Evaluation of Bond Performance of FastTack® Emulsion for Tack Coat Applications

FINAL REPORT

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The purpose of this study was to evaluate the bond performance of FastTack® relative to that of AET through a host of laboratory tests. FastTack is a proprietary, rapid-setting emulsion used as a bituminous tack coat for pavement applications. The product, produced by Whitaker Roads Corporation, is touted to exhibit a very fast set time feature that distinguishes it from regular rapid-setting emulsions. This is achieved by the introduction of certain additives, a process referred to as Colnet®. The rapid set time is beneficial for fast-track paving projects and hence could prove to be highly cost effective. However, the adoption of FastTack as an approved replacement to typical tack coats used by PennDOT is contingent on it exhibiting bond characteristics similar to those exhibited by other rapid-setting emulsions such as AET.
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Executive Summary

The study presented in this report is part of a research project aimed at assessing whether the adhesion of FastTack®, a proprietary ultra-rapid-setting emulsion, when used as tack coat between asphalt concrete layers is similar to that of standard AET emulsion used as a rapid-setting emulsion by the Pennsylvania Department of Transportation. Three tests were conducted to evaluate the bond performance of FastTack: a Modified Marshall test at 25 °C and SST tests at 25 °C and 51 °C. Each sample consisted of a field core for the bottom layer, with a fresh asphalt mixture compacted on top of it, using the Superpave gyratory compactor, constituting the upper layer. Half of the specimens fabricated had regular AET tack coat applied at the interface, while the other half had FastTack.

In general, the results from the Modified Marshall and SST tests at 25 °C revealed similar values for shear strength for both types of specimens, and so did the SST tests at 51 °C. The strengths of the specimens with AET were slightly higher than those with FastTack in the Modified Marshall test, while the opposite is true for the SST test at 51 °C. Statistical analyses done on the test results confirm that the observed differences in the strengths between the two types of specimens were statistically insignificant, and for a 95% confidence interval the means of the strengths are the same. The study found no statistical difference between the performance of FastTack and regular emulsion, AET, with regard to adhesion for all conditions and tests performed in the course of this project.
1 Introduction

An asphalt tack coat is a film of bituminous emulsion that is used to enhance adhesive bonding between an existing layer and a new layer. Adhesion between pavement layers is a key factor regarding the proper stress distribution among the pavement layers. The use of tack coat ensures that the layers act as a monolithic system, preventing any slippage on the layer interface. Improper bonding between layers can cause a deficient transfer of radial tensile and shear stresses into the entire pavement structure. It can also cause a stress concentration at the bottom of the wearing course (Louay et al., 2002). The lack of tack coat can lead to de-bonding of the overlay, slippage between layers, and premature fatigue cracking (WSDOT, 2002). The only exception for the use of tack coat is when an overlay is placed after 1 or 2 days on a new asphalt layer that has not yet been opened for traffic. Mrawira and Damude (1999) compared the shear strength of an interface between fresh overlays with and without tack coat by applying a shear load of 1 mm/min (0.04 in/min). The authors have found that the tack coat doesn’t improve shear strength.

Normally, hot asphalt liquid, emulsified asphalt, or cutback asphalt are used for tack coat. The application process consists of spraying the material on the surface of an existing pavement prior to an overlay. Tack coats are also used where the asphalt mixture comes in contact with the vertical face of curbs, gutters, cold pavement joints, and structures. FastTack is a proprietary, rapid-setting emulsion used as a bituminous tack coat for pavement applications. Produced by Whitaker Roads Corporation, the product is touted to exhibit a very fast set time feature that distinguishes it from regular rapid-setting emulsions. This is achieved by the introduction of certain additives, a process referred to as Colnet®. The rapid set time is beneficial for fast-track paving projects and hence could prove to be highly cost effective.


2 Study Objective

The purpose of this study was to evaluate the bond performance of FastTack® relative to that of AET through a host of laboratory tests. FastTack is a proprietary, rapid-setting emulsion used as a bituminous tack coat for pavement applications. The product, produced by Whitaker Roads Corporation, is touted to exhibit a very fast set time feature that distinguishes it from regular rapid-setting emulsions. This is achieved by the introduction of certain additives, a process referred to as Colnet®. The rapid set time is beneficial for fast-track paving projects and hence could prove to be highly cost effective. However, the adoption of FastTack as an approved replacement to typical tack coats used by PennDOT is contingent on it exhibiting bond characteristics similar to those exhibited by other rapid-setting emulsions such as AET.

3 Literature Review

3.1 Tack Coats: Composition and Construction

Emulsified asphalts are increasingly being used instead of cutback asphalts or hot asphalt cements because of their lower application temperature and environmental concerns related to the volatile components. According to the emulsifying agent and other manufacturing controls, the emulsified asphalt may be anionic or cationic. Anionic emulsions have positive-charge droplets, in contrast with the cationic emulsions. The aggregate surface’s electronic charge defines the type of emulsion. Aggregates with a negative surface charge require an anionic emulsion asphalt, while cationic emulsion asphalts are used with aggregates that have a positive surface charge. The reactivity between the emulsifying agent and the aggregates will define the break (or setting) time. Emulsions can be categorized as rapid-setting (RS), medium-setting (MS), or slow-setting (SS).

The most common emulsified asphalts used as tack coat materials are SS-1, SS-1h, CRS-2 (Cationic Rapid Setting), CMS-2, or CSS-1h (Asphalt Institute, 1989). Surface
preparation is the first step in the proper application of tack coat. The pavement must be
dry and cleaned of any dust in order to ensure the absorption of the emulsion into the
existing surface. When the surface is not appropriately cleaned, the tack coat doesn’t
bond to the existing surface and can stick to the paving equipment’s tires, creating tracks
of reduced coat thickness. The uniform application of tack coat and an appropriate
application rate are the most influential factors in tack coating. The application spread
rate can be checked in situ using procedures documented in ASTM D2995 Standard.

A survey conducted in 13 Midwestern and Western States in the United States
indicated that slow-setting emulsions are the primary materials used for tack coat (Table
1), with the exception of work performed in California by CALTRANS, where the AR-
4000 was the most common tack coat material (Cross and Shrestha, 2004). The Kansas
Department of Transportation was the only agency that reported occasionally using
cutback asphalts as tack coat. New Mexico and Texas reported that PG binders (asphalt
cement) were occasionally used as tack coat materials. It should be noted that there exists
a trend of allowing a wider range of materials in tack coat applications.

The amount of residual asphalt content is calculated by the residual tack coat rate,
which is the amount of material remaining on the pavement surface after the total
evaporation of the water. Several authors (Paul and Scherocman, 1998; Louhay et al.,
2002; WSDOT, 2002) recommend a range of 0.18 to 0.27 L/m² (0.04 to 0.06 gal/yd²),
depending on the existing surface condition; however, studies have found that some
materials can perform better at different application rates (Uzan et al., 1978; Mrawira and
Damude, 1999).

Table 2 shows the values recommended by the Washington Department of
Transportation for slow-setting asphalt emulsions (SS-1, SS-1h) containing
approximately 60% bituminous material.
Table 1. Summary of agency prime coat specifications (Cross and Shrestsha, 2004).

<table>
<thead>
<tr>
<th>Agency</th>
<th>Application Rates (L/m²)</th>
<th>Temperature Limitations</th>
<th>Require Dry Surface</th>
<th>Tack Vertical Surfaces</th>
<th>Require Dilution</th>
<th>Limits on Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arizona (57)</td>
<td>Target rate of 0.3 - 0.5 (0.06 - 0.12 gal/yd²)</td>
<td>NF</td>
<td>Yes</td>
<td>NF</td>
<td>NS</td>
<td>Same Day Coverage</td>
</tr>
<tr>
<td>California (58)</td>
<td>See table 8</td>
<td>A &amp; B mix &gt;10 C (50 F) Base mix &gt; 5 C (40 F)</td>
<td>Yes</td>
<td>Yes</td>
<td>NS</td>
<td>Same Day Coverage</td>
</tr>
<tr>
<td>Colorado (59)</td>
<td>Shown in Plans and Specifications</td>
<td>Surface or Ambient &gt; 5 C (40 F)</td>
<td>Yes</td>
<td>Yes</td>
<td>NS</td>
<td>NF</td>
</tr>
<tr>
<td>Kansas (60)</td>
<td>Shown in Plans and Specifications</td>
<td>Air &gt;4C (40 F) Surface &gt; 7 C (45)</td>
<td>Yes</td>
<td>Yes</td>
<td>50%</td>
<td>NF</td>
</tr>
<tr>
<td>Nebraska (61)</td>
<td>0.2 - 0.45 (0.05 - 0.10 gal/yd²)</td>
<td>Surface &gt; 3 C (37 F)</td>
<td>Yes</td>
<td>NF</td>
<td>50%</td>
<td>NF</td>
</tr>
<tr>
<td>Nevada (62)</td>
<td>Shown in Plans and Specifications</td>
<td>Ambient &amp; Aggregate &gt; 4 C (40 F)</td>
<td>Yes</td>
<td>Yes</td>
<td>40% Water</td>
<td>Same Shift Coverage</td>
</tr>
<tr>
<td>New Mexico (63)</td>
<td>Provided by Project Manager</td>
<td>Ambient &gt; 7 C (40 F)</td>
<td>Yes</td>
<td>Yes</td>
<td>NS</td>
<td>NF</td>
</tr>
<tr>
<td>North Dakota (64)</td>
<td>Shown in Plans and Specifications</td>
<td>Surface or Ambient &gt; 5 C (40 F)</td>
<td>Yes</td>
<td>NF</td>
<td>50%</td>
<td>NF</td>
</tr>
<tr>
<td>Oklahoma (65)</td>
<td>&lt; 0.45 (0.10 gal/yd²)</td>
<td>NF</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Same Day Coverage</td>
</tr>
<tr>
<td>South Dakota (66)</td>
<td>Shown in Plans and Specifications</td>
<td>Surface or Ambient &gt; 2 C (35 F)</td>
<td>Yes</td>
<td>Yes</td>
<td>As Per Engineer</td>
<td>Same Day Coverage</td>
</tr>
<tr>
<td>Texas (67)</td>
<td>0.2 - 0.45 (0.04 - 0.10 gal/yd²)</td>
<td>Surface &gt; 15 C (60 F)</td>
<td>Yes</td>
<td>Yes</td>
<td>Not Allowed</td>
<td>NF</td>
</tr>
<tr>
<td>Utah (68)</td>
<td>Shown in Plans and Specifications</td>
<td>Surface &gt; 10 C (50 F)</td>
<td>Yes</td>
<td>Yes</td>
<td>In Plans</td>
<td>Same Day Coverage</td>
</tr>
<tr>
<td>Wyoming (69)</td>
<td>Shown in Plans and Specifications</td>
<td>Surface &amp; Air &gt; 5 C (40 F)</td>
<td>NF</td>
<td>Yes</td>
<td>50%</td>
<td>Same Day Coverage</td>
</tr>
<tr>
<td>USFS (70)</td>
<td>0.15 - 0.70 (0.03 - 0.15 gal/yd²)</td>
<td>Surface &gt; 5 C (40 F)</td>
<td>Yes</td>
<td>NF</td>
<td>50%</td>
<td>Cover Within 4 hrs</td>
</tr>
<tr>
<td>UFC (4)</td>
<td>0.23 - 0.68 (0.05 - 0.15 gal/yd²)</td>
<td>NF</td>
<td>Yes</td>
<td>NF</td>
<td>Yes</td>
<td>Same Day Coverage</td>
</tr>
<tr>
<td>CFLHD (53)</td>
<td>0.15 - 0.70 (0.03 - 0.15 gal/yd²)</td>
<td>Surface &gt; 2 C (35 F)</td>
<td>Yes</td>
<td>NF</td>
<td>Yes</td>
<td>Cover Within 4 hrs</td>
</tr>
</tbody>
</table>

NF = Not found in specifications. NS = Not specified.
Table 2. Typical application rates (WSDOT, 2002).

<table>
<thead>
<tr>
<th>Existing Pavement Condition</th>
<th>Application Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Undiluted (gal/yd(^2))</td>
</tr>
<tr>
<td>New Asphalt</td>
<td>0.05 - 0.07</td>
</tr>
<tr>
<td>Oxidized Asphalt</td>
<td>0.07 - 0.10</td>
</tr>
<tr>
<td>Milled Surface (HMA)</td>
<td>0.10 - 0.13</td>
</tr>
<tr>
<td>Milled Surface (PCC)</td>
<td>0.10 - 0.13</td>
</tr>
<tr>
<td>PCC</td>
<td>0.07 - 0.10</td>
</tr>
</tbody>
</table>

### 3.2 Evaluation of Tack Coat Adhesion

Uzan et al. (1978) investigated the influence of application rate on the adhesion of tack coat at the interface between layers. The direct shear test is used to compare adhesion of the same material at different application rates. The optimum tack coat application for the material studied was found to be 1.0 Kg/m\(^2\) at 25 °C. Moleenar et al. (1986) concluded that shear resistance between HMA layers treated with stress-absorbing interlayers is about the same for specimens with and without tack coat. The tests are performed using a modified Marshall stability load press at a rate of 0.85 mm/sec.

Performing shear tests in rectangular and cylindrical specimens, Hachiya and Sato (1997) investigated the influence of temperature, loading rate, and curing period in two different emulsion tack coats. The results showed little effect at 20 °C; however, the bond strength was greater at 40 °C. The results regarding the load application rate showed a significant impact on the bond strength. The specimens tested at the rate of 101.6 mm/min (4 in/min) showed higher bond strength than those tested at 1.01 mm/min (0.04 in/min). Louay et al. (2002) analyzed the performance of six different materials, two asphalt cement (PG 64-22 and PG 76-22M) and four emulsions (CRS-2P, SS1, CSS-1 and SS-1h). Shear tests using SST (Simple Shear Tester) were conducted and the results showed the best performer to be the CRS-2P emulsion at the application rate of 0.09 L/m\(^2\) (0.02 gal/yd\(^2\)).
3.3 Adhesion Testing Methods and Equipment

Several test protocols and corresponding equipment are commonly used by highway agencies to evaluate bond strength.

ASTRA

Figure 1 shows the ASTRA (Ancona Shear Testing Research and Analysis apparatus), designed at the Università Politecnica delle Marche in Italy (Santagata et al., 1993). The system consists of a direct shear box, similar to the device usually used in soil mechanics. It allows for evaluation of the interlayer shear zone between two bituminous layers under laboratory conditions. The specimens, in contact, can be either prismatic with a maximum square cross-section area of 100 x 100 mm, or cylindrical with diameters ranging from 94 to 100 mm.

![Figure 1. Working scheme for the ASTRA test device (Santagata et al., 2005).](image)

Torque Bond Test

The Torque Bond Test, originally developed in Sweden, is a common test for assessing bond strength using an in-situ torque test procedure. In this test, the pavement is cored below the interface of interest and left in place. A plate is glued to the surface of the core, then a torque wrench is attached to the plate and a torque is applied manually until failure occurs (West, 2005). A similar test was developed to be conducted in the laboratory. The
procedure is the same except that the core is removed and placed in a clamp device (Figure 2). The specimen is held at the bottom and the torque is manually applied to the metal plate glued at the top of the core by a torque wrench. The force required for failure is recorded as well as the location of the failure.

![Figure 2. Torque bond testing device and procedure (Tashman et al., 2006).](image)

The bond strength for the specimen is then calculated using Equation 1.

\[
\tau = \frac{12M \times 10^6}{\pi D^3}
\]  

(1)

where \(\tau\) is the interlayer bond strength (kPa), \(M\) is the peak torque at failure (N·m), and \(D\) is the diameter of the core (mm). The laboratory Torque Bond Test is conducted at 20±2 °C (68±4 °F).

**Pull-Off Test**

For the pull-off test, a circular drill bit (100-mm diameter) is used to drill into the pavement from the top surface, passing through the interface and penetrating 50 mm into the base layer. Steel plates are glued to the top surface of the core and the core is pulled out of the pavement. The system used to apply the tensile force also records the maximum load registered during the test (Tschegg et al., 1995).

However, this procedure presents a wide scattering of results. Some of the possible reasons are: eccentricity of load, small core diameter and large aggregate size,
notches at the surface of the cores due to drilling or burst out aggregates, stress concentrations, uncontrolled temperature, and indentation effects due to rough surfaces (Tschegg et al., 1995).

**UPOD**

The UTEP Pull-Off Device (UPOD) developed at the University of Texas at El Paso measures the tensile strength of the tack coat before a new overlay is applied (Deysarkar, 2004). The UPOD measures the strength of the tack coat in tension. The instrument weighs about 10.4 Kg (23 lb) and it is leveled by adjusting the pivoting feet, as can be seen in Figure 3. A torque wrench, which is attached to the device, pulls the plate up from the tacked surface.

![Figure 3. UTEP Pull-Off test Device (Tashman, 2006).](image)

After the tack coat is applied on the pavement, it is allowed to set for 30 minutes. Thereafter, the device is placed on the tack-coated surface. A 18 Kg (40 lb) load is placed on the weight key (at the top of the device) for 10 minutes prior to testing in order to set the contact plate. The load is then removed and the torque wrench is rotated in the counterclockwise direction to detach the contact plate from the tack-coated pavement (Figure 4).
The torque required to detach the contact plate from the tacked pavement is recorded in inch-pounds and is then converted to the strength using a calibration factor.

**LCB**
The LCB (Laboratorio de Caminos de Barcelona) shear test is intended to measure the resistance to tangential stresses caused by the application of a shear force (Figure 5). The stresses are produced in the bond between the two asphalt layers, whether or not a tack coat has been used. The displacement of one layer with respect to the other is also measured.

The test can be used on laboratory-produced specimens or cores from pavements.
**LPDS**

The Layer-Parallel Direct Shear (LPDS) test device (Figure 6) is a modified version of equipment developed in Germany by Leutner (1979). The device fits into an ordinary servo-hydraulic Marshall testing machine and allows testing of cores with a diameter of about 150 mm (Raab and Partl, 2002). The load is applied near the interface of two bonded layers, one that is supported and another that is suspended. The shear test device holds the bottom part of the compacted cylinder and a shear load is applied perpendicularly to the axis of the cylinder of the top layer to measure the shear resistance at the interface. The load is applied at a rate of 50.8 mm/min at a temperature of 20 °C.

![Figure 6. Schematic view of the LPDS (Layer-Parallel Direct Shear) test device with pneumatic clamping (Raab and Partl, 2002).](image)

**Florida DOT Shear Test Method**

The Florida Department of Transportation (FDOT) developed a similar, simple direct shear device that can be used in a universal testing machine or a Marshall press, as seen in Figure 7. The test is performed using 150-mm-diameter specimens.
FDOT uses this method to evaluate pavement layer bonding on projects where there is concern about the integrity of the tack coat bonding due to rain during paving operations. Specimens should be 150 mm (6 inches) in diameter in order to reduce testing variability (larger shear surface area). The gap between the two rings is 4.76mm (3/16 inch). This is to account for the irregular surface of the cored specimens.

The load is applied in strain-controlled mode at a rate of 50.8-mm/min (2-in/min), which is performed using the Marshall test apparatus or any universal testing machine. The specimens are conditioned at a temperature of 25±1 °C for a minimum of 2 hours before the test. The core is then placed between the shear plates so that the direction of traffic marked on the core is parallel to the shear direction. The core is then loaded until failure occurs. The shear strength is then calculated using Equation 2 (Sholar et al., 2003):

\[
S_B = \frac{4P_{\text{MAX}}}{\pi D^2}
\]  

where \(S_B\) is the shear strength (psi), \(P_{\text{MAX}}\) is the maximum load applied to the specimen (lbf), and \(D\) is the specimen diameter (in inches).
Louay et al. (2002) developed a shearing apparatus designed to hold a cylindrical specimen and is mounted inside an SST machine. The apparatus produces a failure at the interface of the bottom and top layers of the specimen. In Error! Reference source not found., both the jig and the assembled test can be seen. The procedure adopted consisted of applying a simple shear test by shearing the specimens at the interface. Lateral confinement was attained by a circular jig (Figure 8-a) that ensured the failure at the interface. The bottom part of the specimen was compacted in a Superpave gyratory compactor. After cooling, the tack coat was applied and the specimen was reintroduced into the compactor for compaction of the top layer.

The target air void content for each of the bottom and top specimens was 6%. The specimens were tested in an SST machine at temperatures of 25 °C and 55 °C. A loading rate of 50 lb/min was applied until the failure of the specimens. It was observed that the CRS-2P emulsion performed better than PG64-22, PG76-22M, SS-1, SS-1h, and CSS-1h. The optimum rate of application for each tack coat was determined based on the highest shear strength. The authors concluded that the maximum strength obtained was only 83% compared to the same mixture specimens without interface (monolithic structure), implying that interfaces potentially cause slip planes.

Figure 8. Designed shear mold with sample inside (a); SST environmental chamber with the shearing apparatus (b) (Louay, 2002).
Bond Strength Test Developed at Kansas State University

A bond strength test procedure as well as the necessary testing apparatus were developed by Wheat (2006) in order to investigate the influence of different shear stress planes on the bond strength of the tack coat interface. The author created two supports for the test (Figure 9), one holding the bottom part of the specimen and the other one responsible for holding the top layer of the specimen as well as changing the direction of the load force. The angle between the specimen axis and the actuator axis can be adjusted, which allows different planes of shear stresses acting on the specimen. The test is performed under a sinusoidal loading at six different frequencies (25, 10, 5, 1, 0.5, and 0.1 Hz). Deflection between the top and bottom layers is measured by two LVDTs mounted on the interface.

![Figure 9. KSU bond strength test (Wheat, 2006).](image)

3.4 FastTack®

As described previously, FastTack® is a proprietary, rapid-setting emulsion used as a bituminous tack coat for pavement applications and touted to exhibit a very fast set time that distinguishes it from regular rapid-setting emulsions. This is achieved by the introduction of two different additives in a process referred to as Colnet®. The two additives used in the process are the adhesion agent (MC) and the setting solution (XC).
A study conducted by Chehab et al. (2006) evaluated the long-term performance of field sections constructed using FastTack as tack coat. The scheme adopted by the researchers consisted of evaluating the rheological and physical properties of the residue of a CRS-1h emulsion and that of FastTack in order to ensure that the Colnet fast-breaking process of FastTack does not significantly alter the properties of the emulsion, causing it to fail the PennDOT specifications.

The FastTack exhibited an extremely rapid breaking process compared to a rapid-setting emulsion, diluted CRS-1h. The two additives (XC and MC) included in FastTack caused a slight overall decrease in residue density, stiffness, and viscosity and also allowed for faster breaking. A comprehensive PG-grade testing was conducted on both the base AET emulsion and the emulsion with the additives (FastTack) in the laboratory for both high-temperature properties and low-temperature properties. Properties for both emulsions were very similar and the PG grade of the emulsion and FastTack were the same. More information can be found in a detailed report by Chehab et al. (2006). The only property that was not tested in the aforementioned study was adhesion. The focus of the current study was to evaluate the adhesion properties of FastTack as compared to those of the regular base emulsion AET.

4 Specimen Fabrication and Testing Program

The experimental scheme adopted in the course of this project consisted of evaluating the maximum shear strength of the two products: the control emulsion (AET) and FastTack® (AET + MC and XC). A host of three tests was chosen for this purpose: the Modified Marshall Test, performed at 25 °C, and the Simple Shear Test, performed at 25 °C and 55 °C. The specimens consisted of two layers. The bottom layer was obtained from a field core, while the top layer consisted of fresh asphalt mixture compacted on top of the bottom layer in the Superpave Gyratory Compactor at the Thomas D. Larson Pennsylvania Transportation Institute (LTI) at Penn State. Tack coat was applied at the interface of both. More details on the specimens used and the fabrication methodology are provided in section 4.3 of this report.
4.1 Modified Marshall Test

In this experimental method, the specimens were subjected to direct shear force applied at a constant rate of 50.8 mm/min (2 in/min) until the specimen’s failure. A customized jig, referred to as the modified Marshall jig, was fabricated for the testing in this project. The jig, shown in Figure 10, consisted of two hollow cylinders aligned horizontally. One of the cylinders was fixed at its bottom to a base plate, while the other could move vertically with minimal friction along four columns. During the test, a load was applied on a smooth horizontal strip located at the top of the movable cylinder.

![Figure 10. Jig developed for Modified Marshall Test: (a) rendering for manufacturing, (b) front view, (c) lateral view.](image-url)
The vertical load applied perpendicularly to the specimen’s axis caused shear stresses at the interface between the two parts of the jig. For this particular test, the specimen was situated such that the shearing of the specimen occurred along the interface between the old asphalt and new asphalt, thus evaluating the shear strength attributed to the tack coat. The loading stopped once splitting failure of the specimen occurred. The applied load and displacement of the moving jig were measured by a load cell and LVDT, respectively. Measurements were recorded by a data acquisition system for subsequent analysis. A tested specimen can be seen in Figure 11.

![Figure 11. Specimen failure after Modified Marshall Testing.](image)

### 4.2 SST (Simple Shear Test)

The SST test was performed to evaluate the strength of the specimens (core + tack coat + new mixture) when subjected to simple shear. The specimen was glued to the top and bottom steel plates. One of the plates was fixed, while the other moved in a horizontal direction. The specimen remained at a constant height throughout the test. The failure plane, along which shear stress was maximal, lay along an approximately 45° plane. This can be seen in the Finite Element Model shown in Figure 12. The maximum shear
stresses occurred initially at the corners of the specimen and propagated toward each other. Specimens that failed in such a manner are shown in Figure 13. The fact that the failure did not occur along the horizontal interface plane implies that the bonding between the two layers of the specimen was strong enough to sustain the shearing stresses. This was true for specimens bonded with AET as well as those bonded with FastTack.

![Finite element modeling of a standard SST test, with cracks propagating from the corners at a 45° angle.](image)

Figure 12. Finite element modeling of a standard SST test, with cracks propagating from the corners at a 45° angle.

![Broken specimen after SST testing: (a) front view, (b) top view.](image)

Figure 13. Broken specimen after SST testing: (a) front view, (b) top view.

Nevertheless, since the objective of this project was to compare the adhesion/bonding effectiveness of both AET and FastTack, a modification to the testing apparatus needed to be made to ensure maximum stresses were applied at the interface. Therefore, a
testing apparatus to satisfy this objective was built. This apparatus consisted of two platens, each with a 101.6-mm (4-inch) inner diameter and 22.9-mm (0.9-inch) core depth. The plates held the specimen, one capping the top part of the specimen while the other capped the bottom. The specimen’s top and bottom part were not glued but fit tightly into the plates. Figure 14 shows the two platens with and without the specimen. The SST test with modified plates is performed similarly to the original SST test with the standard sized-platens, at a constant displacement of 50.8 mm/min (2 in/min) at 25 °C and 1mm/min at 51 °C, respectively.

Figure 14. SST testing apparatus: (a) load platens, (b) test set up inside the SST chamber, (c) rendering.
When the modified plates were used in SST testing, all the specimen boundaries were fixed, except the predefined weak constraint at the interface between the layers. As seen in Figure 15, the maximum stresses were localized at the edges of the specimen along the interface. Eventually, the failure occurred at the interface, as seen in the FE model shown in Figure 16.

Figure 15. Von Mises stresses for the SST with modified plates.

Figure 16. Failure mode of Modified SST with constrained boundary.
4.3 Sample Preparation

The specimens used for testing in the Modified Marshall and SST tests were 150 mm in diameter and 100 mm in length. Each specimen consisted of two layers with tack coat applied at the interface. The bottom layer was a 35- to 50-mm core taken from an existing pavement (referred to as field mix). The cores were equally divided between 9.5 and 12.5 mm surface course mixes. The second layer consisted of a 9.5-mm Superpave (laboratory) mix compacted on top of the bottom layer in a Superpave Gyratory compactor (Figure 17).

![Sample Preparation](image)

Figure 17. Core specimen: (a) coated with tack-coat and (b) bottom layer (core) with new mix.

The cores were divided into 10 sets with 5 replicates each. Each set of cores was taken from one section of a specific roadway either under construction or undergoing rehabilitation. Table 3 provides a summary of core and mix data for each set of specimens. The recorded height is the average for the five specimens in each set.

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4.3.1 Tack Coat

The tack coat used in the study was an AET-based emulsion. For the FastTack, the XC and MC additives were applied separately from the AET emulsion. In order to determine the proper rate of tack coat the application on the specimens, the density and residue content of the AET were determined using two procedures as discussed in the following section.

**Asphalt Residue**

The emulsion, pre-heated to 60 °C, was poured into a glass lens and weighed. After the emulsion had set, only the residual asphalt was left on the lens (Figure 18). The weight was measured again and the percentage of residual asphalt was calculated. The emulsion yielded 39.3% asphalt residue, which subsequently was assumed to be 40% throughout this work.

![Figure 18. Residual asphalt after setting.](image)

**Emulsion Density**

The density at 60 °C was measured using a graduated cylinder, as shown in Figure 19, and was found to be 998 g/L. With the values of density, residual asphalt and the area of the specimen’s surface, the amount of emulsion applied on each specimen was calculated to be 8.2 g. It was critical to apply consistent amounts of tack coat across specimens. Extra care was taken in applying the emulsion onto the specimen using a previously saturated brush, after which the specimen was placed on a scale. Figure 20 shows the specimens after application of the emulsion.
The application of the FastTack required the application of three liquids. First, 0.365 g of adhesive agent MC was applied followed by application of the AET emulsion. Finally, 0.261 g of breaking agent XC was applied. The agents were sprayed onto the specimen surface rather than brushed to avoid mixing the components on the brush.

After the tack coat on the surface of the specimen broke, the specimen was fitted inside a 150-mm mold of the Superpave Gyratory Compactor and asphalt mixture was then placed on top. The asphalt mixture was compacted such that the total height of the specimen was 100 mm and air void content in the top layer was 4±0.5%. Specimens after compaction are shown in Figure 21.
Specimens to be tested for the SST were cored from the compacted specimens to a final diameter of 100 mm and sawed to a final height of 50.8 mm (2 inches). This extra fabrication step was needed to ensure that the specimen fit tightly inside the modified plates developed for this test, as discussed earlier. Two such specimens are shown in Figure 22; the bottom and top layers of the specimen can be easily identified.

**4.4 Experimental Plan**

Table 4 shows the experimental plan adopted in this study. Each specimen was identified by its sample (replicate) set and its individual number label on its top surface. For
instance, 511-3 designates the third sample in set 511. The set number corresponds to the designation established by PennDOT to identify the road section from which the core was extracted.

The same round of tests, Modified Marshall and SST at 25 °C and 51°C, were conducted for both the 9.5-mm and 12.5-mm core mixes and for both AET and FastTack tack coats. The samples chosen to be tested according to the cells in the experimental plan, shown in Table 4, were chosen such that the effects of tack coat type, NMAS mix, testing temperature, and test type could be statistically determined with minimum attributed to specimen-to-specimen variation.

For further illustration, the following samples are presented. Samples 509-1 and 509-3 (both from set 509) were used in SST testing at 25 °C, where the only difference was that the former had AET as tack coat whereas the latter sample had FastTack. This made it possible to determine the effect of tack coat when comparing the results. Similarly, samples 499-3 and 499-4 were used for tests that enabled determination of the effect of tack coat using the Modified Marshall testing of 12.5-mm surface mixes.

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<th>FastTack®</th>
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5 Results and Analysis

This section discusses the results obtained from the Modified Marshall testing and those from SST on specimens with AET and FastTack. The results are presented graphically followed by a statistical analysis to determine whether FastTack contributes to adhesive
strength between the layers. Complete results for the testing performed in this study can be found in Appendix A.

5.1 Modified Marshall Test

The Modified Marshall test was conducted on four specimens for each type of tack coat at a temperature of 25 °C. As seen in Figure 23, specimens from sets 506 and 508 exhibited slightly higher shear strength than FastTack. The shear strength of specimens for sets 499 and 511 for AET are similar to those of FastTack.

![Figure 23. Comparison of Shear Strength from Modified Marshall tests for AET and FastTack at 25 °C.](image)

Figure 24 and Figure 25 show the stress-strain curves from Modified Marshall loading of AET and FastTack specimens at 25 °C, respectively. The behavior is similar for both specimen types, except for higher variability for those with FastTack. Additionally, similar values of strain are recorded at peak stresses.
Figure 24. Modified Marshall for AET at 25 °C.

Figure 25. Modified Marshall for FastTack at 25 °C.
5.2 SST

The SST test was conducted at 25 °C and 51 °C. At 25 °C, the test was performed at the same loading speed, 50.8 mm/min (2 in/min), as was done with the Modified Marshall test for the purpose of comparison between the two testing procedures. At 51 °C, the test was conducted at a displacement rate of 0.017 mm/sec to examine the effect of loading speed on the shear strength for both specimen types.

Figure 26 shows the shear strength for specimens with AET and FastTack at 25 °C. Specimens from sets 509 and 543 exhibited slightly higher shear strength for FastTack than for AET, whereas the other two sets of specimens, 514 and 558, exhibited slightly higher shear strength for AET than for FastTack. The shear strengths obtained from the Modified Marshall test were slightly higher than those from the SST.

![Figure 26. Comparison of Shear Strength for AET and FastTack at 25 °C.](image)

The shear strength of specimens with AET and FastTack tested at 51 °C are compared in Figure 27. As expected, due to the temperature and loading speed, the overall shear strengths of tested specimens were significantly lower than those at 25 °C. Unlike at 25 °C, almost all sets of specimens yielded higher shear strengths in the case of FastTack than AET.
Analyzing the results graphically, it can be concluded that overall, specimens with AET and FastTack exhibited similar shear strength at the interface between the bottom and top layer. AET exhibited slightly higher values at the moderate temperature tested (25 °C), while FastTack exhibited slightly higher values at elevated temperatures (51 °C).

![Bar chart showing comparison of shear strength for AET and FastTack at 51°C.](image)

**Figure 27. Comparison of Shear Strength for AET and FastTack at 51°C.**

### 5.3 Statistical Analysis

A small difference in shear strength was observed between specimens with AET and those with FastTack, particularly when compared to the variability in strength from one set of specimens to the other. It was thus helpful to conduct a statistical analysis to confirm that the two types of tack coat exhibited similar values for adhesion. The analysis was conducted on data from the Modified Marshall test at 25 °C and the SST test at 51 °C (Table 5).
First, an Anderson-Darling test was conducted on the data to determine whether the data were normally distributed. From the analysis, it was concluded that the results of the tests did follow a normal distribution, and hence t-test statistics could be computed to determine whether there was a significant difference between the means of the two types of samples (FastTack versus AET). A large t-statistic would indicate that there was a significant difference between the means of the two types, and that the FastTack significantly altered the mean shear strength of the asphalt concrete.

The two-sample t-test was conducted for two cases:

- Case I: The test used the estimated standard deviations of the two samples.
- Case II: The test used a pooled standard deviation of the samples.

### 5.3.1 Interpretation of Results

The t-statistic was used to construct the confidence interval within which the difference of means lies for a given confidence level (Table 6). Assuming a 95% confidence interval, the critical t-values for test results at 25 °C and 51 °C are \( t_0 (25) = 2.160 \) and \( t_0 (51) = 2.262 \), respectively. Since \(| t |_{\text{calculated}} < t_0\), the calculated value of \( t \) is consistent with equality of the means.

Additionally, the confidence intervals constructed for a 95% level include zero, which indicates that the hypothesis that the means are equal cannot be neglected. This conclusion can also be drawn from the p-value, which is greater than 0.05, thereby concluding that the two means were not significantly different.
Table 6. Statistical Analysis Results.

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<td>AET</td>
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<td>AD Test P-value</td>
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<td>52.1</td>
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<td>P – value</td>
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6 Conclusions

A study was conducted to evaluate the relative adhesion of a proprietary emulsion known as FastTack to that of regular AET emulsion. FastTack is considered an ultra-rapid-setting emulsion that is to be used as tack coat for fast-track paving operations. Three tests were conducted to evaluate the bond performance of FastTack: Modified Marshal test at 25 °C and SST tests at 25 °C, and 51 °C. The samples used consisted of a field core to form the bottom layer, and a fresh asphalt mixture compacted on top of it, using the Superpave gyratory compactor, to constitute the upper layer. Half of the specimens fabricated had regular AET tack coat applied at the interface, while the other half had FastTack.

In general, the results from the Modified Marshall and SST tests at 25 °C both revealed similar shear strength values for both types of specimens, and so did the SST tests at 51 °C. The strengths of the specimens with AET were slightly higher than those with FastTack in the Modified Marshall test, while the opposite was true for the SST test at 51 °C. Statistical analyses performed on the test results confirmed that the observed differences in the strengths between the two types of specimens were statistically insignificant, and for a 95% confidence interval the means of the strengths were the same. With all aforementioned analysis, it can be concluded that the adhesion properties of the FastTack emulsion and AET are the same.
7 References


Mrawira, D., and Damude, D.J. (1999). “Revisiting the Effectiveness of Tack Coats in Hot Mix Overlays: The Shear Strength of Tack Coats in Young Overlays,” *Proc., 44th*


8 Bibliography


## APPENDIX A – Test Results

<table>
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<th>Specimen ID</th>
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