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research report

Bond Expectations for Milled Surfaces and Typical Tack Coat Materials Used in Virginia

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Abstract

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1. a laboratory comparison of the bond strength of typical tack materials
2. a field study of the effect of tack on bond strength between a new HMA overlay and a milled surface
3. a laboratory investigation of a torque-shear field test to measure bond performance.

The findings from these tasks led to several recommendations. The most substantial of the recommendations was that the Virginia Department of Transportation (VDOT) should no longer require the practice of tacking primary horizontal surfaces when placing a new overlay on a milled surface. Further, field engineers and inspectors should remain diligent when it comes to establishing a clean, sound construction platform for any overlay work. Finally, although laboratory tests were inclusive, the torque-shear device should be field tested, with particular emphasis on exposing the test to more realistic conditions.

An analysis of the costs associated with conventional tack use found that the material cost per lane-mile is between $572 and $836. A review of the typical "mill and fill" paving activity (maintenance) for the 2008 season found that VDOT would save between $488,000 and $650,000 per year by foregoing conventional tacking on milled horizontal surfaces. If the tacking material is of the non-tracking variety, which is becoming more and more common, the savings could be as much as $950,000 per year.

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Virginia Transportation Research Council
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ABSTRACT

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INTRODUCTION

When new hot-mix asphalt (HMA) layers are placed over in-service pavements, a coating of asphalt tack material is specified as part of preparing the original surface in order to provide an adhesive interlock. This tack coat is described in Section 310 of the Virginia Department of Transportation's (VDOT) *Road and Bridge Specifications* (VDOT, 2007). It is generally an asphalt emulsion that serves to improve the bond between the new and existing materials. Typically, this emulsion is applied with an asphalt distributor truck equipped with a multi-nozzle spray bar.

The bond between the new and original surface, as well as that among any of the various layers within a pavement system, is essential to providing a monolithic structure. This monolithic structure allows lower ultimate stresses at the bottom of the bound layers and a longer lasting pavement. Poor bond can lead to early delamination failures (where the new surface slips in relation to the original surface). The HMA overlay has a shorter service life (see Figure 1 for delamination-related failure) because the entire bound pavement structure is not able to distribute the loading over a larger area (i.e., higher load-induced stresses are concentrated near the pavement's surface as opposed to the bottom of the bound layers).

As important as it is to achieve a good bond between new and existing HMA layers, the proper use of tacking materials has often been discouraged for reasons of constructability, aesthetics, and safety. Most typical tacking materials in Virginia use a "softened" liquid asphalt base. When applied at the rate called for in the specifications, these tacking materials tend to stick to haul truck tires and the tracks and tires of other paving equipment. When the trucks and equipment leave the project, the tacking material is tracked over pavement markings as well as deposited at various locations (see Figure 2) where the material build-up can create safety issues. On projects with milling, the tack will stick to the fine milling material (dust) that is not removed during the surface cleaning activities. These conglomerations of tack material and dust "ball up" and clump, creating numerous problems for the paving operation. For both straight HMA overlays and mill and replacement projects, the tack material lost to tracking was located in the wheel paths—the very location where bond strength is most important.

Figure 1. Delamination Pothole

Today, the traditional practices of tacking and bonding HMA layers together are subject to numerous important influences. Among them is the growing proportion of HMA resurfacing work that involves placement of the new surface over a milled platform (i.e., mill and replace). In these cases, the relatively rough-textured milled surface provides more effective surface area at the interface of the new and old surface and may promote better mechanical interlock. In theory, if the bond strengths achieved on milled surfaces with and without tacking are equivalent, the need for tacking can be eliminated, which would result in savings to VDOT and the contractor.

Another more profound influence on traditional HMA construction practices in general may be the move away from prescriptive construction specifications to more performance-oriented criteria. This philosophical shift is partially a response to a reduced public agency inspection force and expertise and partially an effort to encourage more innovation from the industry. Regardless of the motivation, performance requirements in lieu of traditional prescription requirements are likely to evolve in the coming years.

Figure 2. Tack Build-up at Intersection.

Note: The problem with tack tracking led to VDOT's development of a special provision for non-tracking tack for use on selected projects and areas (VDOT, 2008).

PROBLEM STATEMENT

Previous research suggests that the mechanical interlock contributed through conventional milling may be sufficient to reduce or eliminate the need for tacking with HMA resurfacing (Tashman et al., 2006). Up until now, however, VDOT has conducted no controlled testing to determine how these "mechanically improved" bonds are affected by tack, or even what the bond conditions are at conventionally constructed interfaces. It seems reasonable that some measure of the adherence of the new surface to the old would be appropriate. How to make that measurement, however, remains in question. Needless to say, as long as the method of acceptance testing is in question, the acceptance criterion will be difficult to prescribe.

PURPOSE AND SCOPE

The ultimate purpose of the program of research of which this study was a part is to identify a test method and acceptance criteria for bonding of HMA layers. In this study, three tasks were performed to help achieve that purpose:

1. a laboratory comparison of the bond strength of typical tack materials

2. a field study of the effect of tack on bond strength between a new HMA overlay and a milled surface

3. a laboratory investigation of a torque-shear field test to measure bond performance.

The laboratory comparison involved three common tack coat materials (identified under "Methods") and laboratory-prepared specimens of contractor-produced surface mix. Data to support the field study came from VDOT HMA resurfacing activities underway during the summers of 2007 and 2008. The investigation of the torque-shear test used a series of two-layer pavement "models" that were formed and compacted in the laboratory using production HMA.

METHODS

Description of Laboratory Tests for Bond Strength

Fundamental to each activity discussed in this report is a baseline measure of bond strength at the interface of two asphalt concrete layers.

Shear

The first of those tests is a shear strength test. This test is performed using a jig specially designed to operate within a Marshall device for compression loading as described in ASTM D 6927, Standard Test Method for Marshall Stability and Flow of Bituminous Mixtures (ASTM International, 2008). Figure 3 is an image of the shear testing jig. The fixed component of the device is the heavy vertical plate with a 4-in hole in the center and four evenly spaced guide blocks, which stick out from the plane of the plate and surround the left end of the specimen. The 4-in hole in the fixed plate aligns with a similar hole on the moving side of the device (shown to the right of the image). The specimen is oriented such that the layer interface is centered in a ¼-in slot between the left and right plate. The round plate on the end of the threaded rod (oriented horizontally and centered on the specimen) is opposite a similar plate on the back (right) side of the specimen and compressed against a heavy spring. These two plates constrain the specimen during testing.

The guillotine-like test is performed by loading the cylindrical cap on the top of the jig with the Marshall compression device until the interface shears apart. The loading rate is as prescribed in ASTM D 6927, 2.0 ± 0.15 in/min. The total load on the interface is the load applied by the compression device plus the weight of the movable portion of the jig. The shear strength of an interface is the maximum total load achieved divided by the nominal surface area of the specimen. All tests are run at a standard laboratory temperature of 70º F.

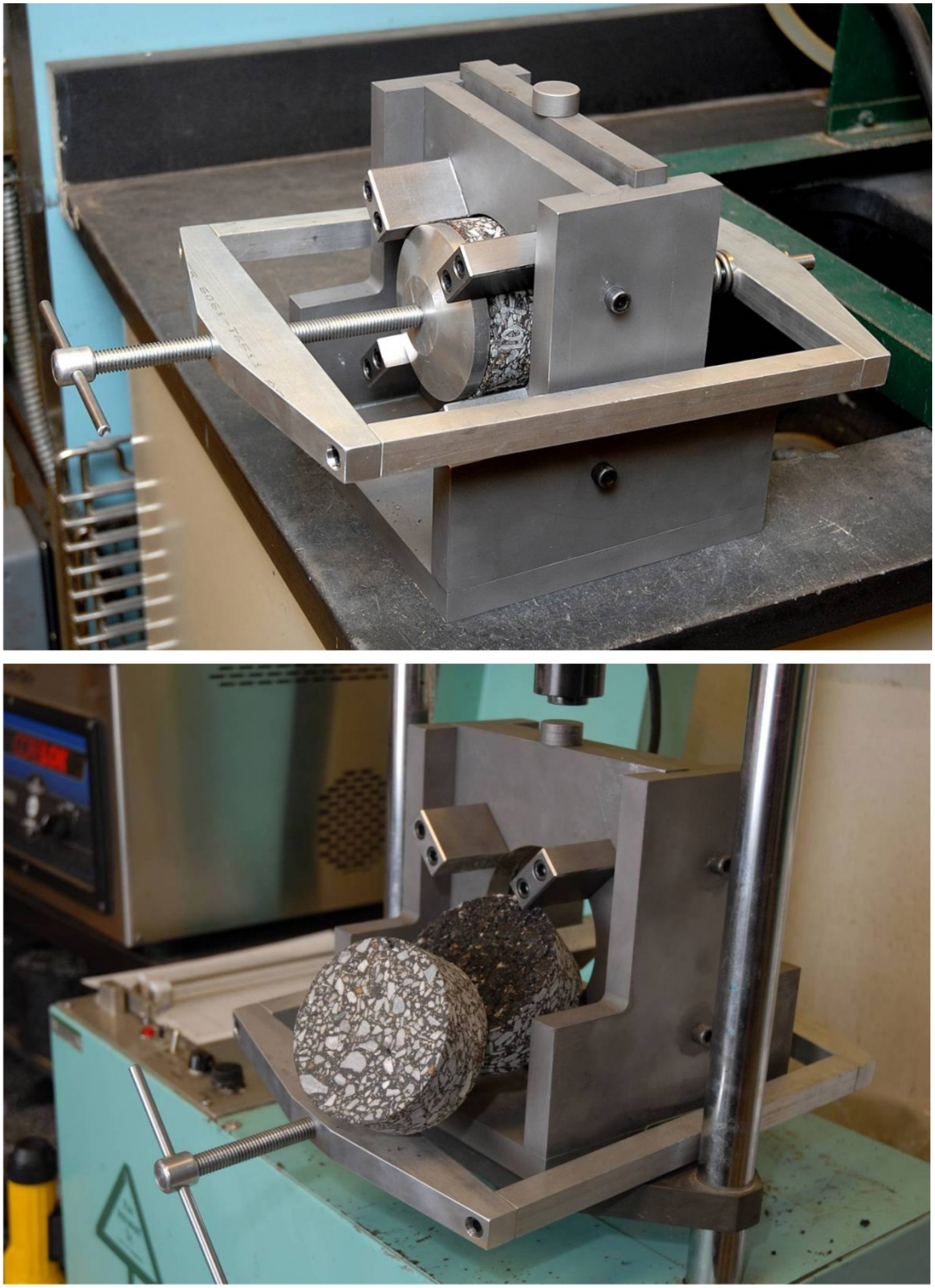

Figure 3. Guillotine-Style Shear-Testing Adapter for Marshall Device

Tension

The second test measures the tensile strength of the interface. This test is also performed with 4-in-diameter specimens. Specimen preparation starts with wet-saw cuts to establish sound material at the top of the upper layer and bottom of the lower layer. These cuts also provide an opportunity to locate the interface of interest at the approximate center of the composite specimen. Circular steel plates with threaded holes in the center are then affixed with epoxy to the clean and dried cut surfaces. After the epoxy has set overnight, eye bolts are threaded into the circular top and bottom plates and the specimens are placed in a universal testing machine for testing. The tensile strength of the interface is the maximum load (failure load at a rate of 1,200 lb/min) divided by the nominal surface area of the 4-in-diameter specimen. Figure 4 shows a fully mounted specimen in the testing machine. Figure 5 shows a specimen after it has been tested to failure. Once again, all testing is performed at 70º F.

Laboratory Comparison of Bond Strength of Typical Tack Materials

Selection of Tack Material

With a set of benchmark bond tests established, it was possible to begin examining (in a laboratory setting) the bond strength that is achieved at the interface of two layers of asphalt concrete. VDOT's Central Office Asphalt Binder Lab was consulted to determine the materials that are most commonly used around the Commonwealth as tack.

Three materials were selected to compare the shear and tensile strength of common tack materials under controlled laboratory conditions: (1) tack material meeting VDOT's requirements for a designation CRS-2 emulsion (VDOT, 2007); (2) tack material meeting VDOT's requirements for a designation CSS-1h emulsion (VDOT, 2007); and (3) a number of newer tack coat materials that are classified by VDOT as non-tracking tack (NTT) material. Samples of those materials were obtained and specimens prepared to simulate field application.

Preparation of Lower Layer

The asphalt concrete used in the laboratory specimens was a typical dense-graded hot-mix from a local producer. After the mix was acquired, the portion of the specimen that represents the lower layer, or "original surface," of a pavement system was prepared. This lower layer was "constructed" in a 4-in gyratory mold using enough material to produce a 2-in layer at about 4% air voids (96% maximum density). Two-inch strips of siliconized paper were placed on the inside of the mold just prior to the addition of the mix. These strips line the inside surface of the mold and act as a thin spacer between the pill and the mold. The slight reduction in specimen diameter that results when the spacers are removed will facilitate the return of this portion of the specimen to the mold later in the process. Once compacted, the siliconized spacer strips were removed and the HMA layer was set aside to cool to room temperature.

Figure 4. Specimen Ready for Tension Test

Figure 5. Specimen After Tension Test

Application of Tack

After cooling overnight, the top surface of the lower layer was sandblasted to remove any binder film, thus mimicking the wear from traffic. The lower layer portion was then warmed in an oven to 50º C to represent an original sun-warmed surface. The warmed lower-layer specimens were then placed on a set of scales, and the tack material was applied to the sandblasted surface using a small brush. The application rate used was the average of the minimum and maximum recommended in Section 310 of VDOT's *Road and Bridge Specifications* (VDOT, 2007) for undiluted tack. For a 4-in-diameter specimen, this average application rate of 0.075 gal/yd^2 required approximately 2.75 g of material.

Application of Specimen Surface

The newly tacked lower layer was set aside for 15 min and then placed back in the bottom of the 4-in gyratory mold. An amount of hot material similar to that use to form the lower layer was then placed into the mold on top of the new tack material. This material was then similarly compacted to form a full specimen. The complete specimen was then set aside to cool overnight.

Testing for Strength

Ten full (bottom, tack, and top) specimens were prepared for each tack material. This allowed five shear and tensile strength tests of each material (at the average application rate of 0.075 gal/yd^2). Both tests were conducted as described previously.

Field Study of Effect of Tack on Bond Strength Between HMA Overlay and Milled Surface

Trial Section Selection

A trial section for this field-oriented phase of the study included typical maintenance resurfacing activity over a working platform of conventionally milled or micro-milled surface. Essential elements of the trial location included a section of the mainline paving for which no tack was applied and a control section (of similar length) in which both the milling and tack application rate was typical of the remaining mainline work.

Field Data and Sampling

A field trial generally started with the selection of a short section of the project for which no tack would be placed on the primary horizontal surfaces. This section was usually several hundred feet near the beginning of a night (or day) of paving and an area that could be safely and easily accessed be the sampling and testing crew. This un-tacked section was coupled with a control section that was located nearby with similar convenience and safety requirements. The basic information collected from each field trial included:

- texture of the milled surface (ASTM E-965)
- application rate of tack material (gallon per square yard)
- density of new overlay (nuclear gauge)
- twelve 4-in cores: 6 from the control and 6 from the trial
  - — 3 cores each for the shear strength test
  - — 3 cores each for the tensile strength test.

The texture measurement characterized the milling activity in a way that was both objective and outcome oriented. The application rate was measured using a pre-weighed 12-in^2 plate that was placed on the surface immediately prior to the tack distributor truck passing over the control section. The tacked plate was then set aside to allow the emulsion to break without exposure to construction traffic. The plate with residual tack was then weighed, and the difference between the clean (pre-tacked) and tacked weight used to determine the undiluted application rate. Density measurements were made as close as possible to locations that would later be cored. Finally, cores were extracted and marked to indicate whether they came from a trial (un-tacked) or control (tacked) location. Other information noted by the field investigators included:

- paving material information (job mix number, mix type, application rate)
- milling and placement equipment type
- cleanliness and condition of milled surface at time of tack
- tack coat material (type, proposed application rate).

Laboratory Testing for Strength

Once in the laboratory, the cores were tested for shear and tensile strength in accordance with the methods described earlier. For those cases in which the interface was a milled surface, the shear-test specimens were oriented so that the loading direction was applied parallel to the ridges that would result from common milling activity (i.e., in the direction of traffic). In ideal situations, three cores from each section were tested for shear strength and three for tensile strength. Unfortunately, there was a number of cases where either the sampling crew was unable to extract six intact cores or the cored specimens failed to survive transport as a single unit. In these cases, the unsuccessful specimens were excluded from further analysis of bond strength (rather than counting the un-testable specimen as having a strength of zero). Many potential causes were identified for the failed cores. The predominant reason was the condition of the material that was milled. This material was deteriorated or had a failure plane immediately below it. When the cores were extracted from the pavement, failure would occur at the interface or immediately below the interface.

Laboratory Investigation of Torque-Shear Field Test to Measure Bond Performance

The last task of this research centered on the laboratory testing of a torque-shear device. In concept, the device can be taken to the field to perform a measure of bond strength in situ without the need to extract a full-depth core and return to the laboratory for acceptance testing.

Device Design and Development

The torque-shear device involves two components. The design of the first component assumes that some process has isolated the new interface from the rest of the newly placed overlay. The most practical process for doing this is partially drilling a core to some depth just below the interface of interest. The first component of the torque-shear device can then slip into the resulting circular slot and “grab” the isolated disc of new mat. Developers of the device worked with machinists to modify two old core barrels to fit into the slot of a 4- or 6-in-diameter barrel. Figure 6 is a schematic of the 6-in device. To “grip” the isolated disc, holes at even spaces around the field of the core barrel were drilled and threaded. These holes made it possible to drill into the body of the asphalt concrete disc below (and within the limits of the barrel) and

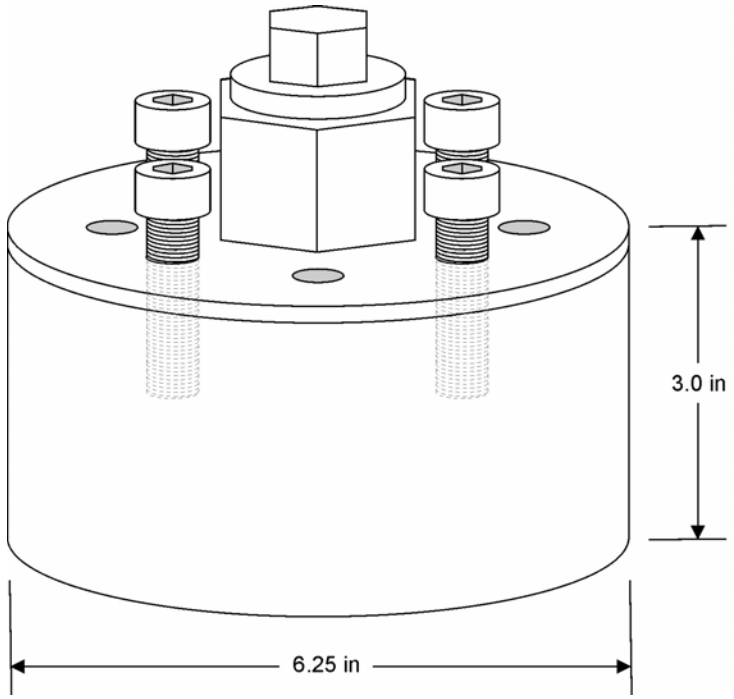

Figure 6. Six-inch Torque Adapter (Component 1) of the Torque-Shear Device

then insert pins to an appropriate depth within the disc. The combination of the penetrating pins and the confinement of the barrel provides sufficient grip of the resulting specimen.

The second component of the device is a heavy-duty torque wrench (Figure 7) that attaches to the center of the modified core barrel. The torque wrench not only supplies a sufficient lever arm for someone to “spin” the isolated disc free from the new interface, but also measures the force required to break the disc free. The width of the circular slot (formed by the cutting core barrel) is wide enough to allow the modified barrel to slip easily onto the disc and into the pavement surface. This is important since any side-force friction that might develop between the modified barrel and the intact pavement is assumed to be negligible.

Pavement Model Design and Preparation

Ideally, the laboratory evaluation of the torque-shear device would involve full-scale testing of the two core barrel sizes on the same layer interface for which baseline data for bond strength were also available. Therefore, rather than producing and testing individual (and independent) specimens, this task incorporated a number of two-layer pavement models that were each large enough to permit a series of tests. The schematic in Figure 8 illustrates the overall size requirements of the model pavement systems. In addition to permitting a test of both barrel sizes (4- and 6-in), each model accommodated two full-depth 4-in cores that were used to conduct the baseline strength tests. The Virginia Transportation Research Council (VTRC) does not have laboratory compaction equipment large enough to construct these specimens. However, those resources do exist at the FHWA’s Turner-Fairbank Highway Research Center in McLean, Virginia. With the cooperation of Turner-Fairbank, the VTRC Asphalt Laboratory Manager spent two days in the McLean laboratory making ten 7-in by 21-in flexible pavement models with plant-produced mix that was acquired from a producer in northern Virginia.

Figure 7. Torque Wrench, Modified Core Barrel, and Core

The time and resources available to prepare the 10 pavement models did not permit the "aging" process applied to the gyratory-prepared specimens that were used to compare tack materials. Since there was no step taken to remove the binder film from the surface of the lower layers, there was also no attempt to apply tack of any sort. The resulting pavement models were therefore straight dense-graded hot-mix on top of day-old dense-graded hot-mix.

Testing for Strength

The complete set of 10 pavement models was transported back to the VTRC laboratory and secured for coring and testing. The two 4-in full-depth cores were first extracted and used to measure baseline shear and tensile strength. While the model remained secured, a 4-in and a 6-in core barrel were oriented on the remaining surface area and drilled to a depth just below the bottom of the top layer. The two modified barrels (component 1 of the device) were then placed into the resulting circular slots, and the four securing pins installed. Finally, the heavy-duty torque-wrench was attached to the centers of the modified barrels and a steady force applied (by hand) until the top-layer disc of material broke free. The maximum applied torque, *T*, was

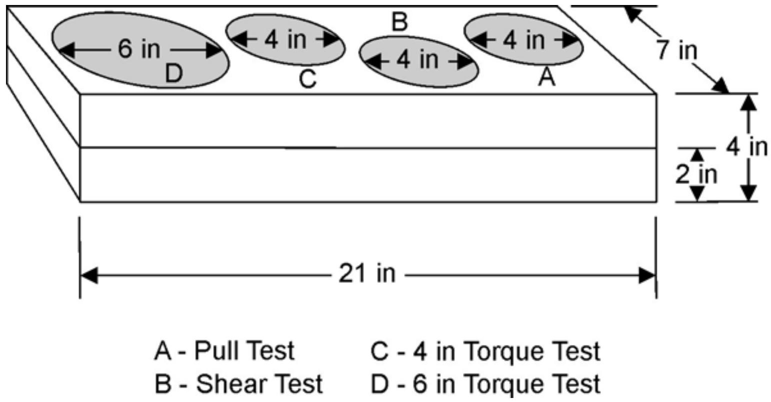

Figure 8. Pavement Model. A and B are cored full depth and extracted. C and D are cored to a depth just below the interface with the lower layer.

recorded by a dial-gauge on the wrench. The maximum shear stress was then calculated using Equation 1.

$$\tau_{max} = \frac{Td}{2J} \qquad \text{[Eq. 1]}$$

where

τ_{max} = maximum shear stress
T = breaking torque force (inch-pounds)
d = diameter of specimen (inches)
J = polar moment of inertia = $\pi d^4 / 32$.

RESULTS AND DISCUSSION

Bond Strength of Typical Tack Coat Materials

As discussed in the "Methods" section and listed in Table 1, three materials were selected to compare the shear and tensile strengths of common tack materials under controlled laboratory conditions. The average shear and tensile strengths for each material and the variability of the test results are also shown in Table 1. Although the NTT material had the weakest bond strength, the bond strength supplied by this material was the most consistent of all the materials.

Table 1. Bond Strength for Selected Tack Materials

Material	Shear Strength		Tensile Strength	
	Strength (psi)	**Std. Dev.**	**Strength (psi)**	**Std. Dev.**
CSS-1h	308	14	94	23
CRS-2	249	9	76	19
NTT	234	4	68	14
Average	264	9	79	19

Unfortunately, while the research team was devising a test plan for these materials, the material samples sat on a shelf. In most cases, the shelf-time was 1 month or more. Although none was observed, the possibility that some separation of the emulsions might have occurred cannot be ruled out. For that reason, the absolute value of these strength numbers may not represent the full potential of at least the NTT material. In fact, more recent tests conducted as part of a preliminary program to qualify NTT materials have reported shear and tensile strengths as much as 50% higher. Results from these more recent tests will be presented in a future report. These results may be obtained from the authors upon request.

Effect of Tack on Bond Strength Between HMA Overlay and Milled Surface

Summary of Project Characteristics

Table 2 summarizes basic information about the field projects. The Northern Virginia (NOVA) District was the most active participant in this phase of the research, but the Culpeper, Fredericksburg, Richmond, Hampton Roads, and Bristol districts also made contributions.

Table 2. Field Project Characteristics

Route/Location	District	Mix
US 17, Fauquier County	Culpeper	BM 25.0A
Jermantown Rd, Fairfax County	NOVA	SM 9.5D
SR 7, Loudoun County	NOVA	IM-19.0A
Gallows RD, Fairfax County	NOVA	SM 9.5D
US 50, Arlington	NOVA	SM 9.5D
SR 28, Prince William County	NOVA	SM 9.5E
US 1, Prince William County	NOVA	SM 9.5D
I-66, Fauquier County	Culpeper	SM 9.5D
US 29, Fairfax County	NOVA	SM 9.5E
US 58, Grayson County	Bristol	SM-9.5D/RAP
US 1, Stafford County	Fredericksburg	SM 12.5D/RAP
US 1, Stafford County	Fredericksburg	SM 12.5D/RAP
US 29, Prince William County	NOVA	SM-9.5D/RAP
SR 10, Chesterfield County	Richmond	SM 12.5D
SR 5, Charles City County	Richmond	SM-12.5D
US 460, City of Suffolk	Hampton Roads	SM-9.5D

SM = surface mix; IM = intermediate mix; BM = base mix; 9.5 = 9.5 mm nominal maximum aggregate size (NMAS); 12.5 = 12.5 mm NMAS; A = PG64-22 performance grading for liquid asphalt cement; D = PG70-22; E = PG76-22; RAP = mix included substantial recycled material.

Shear Versus Tensile Strength

Many researchers (Al-Qadi et al., 2008; Mohammad et al., 2005; Tashman et al., 2006; West et al., 2005) consider the shear strength at the interface to be the most relevant to system performance. Virginia, however, has made extensive use of tensile (i.e., pull-off) tests for the evaluation of polymer overlays for bridge decks (Sprinkel, 2004). The dataset of shear and tensile bond strength data for actual field cores provided an opportunity to explore the relationship between the two strength tests. Figure 9 plots a pair of average strength numbers from every test section, regardless of whether the section incorporated tack or not. The "shotgun-like" distribution gave the researchers little reason to think that one test could be used as a substitute for the other.

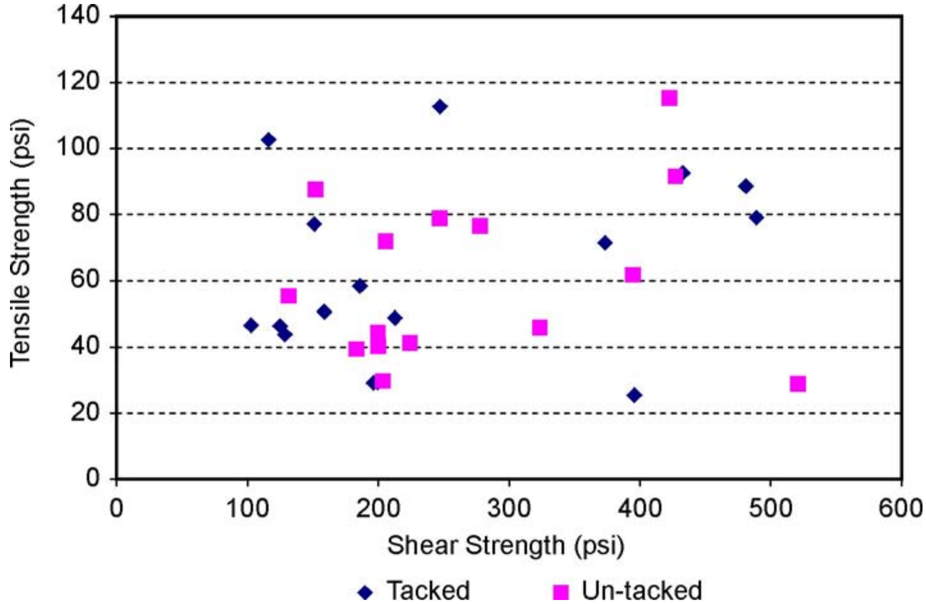

Figure 9. Shear Versus Tensile Strength for Field Cores

Strength Versus Texture

During the first season of testing (2007), the quality assurance teams who retrieved most of the field samples were diligent about quantifying (via the "sand patch" test) the texture on the milled surfaces prior to placement of the overlay. A reduction in available staff by the second season made it difficult to continue to collect all of the data that were obtained in the first season. Nonetheless, at least two additional sets of texture measurements were collected and included with the 2008 data.

The relationship between texture and strength is examined in Figures 10 and 11 for the shear and tensile strength, respectively. Once again, the most notable aspect of this basic analysis was the absence of statistically significant relationships. The strongest correlation was between texture and shear strength of the tacked sections, but that correlation was strong only in relative, not practical, terms.

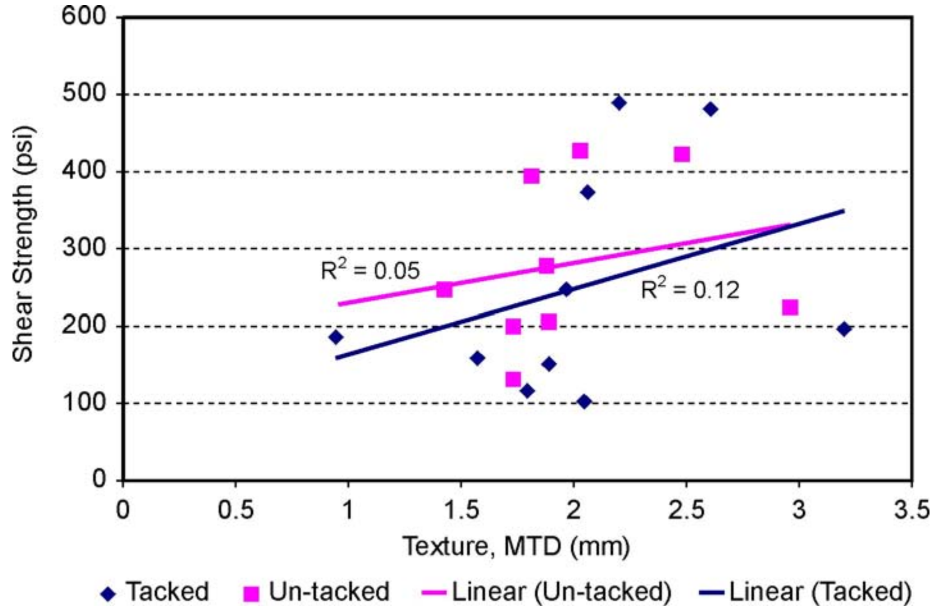

Figure 10. Shear Strength Versus Texture

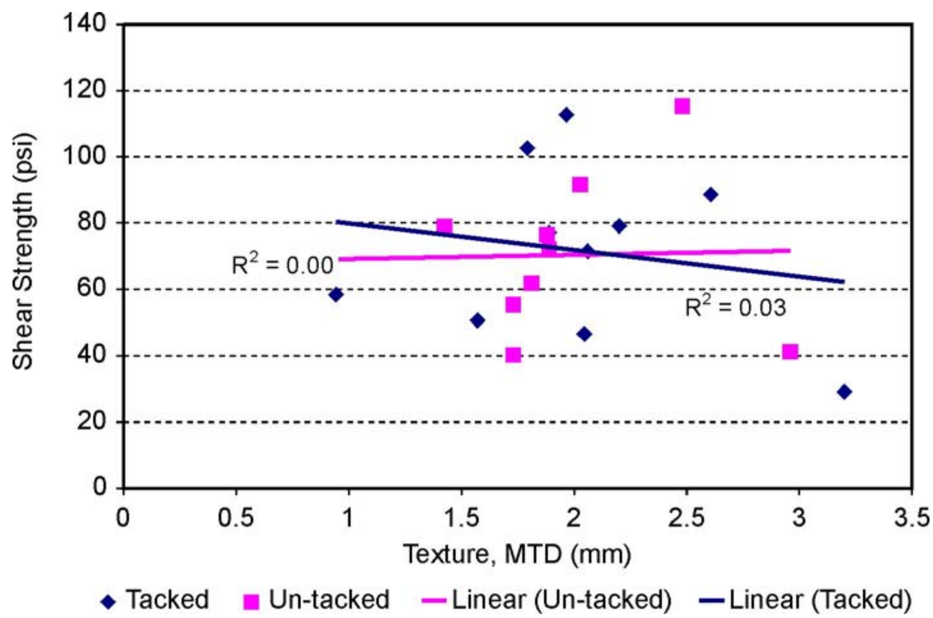

Figure 11. Tensile Strength Versus Texture

Strength Versus Tack Application Rate

Other work (e.g., Tashman et al., 2006; West et al., 2005) has also examined the impact of tack application rate on bond strength. To that end, the application rates (for those sections that did receive tack) were compared with the shear and tensile strength results. Figure 12 illustrates how tack rate affected bond strength. The correlation, although still weak, between tensile bond and application rate was the strongest seen in the analyses thus far. For this limited dataset, the linear best fit of bond versus application rate suggested an inverse relationship. That is, the strength actually dropped slightly with increased application rate. There did not appear to be a relationship between tack application rate and shear strength.

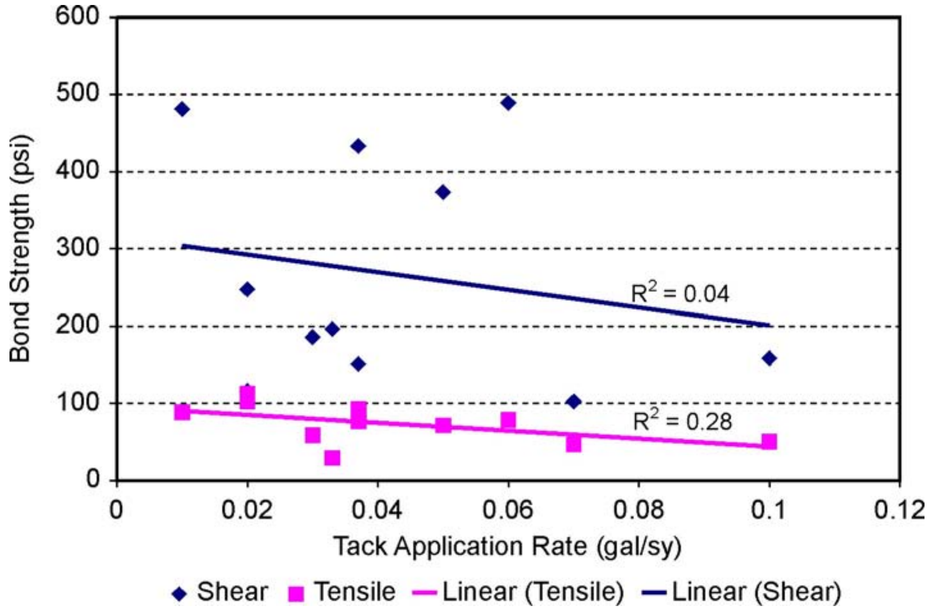

Figure 12. Bond Strength Versus Tack Application Rate

Tack Versus Un-tacked

The principal goal of this task was to determine if and how the application of tack affected the bond achieved between a new overlay and a milled surface. So, the final comparison simply compared the strength from sections that used tack with that of sections that did not. Table 3 summarizes all of the shear and tensile strength results of tests that were conducted on the field specimens as part of this phase of the research. It provides the overall average shear strength for tacked and un-tacked cores and the number of representative test sections and total number of individual specimens tested.

Figures 13 and 14 supply the section-by-section shear and tensile strength results. Each point represents the average strength value for the tacked and un-tacked sections of each project (typically two or three specimens of each type in each section). The shear strength (Figure 13) did not appear to be affected by the presence of tack material. Although there is natural variability in the test results, the best fit of the data nearly obscures the line of equality. Projects with good strength values in the un-tacked section also exhibited good strength in the tacked areas. This agreement was also evident with the lower strength work, although work that otherwise produced a lower shear bond seemed more likely to benefit from the absence of tack. Further, there appeared be two natural groupings: one of higher strength and one of considerably less strength. Unfortunately, there were no obvious characteristics that might explain these groupings.

Table 3. Average Bond Strength of Field Cores

		Tacked			Un-tacked		
Strength Test	**No. Sections**	**Tests**	**Avg.**	**Std. Dev**	**Tests**	**Avg.**	**Std. Dev.**
Shear	16	43	250	136	43	268	106
Tension	16	36	63	32	33	61	27

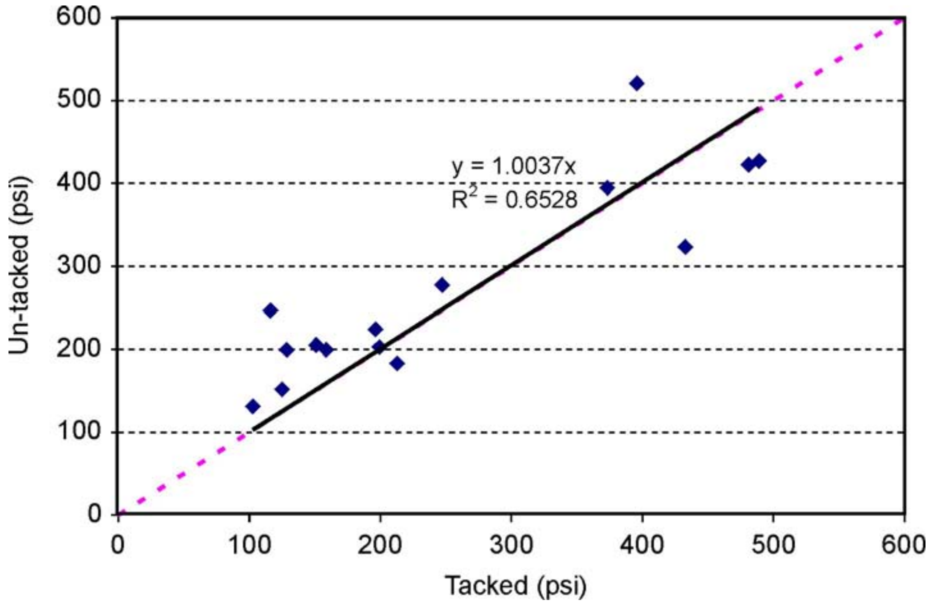

Figure 13. Shear Strength of Cores Taken From Field Projects

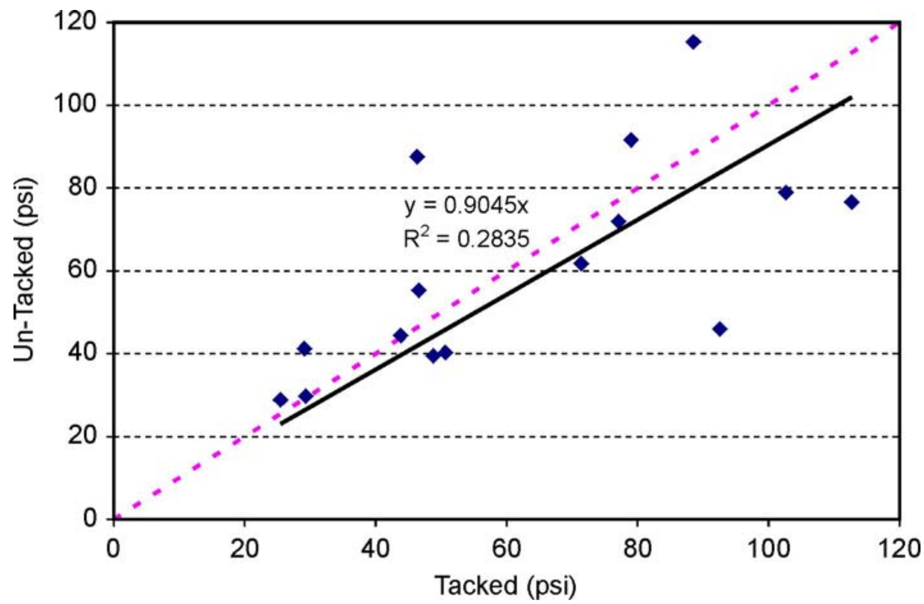

Figure 14. Tensile Strength of Cores Taken From Field Projects

The highest strength pairing was measured with an intermediate mix (IM-19.0D), which may have benefited from the interaction of a larger stone size with a fairly high milled surface texture. The next highest pairing, however, was from one of the finer surface mixes (SM 9.5E). Three of the strongest five pairings came from the NOVA District, a district that likely sees more mill and inlay work that any other (thanks to its predominantly urban landscape). The fourth was from a high-volume interstate just outside the NOVA District. The fifth strong pairing came from a less urban district, and although the shear strength values were high on this fifth project, the accompanying tensile strength values were among the lowest (and the engineer had noted "irregular" milling work in his field notes).

The tensile strength data (Figure 14) showed a slight positive effect from tacking, especially from the higher end of the strength spectrum. Of course, this is an advantage for a property for which theorists lend little significance in this particular application. Tensile strength appears more sensitive than shear strength to the cleanliness and soundness of the milled surface, as three of the lowest four strength pairings were from projects in which a less-than-ideal milled surface was observed in the field or evident at the interface of the broken specimens. Very few of the lower strength tensile values came from specimens from the NOVA District.

Torque-Shear Field Test to Measure Bond Performance

The final task involved laboratory testing of the prototype torque-shear device. Table 4 provides the overall average tensile and simple shear test results and the rupture stress in the torque shear test (as per Equation 1) using the two core barrel adapters. The table also includes a range for each test series and a coefficient of variation. All failures were clean breaks at the interface of the top and bottom layers of the specimens.

The strength values were very low by comparison to those measured during the first two tasks. In task 1 (also laboratory-prepared specimens), for example, the tensile strength averaged almost 80 psi and the average shear strength was more than 250 psi. One important difference was the method of compaction. Although the specimens in this task were prepared, dimensionally speaking, with enough material to achieve about 7% air voids (93% maximum theoretical density), the specimen shapes were so efficient as not to leave enough "scrap" to conduct a reliable bulk density measurement. For that reason, sufficient compaction energy to have applied the top layer firmly to the bottom can only be assumed. Further, mechanical interlock (something that appears important to bond over milled surface) was likely less of a factor with a "finish" that was predominantly applied by the laboratory compaction device. Finally, no tack was applied at the interface of the two layers. The only field specimens (task 2) with tensile strengths this low were those observed to be from an unsound and/or unclean interface.

Table 4. Laboratory Test Results with Torque-Shear Device

Test	Tensile Strength	Simple Shear Strength	Rupture Stress	
			4-in Adapter	6-in Adapter
Average Strength (psi)	29	124	117	103
Range (psi)	25	44	33	31
Coefficient of Variation (%)	27	11	8	10

Torque-Shear Versus Tensile Strength

Figure 15 presents the results of a comparison of tests with the torque-shear device (both adapters) with the simple tensile strength test. Neither adapter varied much with the reference strength values (the simple tension test). Considering the lack of good correlation demonstrated earlier between tensile and shear strengths (Figure 7), perhaps the lack of correlation should be expected.

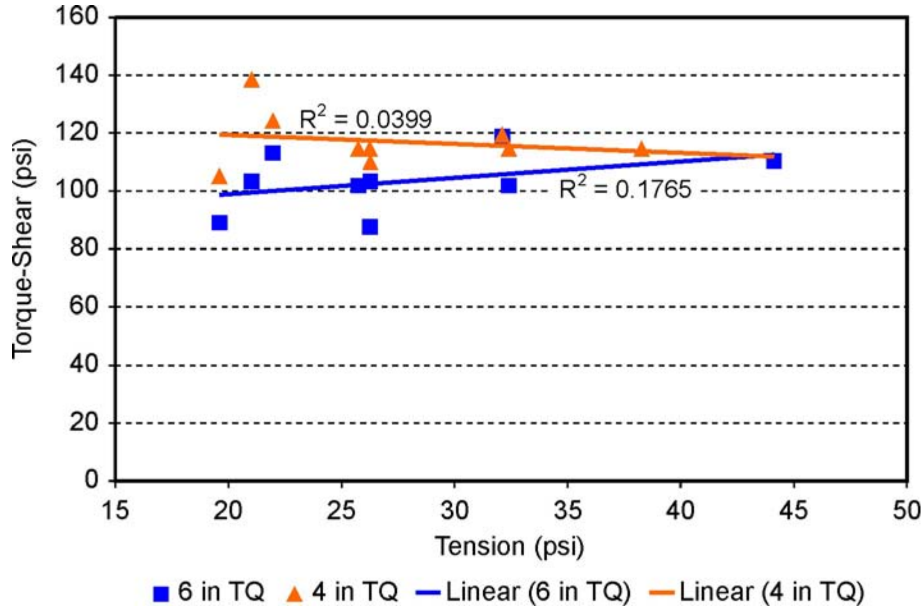

Figure 15. Comparison of Results of Tests with Torque-Shear Device and Simple Tensile Strength Tests

Torque-Shear Versus Simple Shear Strength

Since the torque force applies a predominantly shearing force on the interface, one would expect a better relationship between results of the torque-shear tests and the simple shear strength test. Figure 16 explores this possibility. Unfortunately, at least within the somewhat limited range of varying strength, there appeared to be little relationship between results.

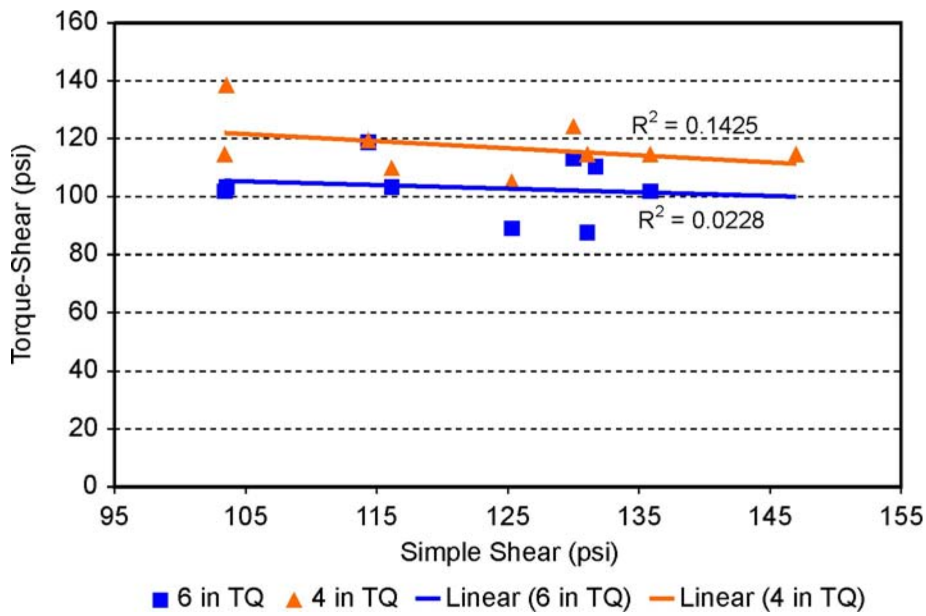

Figure 16. Comparison of Results of Tests with Torque-Shear Device and Simple Shear Strength Tests

Torque-Shear 4-inch Adapter Versus 6-inch Adapter

The last comparison was between the two adapters. The size of the interface effectively represented by the two adapters is appreciably different: 12.5 in^2 for the 4-in adapter versus more than 28 in^2 for the 6-in adapter. Given this difference, it is encouraging that the resulting maximum stress values were within a few pounds per square inch of each other. Figure 17, however, shows only the slightest correlation between the two adapters within this range of strength values. Of course, the failure to find a strong relationship may be attributable to the absence of spread in the dataset. That is, there may have been simply too little difference between the strongest and weakest measured values to conclude anything with confidence about the ability of this prototype to discriminate strength differences of practical significance.

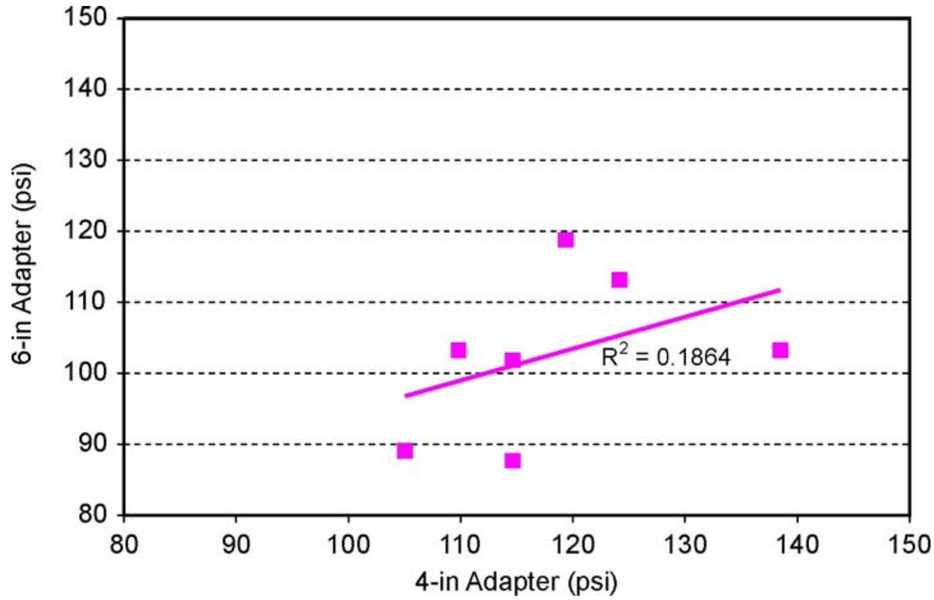

Figure 17. Comparison of Torque-Shear Strength as Measured with the Four-inch and Six-inch Adapters

CONCLUSIONS

- *The bond strength between a new HMA overlay and a milled underlying surface is not affected by the application of tack.* Poor bond is associated with an unsound and/or dirty underlying surface, and such poor bonds are just as likely (if not more so) when tack is used as when it is not. High bond strength is likewise neutral to the practice of tacking.

- *Under ideal laboratory conditions, the most common tacking materials appear capable of contributing to good bond strength of typical plant-mix layers.* The CSS-1h product supplied the highest average strength, followed by the CRS-2 and NTT products. It should be noted, however, that these materials were “aged” on the shelf for 1 month or more. For that reason, the strength values found in this limited exercise should be considered a lower bound for the potential for these products.

- *The ability of the torque-shear device to represent realistic bond conditions is still unknown*. The bond strength for the two-layer pavement models was simply too low and too consistent to permit a fair assessment of the strength-discriminating capacity of the prototype device.

RECOMMENDATIONS

1. *VDOT's Materials Division should develop a special provision for paving that does not require the application of tack to primary horizontal surfaces that have been milled.* Construction districts with substantial experience with mill and fill paving should be particularly receptive to this simplification and be ready to take advantage of it. A recommended special provision, which includes a performance requirement for bond strength, is provided in the Appendix.

2. *VDOT inspection and quality assurance personnel should continue to emphasize the importance of a clean, sound construction platform for new overlay work.* Evidence (field and laboratory observation) confirms that an uneven, unsound, and unclean construction platform will typically lead to poor bonding. "Scabbing" (i.e., thin, loosely bound remnants of the original surface) is one phenomenon that leads to unsound interfaces and immediate or future bond failures.

3. *VTRC should coordinate with VDOT's Materials Division to perform field testing of the prototype torque-shear device.* This next phase of testing should attempt to gather data on a more typical and broader spectrum of bond conditions.

COSTS AND BENEFITS ASSESSMENT

Although VDOT specifications require it, tacking material is not included as a bid item for maintenance resurfacing projects. However, conventional tacking material (CRS-1 and CRS-2) costs approximately $1.30/gal, and the early-curing, heat-adhesive materials (i.e., "trackless" tack) cost about $1.90/gal. At an application rate of 0.075 gal/yd^2 for mainline tacking (middle of the application rate range as per VDOT specifications), resurfacing work that supplies a new mat at 165 to 180 lb/yd^2 (1½ in) will use about three-fourths of a gallon of tack per ton of HMA. Assuming an application rate of 165 lb/ yd^2 (1½ in), 581 tons of HMA and 440 gallons of tack will cover 1 lane-mile 10 ft wide. At $1.30 to $1.90 per gallon, the cost per lane-mile of tack is between $572 and $836.

Resurfacing projects for which the construction platform is a milled surface provided the lead focus for this work because there was a substantial opportunity to implement the findings quickly and statewide. If VDOT were to eliminate the requirement for tack on milled projects, the estimated savings per lane-mile would be a fairly straightforward calculation (as shown in previous paragraph). An estimate of statewide savings can also be offered. According to the Trns*port database kept by VDOT's Scheduling & Contracts Division, VDOT awarded just over

24 million square yards of "flexible pavement planing" (item-code 16388) for maintenance resurfacing between April 2007 and March 2008 (Kiefer, 2008). Although planing (or milling) is awarded in square yards, it is actually paid for by the square-yard-half-inch increment. That is, a milling contractor is paid for every half-inch of material that is removed with each pass. For instance, a pass that removes 1 square yard of surface to a depth of 1½ in would actually count as 3 yd^2 of planing. The vast majority of lane-width milling (or planing) removes and replaces 1½ to 2 in of material. Therefore, the actual milled surface area exposed last year was closer to 6 or 8 million square yards than to 24 million square yards. If VDOT had chosen to forego tacking of that surface area, the savings in conventional tack would have been between $488,000 and $650,000. If that material had been of the non-tracking variety, the savings could have been as much as $950,000.

ACKNOWLEDGMENTS

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APPENDIX

RECOMMENDED SPECIAL PROVISION FOR PAVING OVER MILLED SURFACES

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
PAVING OVER MILLED SURFACES

Month Day, Year

SECTION 315.05(b)1b. Tacking of the Specifications is amended to include the following:

A tack coat shall be applied between the existing un-milled asphalt surface and the asphalt course placed thereafter. A tack coat shall be required between each lift of asphalt.

For milled surfaces, a tack coat will not be required to be applied on the primary horizontal surfaces. As noted above, the milled vertical faces shall be tack coated.

SECTION 315.05(c) PLACING AND FINISHING of the Specifications is amended to include the following:

Roadways from the Traffic Group table in the Special Provision for **SECTION 512—MAINTAINING TRAFFIC (Maintenance)** designated XV and higher that require pavement planing operations shall have all exposed planed pavement areas overlaid in accordance with the requirements in the Special Provisions for **PLANING ASPHALT CONCRETE PAVEMENT (Maintenance)** and **PLACEMENT OF HOT MIX ASPHALT OVERLAYS (Maintenance)** unless otherwise specified elsewhere in the Contract.

When the new asphalt course is to be placed on a milled surface, the Contractor shall take steps to ensure an adequate bond between the new material and existing surface. Such steps may include sweeping, vacuuming, or other actions to remove the majority of the dust and debris left by the milling operation. If the Engineer suspects the Contractor is failing to apply good bond promoting procedures, the Department may core a minimum of 6 locations to determine the shear and tensile strengths at the milled interface. Cores will be tested in the Department's laboratory. For the milled surface to be acceptable, the results for shear and tensile strength must meet the following criteria. A minimum of 3 cores will be tested for shear strength and 3 cores for tensile strength. The average shear strength must meet or exceed 100 psi with no single core having a shear strength less than 50 psi. The average tensile strength of the remaining cores must meet or exceed 40 psi with no single core having a tensile strength less than 20 psi. In the event the minimum shear strength or tensile strength requirements are not met, then payment for the asphalt concrete tonnage placed during that operation shall be 90 percent.