This type of operation allowed the contractor to leave a milled section open to the traveling public and also to place an overlay in one lane but not the adjacent lane. The maximum allowable drop-off of the pavement in these instances was 2 inches.

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INTRODUCTION

Prior to 2005, the Virginia Department of Transportation (VDOT) required contractors working on projects on limited access highways to square up all pavements with an overlay differential greater than 165 pounds per square yard or milled depths greater than 1.5 inches prior to opening the pavement to traffic. *Squaring up* is the process of placing or removing pavement to create an even surface across all traffic lanes without a lane-to-lane drop-off. One of the ways a drop-off is created is by overlaying only a portion of the total width of an existing pavement in a day's work, with the remaining width being overlaid in subsequent operations; this is commonly called a straight overlay. Another way a drop-off is created is by milling less than the total width of the existing pavement and not replacing the milled material during the same day's operation. In Virginia, when existing pavement is milled to a particular depth and a surface layer is immediately placed on the milled surface, the project is termed a *mill and fill operation.*

There are many reasons for milling pavements, including, but not limited to, removal of deteriorated layers of pavement, surface drainage, tie-ins, bridge clearance, and ride quality. Safety is one of the concerns associated with opening a pavement that has been milled or has a drop-off to traffic. A milled surface generally produces a rougher ride than an overlaid surface. The grooved surface created by milling can cause automobiles and motorcycles to track. A drop-off or uneven lanes can be created by milling or placing a straight overlay. One of the safety concerns associated with this is difficulty in changing lanes. A larger drop-off, especially at higher vehicle speeds, can create a driving hazard. Another concern is with the deterioration of the edge of the drop-off created. When exposed to traffic, the edge may ravel. This, in turn, can cause problems with loose debris, which can cause damage to vehicles traveling the roadway. The raveled edge can also cause problems with creating an open longitudinal joint when paving the milled surface. An open longitudinal joint can lead to moisture damage of the pavement.

A final concern involves what is known as "scabbing." This occurs when an existing layer of pavement is not fully removed during the milling process. In some cases, the bond with the remaining pavement layer is strong enough that the layer will not loosen from the underlying pavement layer. However, in other cases, the bond is not strong enough to take the loads produced by traffic and the pavement layer debonds. This creates loose debris on the pavement riding surface that may cause windshield damage and other hazards to the traveling public. In addition, paving on loose "scabs" will result in a less than desirable bond between the new hot-mix asphalt (HMA) overlay and the existing underlying pavement base. This, in turn, can lead to premature distress and/or failure in the pavement.

In 2004, VDOT began examining the effects of allowing a 2-inch drop-off. VDOT implemented a pilot program in the Northern Virginia District on I-66 and I-395 that gave paving contractors the option of not squaring up at the end of each shift on limited access roadways. Based on the experiences of 2004 pilot program and subsequent paving operations in 2005 during the pilot program, VDOT changed the specification for contracts for the 2006 paving season to clarify that the specification was applicable to limited access roadways with a speed limit of 55 mph and greater. This type of operation allowed contractors to leave a milled section open to the traveling public; it also allowed them to place an overlay in one lane but not the adjacent lane. The maximum allowable drop-off of the pavement in these instances was 2 inches. The following restrictions also applied to the pilot program:

- The area milled or paved was limited to a single lane width.
- No partial lane milling was allowed.
- The milled area exposed to the traveling public was limited to 2,500 feet.
- Appropriate signage was displayed in advance of the milled surface or uneven lane areas.
- All areas were squared prior to the weekends or whenever there was a break (2 days plus) in the paving operation.
- Ramps and exits/entries were milled so that traffic did not have to cross the longitudinal joint.

These changes were expected to help increase the productivity and efficiency of the milling and paving operations and reduce lane closure time for paving operations. By allowing a portion of the milled surface to remain exposed, a situation was created where the milling operation could stay ahead of the paving operation. When milling and paving continued, the paving operation was allowed to start without the contractor having to wait for the milling operation to be complete.

For the pilot program, the contractor used a milling machine with a micro-milling head, as opposed to a conventional milling head. The micro-milling head had about 280 teeth, and the conventional milling head had about 150 teeth. Figures 1 through 3 show the different types of milling heads. Figure 1 shows a milling head from the 1960s. Figure 2 shows a conventional milling head currently used. One of the differences between these two heads is the type of teeth; the teeth on the older head produce a much rougher surface and cause more damage than the newer head. Figure 3 shows a micro-milling head; there are more teeth at a closer spacing, producing a more uniform, smoother, and defect-free surface. Because the milled surface was to be exposed to traffic, the smoother surface would enhance safety and ride quality. The depth of milling was 2 inches, designed to remove the entire layer of pavement and reduce the occurrence of scabbing. This operation was referred to as performance planing.

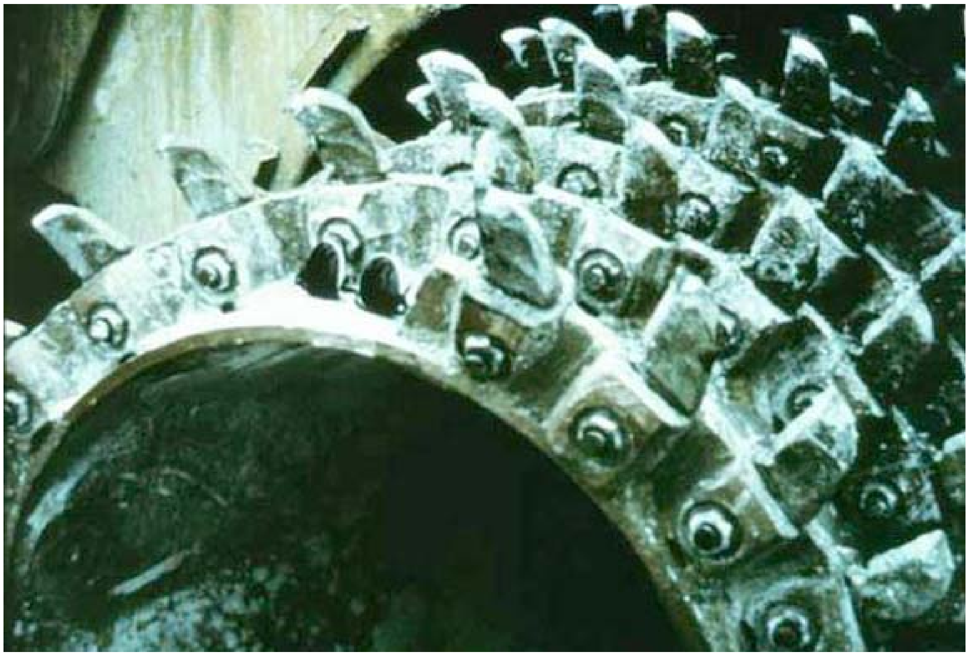

Figure 1. Conventional Milling Head from 1960s

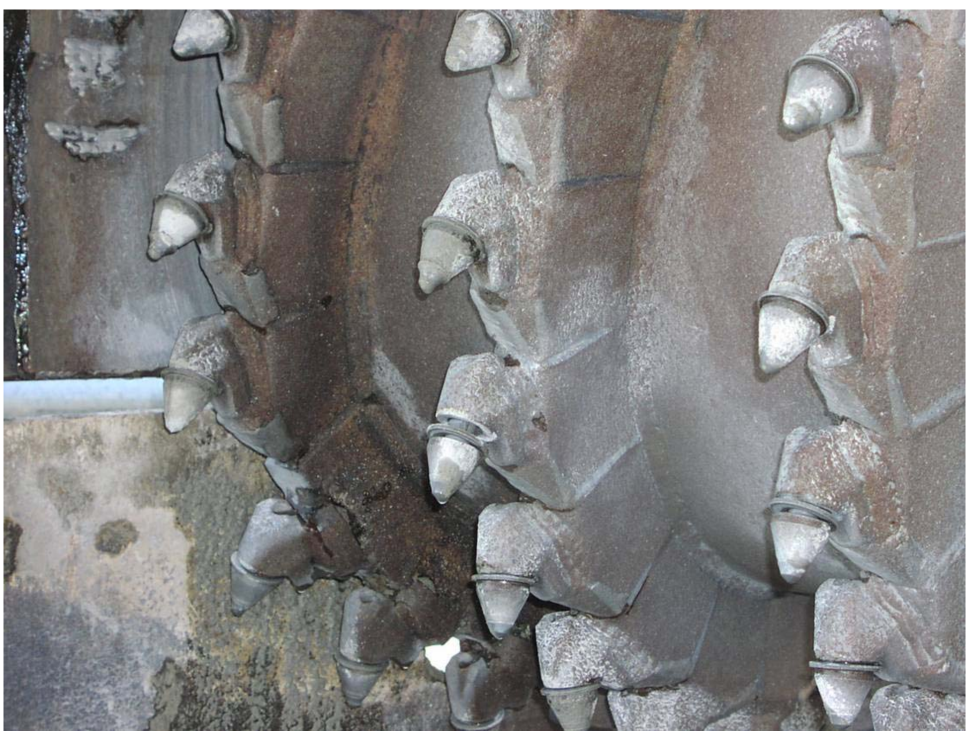

Figure 2. Conventional Milling Head Used Today

Figure 3. Micro-Milling Head Used in Performance Planing

PURPOSE AND SCOPE

The purpose of this study was twofold. The first was to develop a functional performance specification for the milled surface exposed to traffic during paving operations on limited access roadways. This was done by conducting measurements on the roadways in the previously discussed VDOT pilot program in the Northern Virginia District. The practices of other states regarding edge drop-offs were also investigated.

The second and more important purpose was to investigate specific factors affecting paving and milling operations: safety, quality, productivity, and efficiency. The safety issues addressed included the effects of drop-offs created by milling or a straight overlay, loose debris created by raveling and "scabbing," windshield damage and accidents, and lane closure exposure time of the milling and paving crews. The condition of the milled surface was investigated to determine quality. To determine productivity and efficiency, three operations were investigated and compared: performance planing, mill and fill, and straight overlays. These investigations were conducted on particular limited access roadways in VDOT's Northern Virginia, Fredericksburg, and Salem districts.

METHODS

Practices of Other Transportation Agencies

The practices of other transportation agencies with regard to edge drop-offs were investigated. This task was performed through an investigation of the standard specifications of other states.

Development of Functional Performance Specification for Milled Surface Exposed to Traffic During Paving Operations

The development of the performance specification involved the following steps:

1. Three commonly used measurement techniques were chosen to determine the surface characteristics of the milled surface: ASTM E 965 (the sand patch test), ASTM E 2157 (the circular track [CT] meter), and the 10-foot straightedge.

2. Measurements were made at the two sites in VDOT's previously mentioned pilot program in Northern Virginia, i.e., I-495 and I-66.

3. The average mean texture depth (MTD) was determined, and the data analysis was reported to VDOT's Materials Division.

4. Field tolerances for the sand patch technique were verified.

Measurement Techniques Used

The three measurement techniques selected were as follows:

1. *ASTM E 965, Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique*[1]*:* This technique is also known as the sand patch test. It involves spreading a known volume of material into a circle and measuring the diameter of the circle produced. The diameter gives an indication of the surface texture.

2. *ASTM E 2157, Standard Test Method for Measuring Pavement Macrotexture Properties Using the Circular Track Meter*[2]*:* This technique involves analyzing the pavement macrotexture profile using a charge coupled device (CCD) laser displacement sensor. The sensor is mounted on an arm that rotates in a circular track.

3. *Use of a 10-foot straightedge to measure the surface profile.*

The surface characteristics of the milled surface exposed to traffic were important because the surface needs to be as smooth as possible and provide a safe driving surface. Factors such as smoothness and skid resistance are related to the surface texture of the driving surface. The sand patch test and CT meter measure the MTD. The MTD gives an indication of the surface texture. The straightedge measures the surface profile, which does not give an indication of the surface texture. In addition, there was some concern about the orientation of the straightedge measurement (longitudinal or transverse) and the ability to measure in a consistent manner throughout the state. After discussion with VDOT Materials Division personnel, it was decided that the 10-foot straightedge method would not be suitable for measuring the milled surface to be exposed to traffic. It was decided that the sand patch test and the CT meter would be used initially and then a decision would be made concerning which of the two methods would be used for future measurements.

Measurements Made Using the Techniques

In order to develop tolerances for the surface texture, it was determined that measurements needed to be made on both micro-milled surfaces and conventional-milled surfaces.

On the first project on I-495 in Northern Virginia, measurements were made using the sand patch test and the CT meter. The contractor was using a micro-milling head to perform the milling. Ten measurements were taken at random locations over the test section; the locations were generated through the use of a random number generator. Measurements were taken using the CT meter first, and then sand patch tests were performed at the same locations.

In accordance with the sand patch test (ASTM E 965), the MTD was calculated for each test location using Equation 1:

$$MTD = \frac{4V}{\pi D^2} \qquad \text{[Eq. 1]}$$

where

MTD = mean texture depth of pavement macrotexture, inches (mm)
V = sample volume, cubic inches (mm^3)
D = average diameter of the area covered by the material, inches (mm).

Determination of Average MTD

A total of 11 sites were tested to determine the average MTD for micro-milled and conventional-milled surfaces. These sites included the previously mentioned pilot program sites in Northern Virginia that used micro-milling. Testing was also performed in the Fredericksburg (I-95) and Salem (I-81 and Route 220) districts where conventional milling was used. Tests were conducted at 10 random locations along the milled surface at each site. The average MTD for each site was calculated using the test data.

The test data analysis was reported to VDOT's Materials Division, and VDOT used the information in developing a special provision for planing asphalt concrete pavement.[7] In the special provision, in order to be left open to traffic, the finished surface macrotexture of the milled surface must be an average MTD of less than 2 millimeters. The provision also calls for the surface texture measurements to be measured in accordance with the sand patch test (ASTM E 965) at 10 random locations throughout the test section. The special provision is provided in Appendix A.

Verification of Field Tolerances for Sand Patch Test

The next step in this process was to verify the field tolerances for the sand patch test, which was determined to be the most cost-effective measurement technique, as discussed later.

In March and April of 2005, training sessions were conducted for district personnel concerning the sand patch test. Test kits were fabricated and distributed to each district by personnel from the Virginia Transportation Research Council (VTRC). A total of 12 test kits were distributed, 1 for each of the nine VDOT districts, and 1 for each of the three asphalt pavement field engineers. Training was conducted in three sessions at Richmond, Salem, and Culpeper. Field technicians from each district were trained on how to perform the sand patch test. Each district was given the following:

1. a complete sand patch testing kit
2. a copy of the ASTM E 965 test procedure
3. a copy of the special provision for planing asphalt concrete pavements
4. test data sheets to collect test data
5. conversion charts to determine the MTD of the test data.

During the summer of 2005, testing of the micro-milled surfaces was performed in the Northern Virginia (I-395 and Route 7), Fredericksburg (I-95), and Salem (Route 460) districts. This testing was performed by VDOT and VTRC personnel in accordance with ASTM E 965.

Factors Affecting the Paving and Milling Operations

As stated previously, an important goal of this research was to investigate the safety, quality, productivity, and efficiency of the paving and milling operations. These issues were investigated for three types of operations: performance planing, mill and fill, and straight overlays. Data were collected for each type of operation to allow the systems to be compared with regard to safety, quality, productivity and efficiency. With regard to the safety data, VDOT district records of crashes and windshield damage claims were monitored through telephone calls with district personnel for all projects investigated as they pertained to the paving operations included in the investigation.

Performance Planing Operations

Data for performance planing operations were collected from the same sites in VDOT's Northern Virginia, Fredericksburg, and Salem districts that were used to verify the field tolerances for the special provision.

Safety and Quality

Safety and quality concerns associated with performance planing operations include the effects of drop-off edges, scabbing, and drainage. The drop-off edge can cause difficulties for vehicles changing lanes across the drop-off. Since the edge is also exposed to traffic, the edge can ravel. This, in turn, can create loose debris on the roadway, as can scabbing. VDOT requires positive drainage. If positive drainage does not occur, the free-standing water in the roadway can lead to hydroplaning of vehicles. These effects can cause crashes and/or windshield damage.

The method used to accomplish the performance planing was at the contractor's discretion. All contractors used a micro-milling head. This was done to create a smoother riding surface since the milled surface was to be exposed to traffic. The quality of the milled surface was investigated through tests conducted as part of the performance specification developed for this project, namely the sand patch test. The bond of the pavement overlay to the milled surface and the longitudinal joint was also noted by a visual survey during the investigation.

Productivity and Efficiency

The productivity and efficiency of the performance planing operation were measured using milling and paving records from various VDOT districts. These records included the length of milling and paving in lane miles and the time in days to complete the operation. These data were used to calculate the productivity and efficiency of the operation.

Mill and Fill Operations

Data were collected from the two projects in Salem and one in Fredericksburg that were used for the conventional-milling measurements.

Safety and Quality

A major concern associated with the mill and fill operation is scabbing. The presence of scabbing on the milled surface increases the probability of a poor bond between the milled surface and the pavement overlay. Premature pavement failure and delamination can occur because of the poor bond. This, in turn, can lead to loose debris on the roadway, which can create hazardous driving conditions.

Productivity and Efficiency

Productivity and efficiency of the mill and fill operations were determined in the same manner as with the performance planing operation. The milling and paving lengths and times were monitored from the Fredericksburg and Salem districts.

Straight Overlay Operations

Data were collected from four sites on limited access highways: one site on I-64 in Louisa County and three sites in Northern Virginia.

Safety and Quality

As with the performance planing operation, the straight overlay safety issues involve drop-off edge and drainage.

Productivity and Efficiency

The productivity and efficiency of the straight overlay operations were monitored through VDOT records in various districts.

Comparison of Productivity and Efficiency Among the Three Types of Paving Operations

For the three paving operations in this study, productivity and efficiency were compared. This was done by tracking milling and paving records kept by VDOT districts as they apply to the operations investigated in this study on limited access roadways. These records included daily lengths of milling and paving for various jobs throughout the state.

RESULTS AND DISCUSSION

Practices of Other Transportation Agencies

The Center for Transportation Research and Education (CTRE) at Iowa State University published a report in 2002 on traffic control strategies in work zones.[3] This report provided information on the practices of many states with regard to edge drop-offs, including the drop-off height allowed and some of the treatments used for drop-off edges.[3] Table 1 presents the drop-off edge heights allowed and some of the treatments used by states surveyed in the report.

Information was also gathered from the standard specifications of Georgia, Indiana, and Maryland. These were the only states other than those listed in Table 1 that had specifications for milled surfaces exposed to traffic on limited access highways. Georgia allows for a 2-inch drop-off that is exposed to traffic; drop-offs greater than 2 inches must have a beveled longitudinal edge.[4] Indiana allows a 1.5-inch drop-off; drop-offs greater than 1.5-inches must have a 1:1 tapered edge.[5] In Maryland, a 2.5-inch drop-off may be opened to traffic; if the drop-off edge open to traffic is greater than 2.5 inches, the abutting lane or shoulder must be milled or overlaid the same day.[6]

Of the 19 states for which information was obtained, 13 allow a drop-off edge of 2 inches or greater to be opened to traffic without any treatment. The other 6 require some type of edge treatment if the drop-off is to be left open to traffic. From these data, it appears that a 2-inch drop-off height is the maximum used , and any heights above this require some type of edge treatment before being exposed to traffic.

One of the issues discussed in the CTRE report was that of effective edge heights for different edge slopes. The effective edge height is defined as the "height above the lower surface at which a tire makes predominant contact with the edge."[7] Figure 4 shows the effective edge heights. The effective edge height (Δe) is lower as the slope of the edge is lower. For example, a slightly rounded edge has an effective edge height equal to the actual edge height, whereas an edge sloped 45 degrees has an effective edge height of 25 percent of the actual edge height.

Table 1. Other State Practices

State	Drop-Off (in)	Treatments
Arkansas	3	Up to 3-inch drop-off; square up by next working day
California	2	>2 to 3 inch, use 1:1 tapered edge
Florida	3	>3 inch, use channelizing devices or 4:1 wedge
Illinois	2	>3 inch, use edge line delineation
Iowa	2	>2 inch, use 3:1 HMA fillet; 3 inch, use channelizing device
Minnesota	2	>2 inch, use wedges
Missouri	2	>2 inch, use 3:1 tapered edge
Montana	---	All drop-offs treated with 3:1 sloped edge
Nebraska	2	≤2 inch, use 1:1 asphalt wedge; >2 inch, use 3:1 asphalt wedge
New York	2	>2 inch, use wedge; dimensions depend on exposure time, traffic count, and speed limit
North Dakota	1.5	1.5 to 4 inch, use 4:1 sloped wedge
Ohio	1.5	1.5 to 5 inch, use lane closure with drums
Oregon	2	>2 inch, use 10:1 slope
Pennsylvania	2	>2 inch, use lane closure
Texas	1	>1 to 2 inch, use 3:1 compacted edge
West Virginia	2	Use signage and channelizing devices

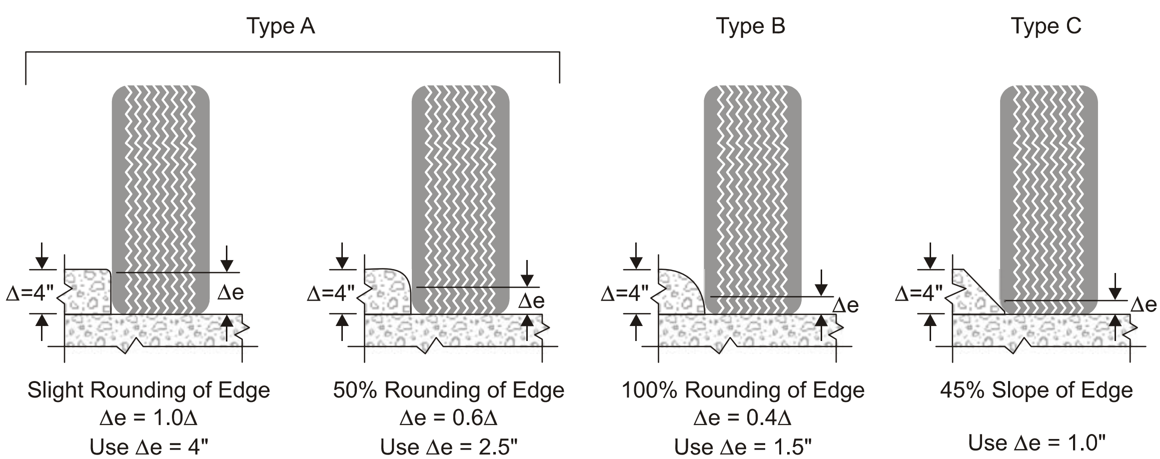

Figure 4. Effective Edge Height

This relationship can be used for drop-off edges in the field to lessen the severity of the drop-off. For edge drop-offs greater than 2 inches, many states require the edge to be sloped or wedged, creating a tapered effect. For instance, if a 3-inch drop-off edge requires a 2:1 tapered edge, then 6 inches of wedge material must extend toward the center of the milled surface from the drop-off edge in a sloped fashion.

In some cases, a 2-inch milling is not deep enough to remove the deteriorated material. At times, a 2.5- to 3-inch depth is required to remove the deteriorated material and/or reduce the occurrence of scabbing. In such cases, because Virginia allows only a 2-inch drop-off on limited access roadways, the milled area would have to be filled immediately and not exposed to traffic.

However, by placing a tapered slope on the drop-off edge, the severity of the drop-off would be less and the roadway could possibly be exposed to traffic without compromising safety.

Development of Performance Specification

Comparison of Measurement Techniques

There was a good correlation between the results from the sand patch test and the CT meter. The time required to run each test was also approximately the same for each technique.

One of the limitations of the CT meter is the cost associated with the equipment. The equipment includes a laser sensor device and a laptop computer to collect the data. The use of this technique would require each district to purchase the required equipment, which would be costly. In comparison, the cost of the sand patch testing equipment was minimal. It was therefore determined that the sand patch test would be the most cost-effective and efficient technique for measuring the surface texture of the milled surface.

Visually, the micro-milled surface produced a smoother surface than the conventional-milled surfaces. Figures 5 through 7 show the differences in the appearances between the surfaces.

Figure 5. Micro-milled Surface

Figure 6. Micro-milled Surface

Figure 7. Conventional-Milled Surface

Average MTD

Table 2 presents the average MTD for the micro-milled sections; Table 3 presents the average MTD for the conventional-milled sections.

Table 2. Average MTD for Micro-milled Sections

Date	Location	Average MTD (mm)
07/21/2004	I-495	1.913
08/05/2004	I-495	1.863
08/10/2004	I-66	1.929
08/17/2004	I-66	1.792
08/24/2004	I-66	1.863
Average MTD for all sites		**1.872**

Table 3. Average MTD for Conventional Milled Sections

Date	Location	Average MTD (mm)
09/22/2004	I-81	3.927
09/29/2004	I-95	3.277
09/29/2004	I-81	2.474
09/29/2004	I-81	3.255
09/29/2004	I-81	3.041
09/30/2004	Rt. 221	2.569
Average MTD for all sites		**3.231**

The micro-milled surface was left open to traffic; there was little to no scabbing present; and the overall performance under traffic was good. After analyzing the micro-milled and conventional-milled test data, it was determined that if the average MTD was less than 2 mm, the surface of the milled area would be adequate for traffic.

The test data analysis was reported to VDOT's Materials Division, and the information was used in developing the special provision for planing asphalt concrete pavement, as discussed previously.[8]

Verification of Field Tolerances After Special Provision Adopted

Table 4 presents the average MTD of the micro-milled sections after the special provision was adopted. The average MTD for the micro-milled surfaces was 1.829 mm. This was less than the 2-millimeter MTD required by the special provision. Interestingly, of all the individual measurements taken on the micro-milled surfaces, the highest MTD was 3.054 mm. The average MTD for the section with the 3.054 mm reading was 1.983 mm, which was still below the 2 millimeters required for the section to be exposed to traffic. It was therefore decided that the upper limit for any individual MTD measurement was 3.10 mm, even if the average MTD was less than 2 millimeters for the section. These findings were reported to VDOT specification

Table 4. Average MTD for Micro-milled Sections After Special Provision Adopted

Date	Location	Average MTD (mm)
05/01/2005	I-395	1.750
05/08/2005	Rt. 7	1.983
05/09/2005	I-95	1.781
05/17/2005	I-95	1.897
06/07/2005	I-95	1.742
06/13/2005	Rt. 460	1.657
06/14/2005	I-95	1.783
Average MTD for all sites		**1.795**

personnel to be included in the specifications. The data obtained from each site are provided in Appendix B. These data include the site location, date, individual measurements, and average measurements.

To date, the measurement technique and calculations of average MTD for these sites have proceeded smoothly. There have been no reports of the milled surfaces exposed to traffic not meeting the average MTD of less than 2 millimeters required by the special provision.

The one issue that has come up involves the number of measurements taken at each job site. Presently, measurements are taken at random locations throughout a 500-foot milled section at the beginning of the milling operations. The entire process, measurements and calculation of average MTD, takes about 45 minutes to 1 hour. During milling and paving operations in the field, the information needed from the measurement and calculation process can be critical. If the surface does not comply with the specification requirements to be exposed to traffic, arrangements need to be made by the contractor to remedy the problem. With regard to the data obtained for the milled surfaces exposed to traffic, about 80 percent of the measurements taken at each site were low in variability. The variability of the calculated average MTD for each site was low as well. In general, there were one or two average MTD readings at each site that produced variability in the overall average. Only three sites had more than two readings that were outside the 95 percent confidence interval for the average MTD for the entire site, and in over half of the sites, all or 90 percent were within the confidence interval. None of the sites investigated had more than four average MTD values outside of the 95 percent confidence interval for the entire site. It appears from this particular analysis that fewer measurements can be taken at each site. However, the overall visual condition of the milled surface to be exposed to traffic must be evaluated before fewer than 10 measurements are taken. If the surface appears to be uniform and free of noticeable imperfections, the inspector should be able to allow as few as 6 measurements. If the surface does not appear to be uniform, or there are many noticeable imperfections, 10 measurements at random locations should be taken. From the data obtained, taking fewer than 6 measurements at any location would probably increase the risk of not obtaining an accurate assessment of the overall surface characteristics.

Safety, Quality, Productivity, and Efficiency

Performance Planing Operations

Safety and Quality

The use of micro-milling heads during performance planing operations has worked well in Virginia. The milling surface produced has been uniform and smooth in most cases. In addition, the windrow produced by the micro-milling head is usually a finer material and is easier to remove. In addition, any dust or residue that is not removed during sweeping is removed by traffic. This produces a cleaner surface that can enhance the bond between the milled surface and the pavement overlay.

The move to a 2-inch milling depth has helped reduce the occurrence of scabbing. By using a 2-inch depth, in most cases, the entire existing surface layer is removed, thus reducing the probability of scabbing. The use of micro-milling heads has also helped reduce the occurrence of scabbing.

The micro-milled surface provided by performance planing has been uniform and smooth in most instances throughout the state. This enhances the bond between the milled surface and the pavement overlay as well as the ride quality of the pavement. However, the pavement has been in place for less than 1.5 years. The pavement should be monitored over time to determine if any problems occur associated with bond and longitudinal joints.

Of the performance planing operations investigated in this study, there were no reports of raveled edges due to traffic. The raveling was probably minimized because most of the drop-off edges were exposed to traffic for less than 24 hours. On one occasion, there was a concern about drainage at one of the sites, a three-lane interstate highway. The middle lane had been performance planed and left open to traffic without positive drainage being provided. Fortunately, there was no rain event that would have created standing water on the surface.

Productivity and Efficiency

Presently, Virginia allows a 2,500-foot section of performance milled surface to be exposed to traffic on limited access roadways. To date, this operation has worked well with few problems. To increase the productivity and efficiency of the milling operations, as well as allow the engineer to adjust for field conditions, the specification was modified to extend the length to 5,000 feet at the engineer's discretion.

In talks with VDOT personnel in various districts that used the performance planing operation, all said that the projects were getting done on time and within budget. In many cases, the projects were finishing early.

According to the data from performance planing operations investigated in this study, a total of 50.78 lane miles were paved in 73 days. It took a total of 64 days to mill the same 50.78 lane miles. Therefore, the performance planing operations investigated in this study were able to pave 0.70 lane mile per day and mill 0.79 lane mile per day.

Mill and Fill Operations

Safety and Quality

There were few reports of excessive scabbing, and in most instances, it was removed before the pavement overlay was placed. The conventional milling head produced a rougher surface than the micro-milling head; however, in most instances, the conventionally milled surface was not left open to traffic. On one occasion, a conventionally milled surface with a 2-inch drop-off was left open to traffic for approximately 24 hours after a plant breakdown. Proper signage was placed at the site and no accident or property damage was reported.

Because these operations usually use a conventional milling head, the material produced by the milling is coarser and may be more difficult to clean from the roadway. The problem with loose debris not being removed in the surface cleaning process persists.

From the mill and fill operations investigated in this study, there did not appear to be problems with bond between the milled surface and the overlay or problems with the longitudinal joint. Because the pavements are new, they should be monitored over time for any bond or longitudinal joint issues.

Productivity and Efficiency

From the data obtained for mill and fill operations investigated in this study, a total of 33.00 lane miles were milled and paved in 62 days, for 0.53 lane mile per day.

Straight Overlay Operations

Safety and Quality

The move from 1.5 to 2 inches for drop-offs on limited access roadways has not appeared to increase the instances of windshield damage and/or crashes. Proper signage has been developed and used to warn motorists of the uneven lanes created by the overlay.

Another concern associated with a straight overlay operation is that of the condition of the drop-off edge after exposure to traffic. A damaged edge can compromise the joint created during overlay of the abutting lane. On one of the straight overlay operations investigated in this study, a stone matrix asphalt (SMA) overlay was used. The 2-inch intermediate layer was place on a concrete pavement. This edge was exposed to interstate traffic for 2 days. There was no edge damage or raveling. The surface layer placed was also an SMA mixture, which was exposed to interstate traffic for 5 days, and the edge was not damaged (see Figure 8). This is

Figure 8. Drop-off Edge for Straight Overlay Operation

probably because of the stone skeleton of the SMA mixture as compared to a conventional hot-mix asphalt mixture. The bond and the longitudinal joint appear to be in good condition at this time. The pavement is less than 4 months old and will need to be monitored for any bond or longitudinal joint problems.

Productivity and Efficiency

From the data obtained for straight overlay operations investigated in this study, a total of 53.64 lane miles were paved in 32 days, for 1.68 lane miles per day.

Comparison of Productivity and Efficiency Among the Three Types of Paving Operations

Table 5 presents the time, in days, and length, in lane miles, of paving for the operations investigated in this study. From the data presented, it is clear that the straight overlay operation, as expected, is the most productive.

A comparison of the paving productivity of the three operations yielded the following results:

- For paving, the performance planing operation was 32 percent more productive than the mill and fill operation.

- For paving, the straight overlay operation was 140 percent more productive than the performance planing operation.

- For paving, the straight overlay operation was 216 percent more productive than the mill and fill operation.

In many instances, when a limited access roadway is paved, some type of milling is needed. Therefore, the most important comparison is between the performance planing operation and the mill and fill operation. With the performance planing operation being 32 percent more productive than the mill and fill operation, 33 lane miles could be paved with a mill and fill operation in 66 days and only 47 days with a performance planing operation. This is a reduction of 19 days. This may reduce not only costs but also the risk of worker injury due to exposure to traffic during operations.

The same data used for the paving productivity analysis were used for the milling productivity analysis. The milling operations for the mill and fill operations took the same number of days to complete as the paving. For the performance planing operations, the milling operations took fewer days to complete than the paving. Table 6 presents the milling productivity data for the performance planing and mill and fill operations.

Table 5. Paving Productivity Data

Method	Days	Length (Lane Miles)	Lane Miles/Day
Performance Planing	73	50.78	0.70
Mill and Fill	62	33.00	0.53
Straight Overlay	32	53.64	1.68

Table 6. Milling Productivity Data

Method	Days	Length (Lane Miles)	Lane Miles/Day
Performance Planing	64	50.78	0.79
Mill and Fill	62	33.00	0.53

For the milling operations, the performance planing operation was 49 percent more productive than the mill and fill operation. Thus, 33 lane miles could be milled in 62 days with a mill and fill operation and only 42 days for a performance planing operation. This would reduce costs and injury risk.

From the data presented, if a project on a limited access roadway requires milling and paving, the performance planing operation is the most productive and efficient operation to use. By using this type of operation, savings will be realized in not only dollars but, more important, also in a decreased exposure time of milling and paving workers to lane closures.

CONCLUSIONS

- Testing in accordance with the sand patch test (ASTM E 965) allows for the calculation of MTD of milled surfaces. The MTD gives an indication of the surface texture of the milled surface.
- A maximum average MTD of 2 millimeters is valid and attainable for micro-milled surfaces.
- For limited access roadways where the milled surface will be exposed to traffic, all of the individual average MTD values should be less than 3.10 mm in order for the roadway to be exposed to traffic.
- The micro-milling head used for performance planing operations produces a smoother and more uniform surface than does the conventional milling head.
- The windrow of material produced from the micro-milling head is finer than that produced by the conventional milling head. This provides for easier cleaning of the surface.
- SMA is associated with a low level of raveling at the drop-off edges when exposed to traffic.
- The exposure of a 2-inch drop-off on limited access roadways in Virginia works well.
- The use of a performance planing operation increases paving production by 32 percent over that of the mill and fill operation. Milling production is increased by 49 percent for the performance planing operation over that of the mill and fill operation.

RECOMMENDATIONS

1. *VDOT should continue allowing a 2-inch drop-off on limited access roadways as allowed by the Special Provision for Planing Asphalt Concrete Pavement provided in Appendix A.*

2. *VDOT should continue to test milled surfaces exposed to traffic on limited access roadways in accordance with ASTM E 965 (the sand patch test).*

3. *In the event milling and paving are required on a limited access roadway, VDOT should encourage the use of performance planing operations, as opposed to conventional mill and fill operations, as much as possible.*
4. *In the event that Virginia allows a drop-off of greater than 2 inches on limited access roadways to be exposed to traffic, drop-off edge treatments should be considered.*

BENEFITS AND COSTS ASSESSMENT

This study showed that performance planing operation can pave 0.70 lane mile per day as opposed to 0.53 lane mile per day for mill and fill operations. A review of the pavement schedules of limited access roadways from the past few years showed that Virginia paves approximately 150 lane miles of interstate per year. If the average lane miles paved per day for each operation are applied to the 150 lane miles of interstate paved per year, it would take 214 paving days to complete the performance planing operation. Conversely, it would take 283 paving days to complete the mill and fill operation. Thus, the performance planing operation would be completed in 69 fewer paving days than would the mill and fill operation. A reasonable estimate of traffic control costs for these types of paving operations is $1,500 per day. Therefore, the cost savings from using a performance planing operation would be $103,500 per year (traffic control only).

Cost savings can also be realized for labor and equipment. From talks with VDOT personnel and industry representatives, the estimated average cost for labor and equipment for interstate paving is approximately $8,000 per shift. These shifts constitute 1 paving day. If the 150 lane miles of interstate paving can be completed in 69 fewer paving days, the cost of labor and equipment could be reduced by $552,000 per year. Therefore, by using the performance planing operations on interstate paving operations, VDOT has the potential to save about $652,500 per year on the costs associated with traffic control, labor, and equipment on interstate paving operations.

One of the most important savings regards safety. Through the use of a performance planing operation as opposed to a mill and fill operation, a project would be completed sooner and the exposure time of paving and milling workers to lane closures would be reduced. In the same manner, the use of a performance planing operation would help reduce user delays.

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APPENDIX A

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
PLANING ASPHALT CONCRETE PAVEMENT
(Asphalt Schedule Work)

October 1, 2004

I. DESCRIPTION

This work shall consist of the planing of hot mix asphalt pavement to the depth indicated on the schedule of work or as directed by the Engineer. The Contractor shall have the option of performing standard pavement planning in accordance with the requirements of Section 315 and Section 515 or performing performance pavement planning in accordance with the requirements stated herein. Equipment and methodology used for performance planing shall be capable of producing a planed pavement surface with a mean texture depth as specified herein.

II. EQUIPMENT

Pavement planing equipment shall be a power operated pavement planing machine or pavement grinder capable of removing in one pass a layer of asphalt pavement not less than half the lane width to be removed. The machine shall also be capable of cutting to the maximum depth specified for flexible pavements in schedule of work listed in the proposal and at least ½ inch in rigid pavements in a single pass. The machine shall also be capable of accurately establishing grade control and have a positive means of controlling slope elevations transversely. The machine shall also have a dust collection system to prevent dust created by the milling operation from escaping into the atmosphere.

The finished planed (milled) surface shall be true to grade and shall be skid resistant. Unless otherwise directed by the Engineer, the finished surface for standard pavement planing and performance planing shall have a tolerance of ± ¼" per foot between any two contacts of the resultant surface and the testing edge of a 10-foot straightedge.

The finished surface macrotexture for performance planing shall have a pavement macrotexture mean texture depth (MTD) of less than 2.0 mm. Testing for performance pavement planing shall be as described herein.

Additional grinding or planing at the Contractor's expense shall correct humps and depressions exceeding the specified tolerances.

III. PERFORMANCE PAVEMENT PLANING

This section gives testing procedures and criteria for opening a section of performance planed pavement on a limited access roadway to public traffic. The test procedure performed by the Department will measure the MTD of the resultant macrotexture surface after planing operations have been performed. The measurement for performance planed surface texture shall be conducted in accordance with the requirements of ASTM E965 using a volumetric technique. The Department will randomly select 10 locations at each site. Each individual location will be tested and the average MTD of the entire 10 locations per site determined. Prior to opening a lane or roadway to traffic the average MTD of the performance planed site shall be less than 2.0 mm.

IV. PROCEDURES

A. Limited Access Roadways

The Contractor will be permitted to perform either standard pavement planing and pave such planed (milled) areas in accordance with the requirements of Section 315, or the Contractor will be permitted to perform performance planing (milling) to the contract specified depth or as directed by the Engineer to provide a uniform sound substrate. Regardless of planing option chosen, pavement planing operations shall be performed in only one traffic lane at a time. The Contractor will be permitted to leave up to 2500 feet of one travel lane of performance planed surface open to the traveling public provided such planing (milling) is performed across the entire lane width. Under no circumstance will the Contractor be permitted to plane a portion of the width of a travel lane, ramp or loop and leave it overnight. When planing to a depth of 2 inches or less, the Contractor shall have the option of planing the abutting lane or shoulder on alternate days or squaring up the planing operation at the end of each work shift. However, the abutting lane or shoulder shall be planed and squared up regardless of planing depth prior to weekends; except as otherwise permitted herein, holidays or any temporary shutdowns. Where the Contractor is directed to plane (mill) or grind to a depth greater than 2 inches the Contractor shall square up the planing operation at the end of each workday. This requirement shall apply to both pavement and shoulders.

Where uneven pavement joints exist either transversely or longitudinally at the edges of travel lanes, the Contractor shall provide advance warning traffic control devices to inform the traveling public in accordance with the details provided in the plans for the scope of operation he is performing.

The following additional restrictions will apply:

> On roadways with a combination of 4 travel lanes and shoulders (i.e. 2 travel lanes and 2 shoulders) in one direction, all lanes and shoulders must be paved back before the weekend.

On roadways with a combination of 5 or more travel lanes and shoulders (i.e. 3 lanes and 2 shoulders) in one direction 2500 feet of shoulder may be planed and left over the weekend provided the portion of planed shoulder left unpaved over the weekend is paved within 48 hours after the end of the weekend period.

Ramps and loops shall be performance planed full width by the end of each workday. The Contractor shall pave all ramps and loops within 48 hours after planing operations.

Ramps and exits are to be performance planed so that a long longitudinal joint will not be left for vehicles to cross. Ramps and exits are to be performance planed to the extent that the joint crossed is transverse.

In the event an emergency or unforeseen circumstances develop due to the Contractor's operations that prevent the Contractor from squaring up the planed surface on adjacent lanes prior to a weekend or a holiday any additional signage required to protect the traveling public shall be the Contractor's expense.

Temporary transverse pavement tie-ins shall be constructed a minimum of 10 feet in length for every inch of depth of pavement planing performed. Final transverse pavement tie-in shall conform to the requirements of Section 315.05(c) except that all joints at tie-in locations shall be tested using a 10-foot straightedge in accordance with the requirements of Section 315.07(a). The variation from the testing edge of the straightedge between any two contact points with the pavement surface shall not exceed ¼ inch.

The Contractor shall ensure positive drainage is provided for all planed surfaces in accordance with the requirements of Section 315.05(c).

Only approved mixes that have been verified in accordance with the requirements of Section 211.03(f) and have met the requirement for roller pattern density shall be placed on limited access roadways. Where test strips are required, areas shall be squared up at the end of each workday and no planed surface shall be left exposed.

B. All Other Roadways

The Contractor shall perform standard pavement planing to the contract specified depth(s) or as directed by the Engineer and pave such planed (milled) areas in accordance with the requirements of Section 315 and Section 515.

Where the depth of pavement planing is 2 inches or less the Contractor shall plane only that amount of pavement that can be paved back within 72 hours of completion of planing that portion of roadway. Where the Contractor is directed to perform pavement planing to a depth greater than 2 inches the Contractor shall square up the planing operation at the end of each workday. This requirement shall apply to both pavement and shoulders. Under no circumstance will the Contractor be permitted to plane a portion of the width of a travel lane, ramp or loop and leave it overnight.

When planing to a depth of 2 inches or less, the Contractor shall have the option of planing the abutting lane or shoulder on alternate days or squaring up the planing operation at the end of each work shift. However, the abutting lane or shoulder shall be planed and squared up regardless of planing depth prior to weekends, holidays or any temporary shutdowns. Roadways on which the roadway edges are planed shall be paved back within 10 days from the completion of the planing operation. Where uneven pavement joints exist either transversely or longitudinally at the edges of travel lanes, the Contractor shall provide advance warning traffic control devices to inform the traveling public in accordance with the details provided in the plans for the scope of operation he is performing.

Ramps and exits are to be performance planed so that a long longitudinal joint will not be left for vehicles to cross. Ramps and exits are to be performance planed to the extent that the joint crossed is transverse.

In the event an emergency or unforeseen circumstances develop due to the Contractor's operations that prevent the Contractor from squaring up the milled surface on adjacent lanes prior to a weekend or a holiday any additional signage required to protect the traveling public shall be the Contractor's expense.

Temporary transverse pavement tie-ins shall be constructed a minimum of 10 feet in length for every inch of depth of pavement planing performed. Final transverse pavement tie-in shall conform to the requirements of Section 315.05(c) except that all joints at tie-in locations shall be tested using a 10-foot straightedge in accordance with the requirements of Section 315.07(a). The variation from the testing edge of the straightedge between any two contact points with the pavement surface shall not exceed ¼ inch.

The Contractor shall ensure positive drainage is provided for all planed surfaces in accordance with the requirements of Section 315.05(c).

APPENDIX B

SAND PATCH TEST FIELD DATA

July 21, 2004 (I-495, Micro-Milling)

	Measurements 1	2	3	4	Average Diameter (in)	Mean Texture Depth (in)
Site #1	4.500	4.375	4.750	4.625	4.563	0.096
Site #2	4.500	5.000	5.000	5.125	4.906	0.083
Site #3	4.750	4.875	5.000	5.125	4.938	0.082
Site #4	5.500	5.000	6.125	6.000	5.656	0.063
Site #5	5.000	5.875	5.500	5.500	5.469	0.067
Site #6	5.000	5.000	5.000	5.250	5.063	0.078
Site #7	5.250	6.125	6.250	6.125	5.938	0.057
Site #8	4.500	5.000	5.000	5.250	4.938	0.082
Site #9	4.500	5.500	5.000	5.000	5.000	0.080
Site #10	5.000	5.000	5.250	5.000	5.063	0.078
				Average	**5.153**	**0.075**

	Measurements 1	2	3	4	Average Diameter (mm)	Mean Texture Depth (mm)
Site #1	114.3	111.1	120.7	117.5	115.89	2.440
Site #2	114.3	127.0	127.0	130.2	124.62	2.110
Site #3	120.7	123.8	127.0	130.2	125.41	2.084
Site #4	139.7	127.0	155.6	152.4	143.67	1.588
Site #5	127.0	149.2	139.7	139.7	138.91	1.699
Site #6	127.0	127.0	127.0	133.4	128.59	1.982
Site #7	133.4	155.6	158.8	155.6	150.81	1.441
Site #8	114.3	127.0	127.0	133.4	125.41	2.084
Site #9	114.3	139.7	127.0	127.0	127.00	2.032
Site #10	127.0	127.0	133.4	127.0	128.59	1.982
				Average	**130.889**	**1.913**

August 5, 2004 (I-495 Micro-Milling)

	Measurements 1	2	3	4	Average Diameter (in)	Mean Texture Depth (in)
Site #1	5.250	5.375	5.750	5.500	5.469	0.067
Site #2	5.000	5.250	5.250	5.125	5.156	0.075
Site #3	5.250	5.000	5.250	5.250	5.188	0.074
Site #4	5.000	4.750	5.125	5.250	5.031	0.079
Site #5	4.500	4.750	5.000	5.000	4.813	0.086
Site #6	5.500	5.500	5.750	5.750	5.625	0.063
Site #7	5.000	5.750	5.750	6.000	5.625	0.063
Site #8	5.000	5.500	5.500	5.500	5.375	0.069
Site #9	5.000	5.000	5.250	4.750	5.000	0.080
Site #10	5.250	5.250	4.750	4.500	4.938	0.082
				Average	**5.222**	**0.073**

	Measurements 1	2	3	4	Average Diameter (mm)	Mean Texture Depth (mm)
Site #1	133.4	136.5	146.1	139.7	138.91	1.699
Site #2	127.0	133.4	133.4	130.2	130.97	1.911
Site #3	133.4	127.0	133.4	133.4	131.76	1.888
Site #4	127.0	120.7	130.2	133.4	127.79	2.007
Site #5	114.3	120.7	127.0	127.0	122.24	2.193
Site #6	139.7	139.7	146.1	146.1	142.88	1.606
Site #7	127.0	146.1	146.1	152.4	142.88	1.606
Site #8	127.0	139.7	139.7	139.7	136.53	1.758
Site #9	127.0	127.0	133.4	120.7	127.00	2.032
Site #10	133.4	133.4	120.7	114.3	125.41	2.084
				Average	**132.636**	**1.863**

August 10, 2004 (I-66, Micro-Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	5.500	5.375	5.625	5.625	5.531	0.065
Site #2	5.000	4.750	4.750	4.250	4.688	0.091
Site #3	4.750	4.500	4.750	4.500	4.625	0.093
Site #4	4.750	5.000	4.750	5.125	4.906	0.083
Site #5	4.750	5.250	5.750	5.500	5.313	0.071
Site #6	5.125	5.125	5.250	5.000	5.125	0.076
Site #7	5.125	5.125	5.375	5.125	5.188	0.074
Site #8	5.250	5.375	5.500	5.500	5.406	0.068
Site #9	5.500	5.625	5.500	5.750	5.594	0.064
Site #10	4.750	4.875	5.000	5.125	4.938	0.082
				Average	**5.131**	**0.076**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	139.7	136.5	142.9	142.9	140.49	1.660
Site #2	127.0	120.7	120.7	108.0	119.06	2.312
Site #3	120.7	114.3	120.7	114.3	117.48	2.375
Site #4	120.7	127.0	120.7	130.2	124.62	2.110
Site #5	120.7	133.4	146.1	139.7	134.94	1.800
Site #6	130.2	130.2	133.4	127.0	130.18	1.934
Site #7	130.2	130.2	136.5	130.2	131.76	1.888
Site #8	133.4	136.5	139.7	139.7	137.32	1.738
Site #9	139.7	142.9	139.7	146.1	142.08	1.624
Site #10	120.7	123.8	127.0	130.2	125.41	2.084
				Average	**130.334**	**1.929**

August 17, 2004 (I-66, Micro-Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	5.000	5.000	5.250	5.375	5.156	0.075
Site #2	5.500	5.250	5.250	5.500	5.375	0.069
Site #3	5.375	5.000	5.000	5.750	5.281	0.072
Site #4	5.375	5.375	5.000	5.500	5.313	0.071
Site #5	5.000	5.250	5.000	5.500	5.188	0.074
Site #6	5.000	5.375	5.250	5.500	5.281	0.072
Site #7	5.500	5.000	5.375	5.500	5.344	0.070
Site #8	5.375	5.000	5.250	5.500	5.281	0.072
Site #9	5.500	5.500	5.250	5.500	5.438	0.068
Site #10	5.750	5.375	5.500	5.750	5.594	0.064
				Average	**5.325**	**0.071**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	127.0	127.0	133.4	136.5	130.97	1.911
Site #2	139.7	133.4	133.4	139.7	136.53	1.758
Site #3	136.5	127.0	127.0	146.1	134.14	1.821
Site #4	136.5	136.5	127.0	139.7	134.94	1.800
Site #5	127.0	133.4	127.0	139.7	131.76	1.888
Site #6	127.0	136.5	133.4	139.7	134.14	1.821
Site #7	139.7	127.0	136.5	139.7	135.73	1.779
Site #8	136.5	127.0	133.4	139.7	134.14	1.821
Site #9	139.7	139.7	133.4	139.7	138.11	1.718
Site #10	146.1	136.5	139.7	146.1	142.08	1.624
				Average	**135.255**	**1.792**

August 24, 2004 (I-66, Micro-Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	5.000	5.125	5.000	5.250	5.094	0.077
Site #2	5.375	5.500	5.000	5.500	5.344	0.070
Site #3	5.125	5.125	5.375	5.000	5.156	0.075
Site #4	5.000	5.625	5.125	5.250	5.250	0.073
Site #5	5.000	5.125	5.125	5.750	5.250	0.073
Site #6	5.000	5.750	5.375	5.375	5.375	0.069
Site #7	5.250	5.125	5.500	5.500	5.344	0.070
Site #8	5.000	5.000	5.000	5.125	5.031	0.079
Site #9	5.125	5.125	5.125	5.500	5.219	0.073
Site #10	5.125	5.375	5.125	5.000	5.156	0.075
				Average	**5.222**	**0.073**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	127.0	130.2	127.0	133.4	129.38	1.958
Site #2	136.5	139.7	127.0	139.7	135.73	1.779
Site #3	130.2	130.2	136.5	127.0	130.97	1.911
Site #4	127.0	142.9	130.2	133.4	133.35	1.843
Site #5	127.0	130.2	130.2	146.1	133.35	1.843
Site #6	127.0	146.1	136.5	136.5	136.53	1.758
Site #7	133.4	130.2	139.7	139.7	135.73	1.779
Site #8	127.0	127.0	127.0	130.2	127.79	2.007
Site #9	130.2	130.2	130.2	139.7	132.56	1.865
Site #10	130.2	136.5	130.2	127.0	130.97	1.911
				Average	**132.636**	**1.863**

May 1, 2005 (I-395, Micro-Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	6.000	6.250	6.000	6.000	6.063	0.0797
Site #2	6.500	6.000	7.000	5.500	6.250	0.0750
Site #3	7.000	6.000	6.250	5.500	6.188	0.0765
Site #4	7.000	6.750	6.500	6.000	6.563	0.0680
Site #5	9.000	7.750	9.000	9.500	8.813	0.0377
Site #6	6.500	6.250	6.000	6.000	6.188	0.0765
Site #7	8.000	7.500	6.750	7.250	7.375	0.0539
Site #8	6.500	5.750	6.000	6.500	6.188	0.0765
Site #9	5.750	6.000	6.000	5.750	5.875	0.0849
Site #10	6.500	6.500	7.500	7.500	7.000	0.0598
				Average	**6.650**	**0.0689**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	152.4	158.8	152.4	152.4	153.988	2.0257
Site #2	165.1	152.4	177.8	139.7	158.750	1.9060
Site #3	177.8	152.4	158.8	139.7	157.163	1.9447
Site #4	177.8	171.5	165.1	152.4	166.688	1.7288
Site #5	228.6	196.9	228.6	241.3	223.838	0.9587
Site #6	165.1	158.8	152.4	152.4	157.163	1.9447
Site #7	203.2	190.5	171.5	184.2	187.325	1.3688
Site #8	165.1	146.1	152.4	165.1	157.163	1.9447
Site #9	146.1	152.4	152.4	146.1	149.225	2.1570
Site #10	165.1	165.1	190.5	190.5	177.800	1.5194
				Average	**168.910**	**1.7498**

May 8, 2005 (Rte. 7, Micro-Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	6.000	6.500	6.500	6.500	6.375	0.0721
Site #2	6.000	6.000	6.250	6.250	6.125	0.0781
Site #3	6.750	6.000	6.000	6.500	6.313	0.0735
Site #4	7.500	6.000	7.500	6.750	6.938	0.0609
Site #5	7.000	7.000	6.750	6.500	6.813	0.0631
Site #6	6.250	5.750	6.250	6.250	6.125	0.0781
Site #7	6.250	6.000	6.500	6.000	6.188	0.0765
Site #8	6.000	6.500	6.000	6.000	6.125	0.0781
Site #9	6.000	6.250	6.000	6.000	6.063	0.0797
Site #10	4.750	5.000	5.000	5.000	4.938	0.1202
				Average	**6.200**	**0.0780**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	152.4	165.1	165.1	165.1	161.925	1.8319
Site #2	152.4	152.4	158.8	158.8	155.575	1.9845
Site #3	171.5	152.4	152.4	165.1	160.338	1.8684
Site #4	190.5	152.4	190.5	171.5	176.213	1.5469
Site #5	177.8	177.8	171.5	165.1	173.038	1.6042
Site #6	158.8	146.1	158.8	158.8	155.575	1.9845
Site #7	158.8	152.4	165.1	152.4	157.163	1.9447
Site #8	152.4	165.1	152.4	152.4	155.575	1.9845
Site #9	152.4	158.8	152.4	152.4	153.988	2.0257
Site #10	120.7	127.0	127.0	127.0	125.413	3.0539
				Average	**157.480**	**1.9829**

May 9, 2005 (I-95, Micro-Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	6.750	6.750	7.000	6.750	6.813	0.0631
Site #2	6.500	6.250	6.000	6.000	6.188	0.0765
Site #3	5.875	6.000	6.250	6.500	6.156	0.0773
Site #4	6.500	6.500	6.750	6.500	6.563	0.0680
Site #5	6.500	7.000	6.750	7.000	6.813	0.0631
Site #6	6.000	6.250	6.125	6.000	6.094	0.0789
Site #7	6.500	7.000	6.500	6.750	6.688	0.0655
Site #8	6.750	6.250	6.750	6.625	6.594	0.0674
Site #9	6.250	6.500	6.500	6.000	6.313	0.0735
Site #10	6.500	6.625	6.750	6.500	6.594	0.0674
				Average	**6.481**	**0.0701**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	171.5	171.5	177.8	171.5	173.038	1.6042
Site #2	165.1	158.8	152.4	152.4	157.163	1.9447
Site #3	149.2	152.4	158.8	165.1	156.369	1.9644
Site #4	165.1	165.1	171.5	165.1	166.688	1.7288
Site #5	165.1	177.8	171.5	177.8	173.038	1.6042
Site #6	152.4	158.8	155.6	152.4	154.781	2.0050
Site #7	165.1	177.8	165.1	171.5	169.863	1.6647
Site #8	171.5	158.8	171.5	168.3	167.481	1.7124
Site #9	158.8	165.1	165.1	152.4	160.338	1.8684
Site #10	165.1	168.3	171.5	165.1	167.481	1.7124
				Average	**164.624**	**1.7809**

June 13, 2005 (Rte. 460, Micro-Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	7.000	7.250	7.000	7.250	7.125	0.0577
Site #2	7.000	6.500	6.750	6.750	6.750	0.0643
Site #3	6.250	6.250	6.500	6.750	6.438	0.0707
Site #4	7.250	7.500	7.000	7.000	7.188	0.0567
Site #5	6.250	6.250	6.500	6.250	6.313	0.0735
Site #6	7.000	7.000	7.250	7.000	7.063	0.0587
Site #7	6.000	6.250	6.750	6.500	6.375	0.0721
Site #8	6.250	6.500	6.500	6.250	6.375	0.0721
Site #9	6.250	6.500	6.750	6.500	6.500	0.0693
Site #10	7.000	7.250	7.500	7.000	7.188	0.0567
				Average	**6.731**	**0.0652**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	177.8	184.2	177.8	184.2	180.975	1.4666
Site #2	177.8	165.1	171.5	171.5	171.450	1.6341
Site #3	158.8	158.8	165.1	171.5	163.513	1.7965
Site #4	184.2	190.5	177.8	177.8	182.563	1.4412
Site #5	158.8	158.8	165.1	158.8	160.338	1.8684
Site #6	177.8	177.8	184.2	177.8	179.388	1.4926
Site #7	152.4	158.8	171.5	165.1	161.925	1.8319
Site #8	158.8	165.1	165.1	158.8	161.925	1.8319
Site #9	158.8	165.1	171.5	165.1	165.100	1.7622
Site #10	177.8	184.2	190.5	177.8	182.563	1.4412
				Average	**170.974**	**1.6567**

May 17, 2005 (I-95, Micro-Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	5.250	5.250	5.000	5.250	5.188	0.074
Site #2	5.250	5.000	5.125	5.125	5.125	0.076
Site #3	5.375	5.000	5.000	5.250	5.156	0.075
Site #4	5.125	5.250	5.500	5.000	5.219	0.073
Site #5	5.500	5.125	5.125	5.000	5.188	0.074
Site #6	5.250	5.375	5.250	5.375	5.313	0.071
Site #7	5.500	5.000	5.000	5.000	5.125	0.076
Site #8	5.000	5.000	5.250	5.125	5.094	0.077
Site #9	5.125	5.000	5.000	5.375	5.125	0.076
Site #10	5.500	5.250	5.000	5.125	5.219	0.073
				Average	**5.175**	**0.075**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	133.4	133.4	127.0	133.4	131.76	1.888
Site #2	133.4	127.0	130.2	130.2	130.18	1.934
Site #3	136.5	127.0	127.0	133.4	130.97	1.911
Site #4	130.2	133.4	139.7	127.0	132.56	1.865
Site #5	139.7	130.2	130.2	127.0	131.76	1.888
Site #6	133.4	136.5	133.4	136.5	134.94	1.800
Site #7	139.7	127.0	127.0	127.0	130.18	1.934
Site #8	127.0	127.0	133.4	130.2	129.38	1.958
Site #9	130.2	127.0	127.0	136.5	130.18	1.934
Site #10	139.7	133.4	127.0	130.2	132.56	1.865
				Average	**131.445**	**1.897**

June 7, 2005 (I-95, Micro-Milling)

	Measurements 1	2	3	4	Average Diameter (in)	Mean Texture Depth (in)
Site #1	5.500	5.625	6.000	5.500	5.656	0.063
Site #2	5.500	5.500	5.250	6.000	5.563	0.065
Site #3	5.250	5.500	5.625	5.000	5.344	0.070
Site #4	5.000	5.625	5.250	5.250	5.281	0.072
Site #5	5.000	5.000	5.500	5.250	5.188	0.074
Site #6	5.500	5.500	5.625	5.000	5.406	0.068
Site #7	5.625	5.625	5.250	6.000	5.625	0.063
Site #8	5.625	5.250	5.250	5.500	5.406	0.068
Site #9	5.250	5.000	5.625	5.000	5.219	0.073
Site #10	5.000	5.625	5.625	5.000	5.313	0.071
				Average	**5.400**	**0.069**
	Measurements 1	**2**	**3**	**4**	**Average Diameter (mm)**	**Mean Texture Depth (mm)**
Site #1	139.7	142.9	152.4	139.7	143.67	1.588
Site #2	139.7	139.7	133.4	152.4	141.29	1.642
Site #3	133.4	139.7	142.9	127.0	135.73	1.779
Site #4	127.0	142.9	133.4	133.4	134.14	1.821
Site #5	127.0	127.0	139.7	133.4	131.76	1.888
Site #6	139.7	139.7	142.9	127.0	137.32	1.738
Site #7	142.9	142.9	133.4	152.4	142.88	1.606
Site #8	142.9	133.4	133.4	139.7	137.32	1.738
Site #9	133.4	127.0	142.9	127.0	132.56	1.865
Site #10	127.0	142.9	142.9	127.0	134.94	1.800
				Average	**137.160**	**1.742**

June 14, 2005 (I-95, Micro-Milling)

	Measurements 1	2	3	4	Average Diameter (in)	Mean Texture Depth (in)
Site #1	5.000	5.375	5.250	5.250	5.219	0.073
Site #2	5.000	5.000	5.375	5.500	5.219	0.073
Site #3	5.500	5.000	5.250	5.750	5.375	0.069
Site #4	5.000	5.250	5.500	5.500	5.313	0.071
Site #5	5.375	5.000	5.500	5.750	5.406	0.068
Site #6	5.500	5.250	5.000	6.000	5.438	0.068
Site #7	5.250	5.250	5.000	5.500	5.250	0.073
Site #8	6.000	5.000	5.250	5.000	5.313	0.071
Site #9	6.000	5.375	5.000	5.500	5.469	0.067
Site #10	5.500	5.000	5.250	5.750	5.375	0.069
				Average	**5.338**	**0.070**
	Measurements 1	**2**	**3**	**4**	**Average Diameter (mm)**	**Mean Texture Depth (mm)**
Site #1	127.0	136.5	133.4	133.4	132.56	1.865
Site #2	127.0	127.0	136.5	139.7	132.56	1.865
Site #3	139.7	127.0	133.4	146.1	136.53	1.758
Site #4	127.0	133.4	139.7	139.7	134.94	1.800
Site #5	136.5	127.0	139.7	146.1	137.32	1.738
Site #6	139.7	133.4	127.0	152.4	138.11	1.718
Site #7	133.4	133.4	127.0	139.7	133.35	1.843
Site #8	152.4	127.0	133.4	127.0	134.94	1.800
Site #9	152.4	136.5	127.0	139.7	138.91	1.699
Site #10	139.7	127.0	133.4	146.1	136.53	1.758
				Average	**135.573**	**1.783**

September 22, 2004 (I-81, Conventional Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	**2**	**3**	**4**		
Site #1	4.000	4.250	3.500	3.750	3.875	0.133
Site #2	3.500	3.500	3.750	3.750	3.625	0.152
Site #3	3.250	3.250	3.000	3.000	3.125	0.205
Site #4	3.000	3.250	3.250	3.500	3.250	0.189
Site #5	3.250	3.625	3.375	3.250	3.375	0.176
Site #6	3.500	3.750	3.750	3.500	3.625	0.152
Site #7	3.000	3.250	3.125	3.125	3.125	0.205
Site #8	4.000	3.750	4.000	4.000	3.938	0.129
Site #9	3.750	3.750	4.000	4.125	3.906	0.131
Site #10	4.000	4.000	4.250	4.250	4.125	0.118
				Average	**3.597**	**0.155**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	101.6	108.0	88.9	95.3	98.43	3.383
Site #2	88.9	88.9	95.3	95.3	92.08	3.866
Site #3	82.6	82.6	76.2	76.2	79.38	5.202
Site #4	76.2	82.6	82.6	88.9	82.55	4.809
Site #5	82.6	92.1	85.7	82.6	85.73	4.460
Site #6	88.9	95.3	95.3	88.9	92.08	3.866
Site #7	76.2	82.6	79.4	79.4	79.38	5.202
Site #8	101.6	95.3	101.6	101.6	100.01	3.277
Site #9	95.3	95.3	101.6	104.8	99.22	3.329
Site #10	101.6	101.6	108.0	108.0	104.78	2.985
				Average	**91.361**	**3.927**

September 29, 2004 (I-95, Conventional Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	**2**	**3**	**4**		
Site #1	4.000	3.875	4.000	4.125	4.000	0.125
Site #2	3.500	3.500	3.750	3.250	3.500	0.163
Site #3	3.500	4.000	3.500	4.000	3.750	0.142
Site #4	4.000	4.750	4.500	4.500	4.438	0.102
Site #5	4.000	3.750	4.000	4.250	4.000	0.125
				Average	**3.938**	**0.129**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	101.6	98.4	101.6	104.8	101.60	3.175
Site #2	88.9	88.9	95.3	82.6	88.90	4.147
Site #3	88.9	101.6	88.9	101.6	95.25	3.612
Site #4	101.6	120.7	114.3	114.3	112.71	2.580
Site #5	101.6	95.3	101.6	108.0	101.60	3.175
				Average	**100.013**	**3.277**

September 29, 2004 (I-81, Conventional Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	6.000	5.000	5.500	5.000	5.375	0.091
Site #2	5.000	5.500	4.000	5.000	4.875	0.110
Site #3	5.500	5.250	5.500	5.300	5.388	0.090
Site #4	6.000	5.500	4.500	4.500	5.125	0.100
				Average	**5.191**	**0.097**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	152.4	127.0	139.7	127.0	136.53	2.307
Site #2	127.0	139.7	101.6	127.0	123.83	2.804
Site #3	139.7	133.4	139.7	134.6	136.84	2.296
Site #4	152.4	139.7	114.3	114.3	130.18	2.538
				Average	**131.842**	**2.474**

September 29, 2004 (I-81, Conventional Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	4.500	5.000	4.000	4.700	4.550	0.127
Site #2	4.700	4.800	4.700	5.000	4.800	0.114
Site #3	4.200	5.000	4.400	4.400	4.500	0.130
Site #4	4.100	4.500	4.400	4.000	4.250	0.145
				Average	**4.525**	**0.128**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	114.3	127.0	101.6	119.4	115.57	3.219
Site #2	119.4	121.9	119.4	127.0	121.92	2.893
Site #3	106.7	127.0	111.8	111.8	114.30	3.291
Site #4	104.1	114.3	111.8	101.6	107.95	3.690
				Average	**114.935**	**3.255**

September 29, 2004 (I-81, Conventional Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	4.600	5.000	4.200	4.500	4.575	0.125
Site #2	6.300	4.600	3.800	5.000	4.925	0.108
Site #3	5.200	4.100	4.700	4.400	4.600	0.124
Site #4	4.800	4.700	4.900	4.100	4.625	0.123
				Average	**4.681**	**0.120**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	116.8	127.0	106.7	114.3	116.21	3.184
Site #2	160.0	116.8	96.5	127.0	125.10	2.748
Site #3	132.1	104.1	119.4	111.8	116.84	3.150
Site #4	121.9	119.4	124.5	104.1	117.48	3.116
				Average	**118.904**	**3.041**

September 30, 2004 (Rte. 221, Conventional Milling)

	Measurements				Average Diameter (in)	Mean Texture Depth (in)
	1	2	3	4		
Site #1	5.000	4.600	4.300	4.600	4.625	0.123
Site #2	4.800	4.100	4.300	4.000	4.300	0.142
Site #3	6.500	4.300	6.000	5.500	5.575	0.084
Site #4	5.400	6.000	5.900	6.200	5.875	0.076
				Average	**5.094**	**0.101**
	Measurements				**Average Diameter (mm)**	**Mean Texture Depth (mm)**
	1	**2**	**3**	**4**		
Site #1	127.0	116.8	109.2	116.8	117.48	3.116
Site #2	121.9	104.1	109.2	101.6	109.22	3.605
Site #3	165.1	109.2	152.4	139.7	141.61	2.144
Site #4	137.2	152.4	149.9	157.5	149.23	1.931
				Average	**129.381**	**2.569**