BOND EXPECTATIONS FOR ASPHALT CONCRETE LAYERS APPLIED TO MILLED SURFACES IN VIRGINIA

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ABSTRACT

This paper describes a field study of the effect of tack on bond strength between a new asphalt concrete overlay and a milled surface. The study was a supporting activity to a program of research designed to identify a test method and acceptance criteria for bonding of asphalt concrete layers.

The findings of the study led to the recommendation that the Virginia Department of Transportation no longer require the practice of tacking primary horizontal surfaces when placing a new overlay on a milled surface. 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.
INTRODUCTION

When new asphalt concrete (AC) layers are placed over in-service pavements, the Virginia Department of Transportation (VDOT) specifies a coating of asphalt tack material as part of preparing the original surface to provide an adhesive interlock; this tack coat is described in Section 310 of VDOT’s Road and Bridge Specifications. It is generally an asphalt emulsion that serves to improve the bond between the new and existing materials. Typically, this emulsion is applied with a pressure 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 AC overlay has a shorter service life 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 AC 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 “soft” liquid asphalt base (PG 64 or PG 58). 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 1) 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 AC 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.

Today, the traditional practices of tacking and bonding AC layers together are subject to numerous important influences. Among them is the growing proportion of AC 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 AC 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 1 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 (2).

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 AC resurfacing (3). 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

VDOT is supporting a program of research with an ultimate goal of providing a performance test method and acceptance criteria for bonding of AC layers. This paper describes a field study of the effect of tack on bond strength between a new AC overlay and a milled surface, which was performed in support of that overall objective. Data to support the field study came from VDOT AC resurfacing activities underway during the summers of 2007 and 2008.
RESEARCH METHODS

Laboratory Tests for Bond Strength

Fundamental to the performance comparisons made in this paper is a baseline measure of bond strength at the interface of two AC layers. 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 (4). Figure 2 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.

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 3 shows a fully mounted specimen in the testing machine. Once again, all testing is performed at 70º F.

Selection of Trial Sections

A trial section 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.
FIGURE 2 Guillotine-style shear-testing adapter for Marshall device.
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 by 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 objective
and outcome oriented. The application rate was measured using a pre-weighed 12-in² 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 sheargest
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.
RESULTS AND DISCUSSION

Summary of Trial Section Characteristics

Table 1 summarizes basic information about the field projects that were selected for trial sections. 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 1 Field Project Characteristics**

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

*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 more than 20% recycled material; NOVA = VDOT’s Northern Virginia District.

Shear Versus Tensile Strength

Many researchers (3, 5-7) 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 (8). 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 4 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.
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 5 and 6 for the shear and tensile strength, respectively. Once again, the most notable aspect of this basic

![Figure 4: Shear versus tensile strength for field cores.](image)

![Figure 5: Shear strength versus texture.](image)
FIGURE 6 Tensile strength versus texture.

The strongest correlation was between texture and shear strength of the tacked sections, but that correlation was strong only in relative, not practical, terms.

Strength Versus Tack Application Rate

Other work (e.g., 3, 7) 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 7 illustrates how tack rate affected bond strength. The correlation, although still weak, between tensile bond and application rate was the strongest.

FIGURE 7 Bond strength versus tack application rate.
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.

**Tack Versus Un-tacked**

The principal goal of this field study 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 2 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.

**TABLE 2 Average Bond Strength of Field Cores**

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<tr>
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</thead>
<tbody>
<tr>
<td>Shear</td>
<td>16</td>
<td>43</td>
<td>250</td>
<td>136</td>
<td>43</td>
<td>268</td>
<td>106</td>
</tr>
<tr>
<td>Tension</td>
<td>16</td>
<td>36</td>
<td>63</td>
<td>32</td>
<td>33</td>
<td>61</td>
<td>27</td>
</tr>
</tbody>
</table>

Figures 8 and 9 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 8) 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 to 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.

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 than 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 9) 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.

**Summer 2009 Site Re-visit**

During the summer of 2009, eight of the original test sites (established summer 2007) were visually surveyed for signs of premature distress. None of the “no-tack” sections exhibited failures or other distresses indicative of poor bond with the underlying surface.
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/yd² 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/yd² (1½ in) will use about three-fourths of a gallon of tack per ton of AC. Assuming an application rate of 165 lb/yd² (1½ in), 581 tons of AC 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 (9). 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 yd² 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.

CONCLUSION

The bond strength between a new AC 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.

ACKNOWLEDGMENTS

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