Understanding Bond Strength

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1. What is the function of tack coat?
2. What can happen when tack coat is not properly applied?
3. How can you tell if your tack coat is sufficient?
The purpose of a tack coat is...

- to bond layers of a pavement together.
Slippage Failures
Forensic Investigations - Cores

Orlando Airport

City of Auburn
1. Weak bond between binder and base layers
2. Debonding between binder and base layers
3. “Middle-up” crack initiated at bottom of binder
4. “Middle-up” crack reaches surface of pavement
5. Full depth crack extends to bottom of base
Bonding Demonstration
(courtesy of FHWA/AI Tack Workshop)

- 5 plywood strips (layers)
- 48” x 4” x 11/32”
- 60 and 160 pound loadings
- Bonded (glued) and Unbonded
Bonding Demonstration
(courtesy of FHWA/AI Tack Workshop)

½” Deflection, 60lb Load

¼” Deflection, 160lb Load

Unbonded

Fully Bonded
NCAT First Tack Coat Study

- What is the best type of tack coat material?
- What is the best application rate?
# Literature on Bond Strength Testing

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Switzerland</th>
<th>Germany</th>
<th>Austria</th>
<th>United Kingdom</th>
<th>Québec</th>
<th>Florida</th>
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</thead>
<tbody>
<tr>
<td>Standard</td>
<td>SN 671 961</td>
<td>DIN 1999</td>
<td>ÖNORM 3639-1</td>
<td>SG3/05/234</td>
<td>unknown</td>
<td>FM-599</td>
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<tr>
<td>Type</td>
<td>Shear</td>
<td>Shear</td>
<td>Tensile</td>
<td>Torque</td>
<td>Tensile (in-situ)</td>
<td>Shear</td>
</tr>
<tr>
<td>Criteria</td>
<td>12 to 15 kN</td>
<td>unknown</td>
<td>1.0 to 1.5 N/mm²</td>
<td>N.A.</td>
<td>N.A.</td>
<td>N.A.</td>
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<td>Photo</td>
<td><img src="image1.jpg" alt="Image" /> <img src="image2.jpg" alt="Image" /> <img src="image3.jpg" alt="Image" /> <img src="image4.jpg" alt="Image" /></td>
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</table>
Bond Strength Experiment Design

Tack Coat Type:
CRS-2, CSS-1, PG 64-22

Application Rate:
0.02, 0.05, & 0.08 gal/yd²

Gradation:
19.0 mm Coarse & 4.75 mm Fine

Test Temperature:
50, 77, & 140°F

Normal Load:
0, 10, and 20 psi
Sample Preparation and Testing

• SGC specimens cut in half for specimen base
• Tack coat was applied to uncut surface of base
• Tacked specimen base was put back in SGC mold, loose mix compacted on top
• Bond strength test determined after four hours at the test temperature
• A servo-hydraulic testing machine loaded at 2”/min, maintained the temperature, and captured load and strain data.
Bond Strengths @ 140°F

Coarse-Graded Mixes

Fine-Graded Mixes

Application Rates and Normal Pressure

Bond shear strength (psi)

Coarse-Graded Mixes

Fine-Graded Mixes
Bond Strengths @ 77°F

Coarse-Graded Mixes

Fine-Graded Mixes

Application Rates and Normal Pressure

Bond shear strength (psi)

CRS-2
CSS-1
PG64-22

Application Rates and Normal Pressure

Bond shear strength (psi)

CRS-2
CSS-1
PG64-22
Effects of Temperature & Normal Pressure

![Bar chart showing bond shear strength at different temperatures and pressures.](chart.png)
NCAT (ALDOT) Bond Strength Test

- 77°F, no normal pressure
  - Sensitive to key variables including tack coat type, application rates, surface textures
  - Ability to evaluate bond strength of pavement cores
  - Low cost, quick simple

- For most conditions, the PG 64-22 provided better bond strengths than the CSS-1 and CRS-2
- Lower application rates yielded higher bond strengths for all tack coat types
Field Validation Work

- Test sections set up on seven field projects
- Each section had a different tack coat application rate
- Cores taken after HMA compacted and cooled.
Measurement of Application Rate, ASTM D 2995
Test Section Layout

Application rates measured using ASTM D 2995

~100 m

Geotextile pads for checking tack rate
Test Section Layout

Application rates measured using ASTM D 2995
Test Section Layout

Low Rate  Medium Rate  High Rate

HMA overlay
Test Section Layout

Low Rate  Medium Rate  High Rate

3 random cores + 2 at pads per section
Recommendations

• The bond strength test is capable of measuring effects of tack coat type, application rate and surface texture.
• 100 psi proposed as a preliminary criterion
• Tack coat application rates should be specified in terms of residual asphalt.
• Milled/micro-milled surfaces have better bond than unmilled surfaces
• Bond develops quicker for PG 67-22 and NTSS-1HM
This is what happens to tack picked up on truck tires.
States that Perform Interface Bond Strength Testing

Key:
- Do perform bond strength testing
- Do not perform bond strength testing

2018 NCHRP Synthesis 916
## WVDOH Bond Strength Summaries

<table>
<thead>
<tr>
<th>Year</th>
<th>Lots</th>
<th>No Bond</th>
<th>&lt;100 psi</th>
<th>Avg. BS (psi)</th>
<th>Std. Dev. of BS (psi)</th>
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</thead>
<tbody>
<tr>
<td>2013</td>
<td>146</td>
<td>40 (27%)</td>
<td>81 (55%)</td>
<td>113.1</td>
<td>37.6</td>
</tr>
<tr>
<td>2014</td>
<td>216</td>
<td>75 (35%)</td>
<td>97 (45%)</td>
<td>152.6</td>
<td>48.0</td>
</tr>
<tr>
<td>2015</td>
<td>439</td>
<td>86 (20%)</td>
<td>201 (46%)</td>
<td>117.0</td>
<td>37.7</td>
</tr>
<tr>
<td>2016</td>
<td>346</td>
<td>59 (17%)</td>
<td>116 (34%)</td>
<td>150.0</td>
<td>63.3</td>
</tr>
<tr>
<td>2017</td>
<td>667</td>
<td>130 (19%)</td>
<td>238 (36%)</td>
<td>103.6</td>
<td>70.6</td>
</tr>
<tr>
<td>2018</td>
<td>401</td>
<td>122 (30%)</td>
<td>184 (46%)</td>
<td>115.2</td>
<td>98.8</td>
</tr>
</tbody>
</table>
Factors that Affect Bond Strength

- Milled vs Unmilled: milled typically much higher
- Cleanliness of Surface: cleanliness is next to godliness
- Tack Coat Type: emulsions, trackless, PG binder
- Tack Coat Quality: how & where is it checked?
- Tack Coat Appl. Rate: check residual rate, how much stays?
- Overlay gradation: coarse vs. fine?, literature is inconsistent
- Time and Traffic: bond strength typically improves
Key Takeaways

• A good bond between asphalt layers is critical to long-term performance of flexible pavements.
• Measuring bond strength is the only way to ensure a good bond exists.
• WV bond strength data clearly show problems exist.
• Numerous factors can impact bond strength.
Further Analysis Recommended

• How are those pavements with failing bond strengths performing?
• Are bond strengths of wheelpath cores ≤ non wheelpath cores?
• Evaluate tack coat materials and application practices.
• Examine practices for coring.
Thank You

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NCAT Reports
Available Reference Materials

Gierhart, D., and Johnson, D.  
NCHRP Synthesis 516:  
Tack Coat Specifications, Materials and Construction Practices.  
Available Reference Materials

Available Reference Materials

Decker, Dale S.
Best Practices for Emulsion Tack Coats.
Quality Improvement Publication 128,
National Asphalt Pavement Association,
2013
Available Reference Materials

Mohammad, L. N., Elseifi, M. A., Bae, A., Patel, N., Button, J., and Scherocman, J. A.

NCHRP Report 712
Optimization of Tack Coat for HMA Placement.
Recommended Application Rates

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>Residual Rate (gsy)</th>
<th>Approximate Bar Rate Undiluted (gsy)</th>
<th>Approximate Bar Rate Diluted 1:1 (gsy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Asphalt</td>
<td>0.02 – 0.05</td>
<td>0.03 – 0.07</td>
<td>0.06 – 0.14</td>
</tr>
<tr>
<td>Existing Asphalt</td>
<td>0.04 – 0.07</td>
<td>0.06 – 0.11</td>
<td>0.12 – 0.22</td>
</tr>
<tr>
<td>Milled Surface</td>
<td>0.04 – 0.08</td>
<td>0.06 – 0.12</td>
<td>0.12 – 0.24</td>
</tr>
<tr>
<td>Portland Cement Concrete</td>
<td>0.03 – 0.05</td>
<td>0.05 – 0.08</td>
<td>0.10 – 0.16</td>
</tr>
</tbody>
</table>

**NCHRP Report 712, Table 31**

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>Residual Application Rate (gsy)</th>
<th>Approximate Bar Rate Undiluted* (gsy)</th>
<th>Approximate Bar Rate Diluted 1:1* (gsy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Asphalt Mixture</td>
<td>0.035</td>
<td>0.058</td>
<td>0.12</td>
</tr>
<tr>
<td>Old Asphalt Mixture</td>
<td>0.055</td>
<td>0.09</td>
<td>0.18</td>
</tr>
<tr>
<td>Milled Asphalt Mixture</td>
<td>0.055</td>
<td>0.09</td>
<td>0.18</td>
</tr>
<tr>
<td>Portland Cement Concrete</td>
<td>0.045</td>
<td>0.08</td>
<td>0.15</td>
</tr>
</tbody>
</table>

* NCHRP Report 712, Table 31, includes residual application rates only. Values in italics were supplied using an example emulsion with 60% residual asphalt binder for comparison purposes only.

**NAPA QIP 128 Best Practices for Emulsion Tack Coats, Table 4-1**

<table>
<thead>
<tr>
<th>Existing Condition</th>
<th>Residual Asphalt Binder (gsy)</th>
<th>Applied Undiluted Emulsion (gsy)</th>
<th>Applied Diluted Emulsion (gsy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dusty or Dirty</td>
<td>Clean the surface</td>
<td>Clean the surface</td>
<td>Clean the surface</td>
</tr>
<tr>
<td>New Asphalt</td>
<td>0.03 – 0.04</td>
<td>0.04 – 0.06</td>
<td>0.09 – 0.12</td>
</tr>
<tr>
<td>Old, Aged Asphalt</td>
<td>0.04 – 0.06</td>
<td>0.06 – 0.09</td>
<td>0.12 – 0.18</td>
</tr>
<tr>
<td>Milled Asphalt</td>
<td>0.03 – 0.05</td>
<td>0.04 – 0.07</td>
<td>0.09 – 0.15</td>
</tr>
<tr>
<td>PCC</td>
<td>0.04 – 0.06</td>
<td>0.06 – 0.09</td>
<td>0.12 – 0.18</td>
</tr>
</tbody>
</table>
Storing Asphalt Emulsions

- Do not heat the emulsion above 185°F to avoid damaging the product.
- Do not let the emulsion freeze to avoid separation of the asphalt and water.
- Do not use forced air to agitate the emulsion, as it will break the emulsion.
- Do not allow excessive agitation by mixing or pumping.
Handling Asphalt Emulsions

• Agitate gently when heating emulsion to minimize skin formation in the tank

• Clean out lines and leave drain plugs open when not in service.

• Ensure that tanks and equipment contain accurate thermometers. Gradually warm up the pump to about 150°F to facilitate start up.

• *Dilution of the asphalt emulsion should only occur at the emulsion manufacturing facility. Dilution should not be done by the contractor in the distributor tank*

• Polymer-modified and non-tracking emulsions should not be diluted for use as tack coat
“For the effect of water on the tacked surface, the majority of the cases showed no statistically significant difference between dry and wet conditions. This data indicates that a small amount of water can be flashed away by the hot HMA mat and, thus, have inconsequential effects on the quality of the tack coat. This study used only hot mix as the overlay material; the use of warm mix may change this finding. In addition, these results are based on using a small quantity of water to simulate rainy conditions. Therefore, a dry and clean surface is recommended to avoid the negative effects of water on the bonding at the interface.”
Effect of water (rain or damp surface)?

NAPA QIP-128

“A small amount of moisture on the pavement surface should not be detrimental to long-term tack coat performance, although a damp pavement will slow the cure and break time of the tack coat emulsion. If the pavement surface layer is saturated with water and the existing pavement surface is damp or has standing water, the ability of the tack coat emulsion to provide adequate bond between the existing and the new pavement layers will be significantly compromised.”