Effect of Bonding Quality of Tack Materials between Pavement Layers on Durability

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My Story

- Background
  - Durability
  - Bonding & Pavement Performance
- Completed
  - NCHRP Project 9-40
  - NCHRP Project 9-40A
    » Deliverables
    » Experiment/Results
    » Summary and Conclusions

Acknowledgement

- NCHRP
  - Technical Review Panel
  - State DOTs
- Ramendra Das, Wei Cao
- State DOTs
  - Missouri; Louisiana; Florida; Tennessee; Nevada; Oklahoma
- Material Suppliers and Contractors
  - Asphalt Products Unlimited
  - Ergon Asphalts
  - Blacklidge
  - Coastal Bridge
Durable Pavement

- Title 23 Code of Federal Regulations – Part 626.3 Policy.
- “Pavement shall be designed to accommodate current and predicted traffic needs in a safe, durable, and cost effective manner.”

Durable

- … able to exist for a long time without significant deterioration in quality or value.”

Durable Flexible Pavement

- Permanent deformation
- Fatigue cracking – repeated load
- Low temperature cracking
- Moisture induced damage
- Raveling
- etc ...
### Design and Construction of Durable Flexible Pavements

- **Mixture Design**
  - Components Materials
  - Engineered Performance / BMD
  - Sustainable Development

- **Construction**
  - Tack Coat Practices
  - Thermal segregation
  - Warm Mix Asphalt
  - Increased density

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### Purpose of tack coat application
- To ensure adequate bond between pavement layers
- To transmit traffic loads down through the whole pavement structure

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### Durable Pavement – Construction

#### Tack Coat

- **Not properly bonded, increase tendency for**
  - Cracking,
  - Debonding (delamination/slippage/sliding), and/or
  - Fatigue cracking
  - ...and thus failure in the new overlay

- **Tack coat material is relatively inexpensive portion compared to overall pavement construction cost**
  - Bonding failure is extremely $$$!
Improper Tack Coat Application

Durable Pavement – Construction
Proper Tack Coat Application
100% Coverage

Ascertain Bonding Quality/Performance

Supply > Demand
Objectives – NCHRP Project 9-40

- Evaluate factors that affect interlayer bonding
  - Tack coat material type and application rate
  - Pavement surface type
  - Temperature
  - Construction condition
- Develop AASHTO test methods and practices related to tack coats
  - Tack Coat Quality
  - Spray application
  - Interlayer Bond Strength

Outcome – NCHRP Project 9-40

- Worldwide Survey on Tack Coat Practices
  - 92% return
  - Canada, Denmark, Finland, South Africa, and the Netherlands.
- Best Practices and Training Manual
  - recommended construction and testing procedures

Outcomes of NCHRP Project 9-40

- AASHTO TP 114 and AASHTO TP 115 test method was developed to characterize quality and Bond Strength of tack coats
- Recommended threshold Interface Shear Strength criterion
  - Minimum 40 psi
- Recommended optimum tack coat residual application rates

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>Residual Application rate, g/sqy</th>
</tr>
</thead>
<tbody>
<tr>
<td>New HMA</td>
<td>0.035</td>
</tr>
<tr>
<td>Existing HMA</td>
<td>0.055</td>
</tr>
<tr>
<td>Milled HMA</td>
<td>0.055</td>
</tr>
<tr>
<td>PCC</td>
<td>0.045</td>
</tr>
</tbody>
</table>
Objective – NCHRP Project 9-40A

- Validate AASHTO TP 114 test method and minimum recommended ISS threshold (40 psi) criterion
- Evaluate factors that affect interface bonding
  - Pavement Surface Type
  - Tack Coat Material Type
  - Residual Application Rate
  - Service Time
- Investigate the effect of bonding on short-term pavement performance

Scope

- Six field projects
  - Missouri; Louisiana; Florida; Tennessee; Nevada; Oklahoma
- Four Pavement surface types:
  - New HMA; Existing HMA; Milled HMA; PCC
- Tack coat material types:
  - Slow setting (SS-1H, CSS-1H, SS-1)
  - Non-tracking rapid setting (NTSS-1H, CBC-1H, CRS-1 HBC)
- Tack coat residual application rates:
  - One specified by state DOTs
  - Other one as recommended by NCHRP 9-40 study

<table>
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<td>New HMA</td>
<td>0.035</td>
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<tr>
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<td>0.065</td>
</tr>
<tr>
<td>Milled HMA</td>
<td>0.065</td>
</tr>
<tr>
<td>PCC</td>
<td>0.045</td>
</tr>
</tbody>
</table>

Methodology

- Pre-construction
  - Identify test sections
  - Distress survey
  - Distributor/Truck Calibration
  - Pavement surface texture depth measurement
  - Falling weight deflectometer test

- During-construction
  - Application rate measurement
  - Tack coat sample collection
  - Construction related information collection

- Post-construction
  - Field cores collection
  - Falling weight deflectometer test
  - Distress survey
**Project Location**

- Projects were selected based on
  - different climatic conditions
  - relatively high traffic volume

![Map of Project Locations](image)

**Project Description**

- **Missouri Project**
  - Four Pavement surface types (New, Existing, Milled HMA and PCC)
  - Two tack coat types (SS-1H, NTSS-1HM)
  - One residual application rate (0.05 gsp)

- **Louisiana Projects**
  - LA 35 Route
    - Milled HMA pavement surface
    - Two tack coat types (SS-1H, NTSS-1HM)
    - One residual application rate (0.06 gsp)
  - LA 1553 Route
    - New HMA pavement surface
    - Four tack coat types (two NTSS-1HM, CBC-1H, SS-1H)
    - Two residual application rates for each tack coat type

- **Tennessee Project**
  - Milled HMA pavement surface
  - Three tack coat types (CBC-1H, NTSS-1HM, CSS-1H)
  - One residual application rate for each tack coat type

- **Florida Project**
  - Existing HMA pavement surface
  - Two tack coat types (CRS-1HBC, SS-1H)
  - Two residual application rates for each tack coat type

- **Nevada Project**
  - Milled HMA pavement surface
  - Two tack coat types (CBC-1H, CSS-1H)
  - Two residual application rates for each tack coat type

- **Oklahoma Project**
  - PCC pavement surface
  - Two tack coat types (CBC-1H, CSS-1H)
  - Two residual application rates for each tack coat type
**Experimental Program**

- Tack coat distributor truck calibration
- Pavement surface texture measurement
- Falling weight deflectometer test
- Field tack coat application rate measurements
- Characterization of interface bond strength
- Characterization of tack coat materials
- Distress survey

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**Tack Coat Distributor Truck Calibration**

- Geotextile Pad layout
  - ASTM D 2995
  - One transverse
  - Two longitudinal

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**Typical Tack Coat Calibration Test Result**

- Target Application rate = Residual Rate/Percent Residue
  - Target Residual Rate for Milled HMA = 0.055 gsy
  - Percent Residue = 60%
  - Target Total Application Rate = 0.055 gsy/0.60 = 0.09 gsy

± 10% variation allowed by ASTM D2995 (0.10 gsy – 0.08 gsy)

Target total application rate (0.09 gsy)
Characterization of Interface Bond Strength

- AASHTO TP 114 test method
  - Loading rate: 7.54 mm (0.1 in.) per minute
  - Interface Shear Strength

Material Response Parameter - Bond Quality

- Interface Shear Strength (ISS, psi): COV < 15%
- Interface Bond Energy (IBE, lb.-in/in²)
- Interface Shear Stiffness (k-modulus, psi/in)
Pavement Surface Texture

- Sand Patch Test
  - ASTM E 865
  - Mean Texture Depth (MTD)

\[
MTD = \frac{\text{Sand Weight}}{\text{Area}}
\]

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>AVG. Mean Texture Depth, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>New HMA</td>
<td>0.91</td>
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<td>Existing HMA</td>
<td>0.97</td>
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<tr>
<td>Milled HMA</td>
<td>1.77</td>
</tr>
<tr>
<td>PCC</td>
<td>1.49</td>
</tr>
</tbody>
</table>

Application Rate Measurement

- ASTM D 2995 (Method A)
  - Residual Application Rate = Percent Residue × Total Application Rate

Tack Coat Characterization

- Saybolt Furol Viscosity (AASHTO T 36)
- Emulsion
- Residual Asphalt Binder
- Performance Grading (AASHTO M 320)
- Softening Point (AASHTO T 46)
- Penetration (AASHTO T 46)
Distress Identification Manual for the Long-Term Pavement Performance Program

Cracking classification:
- low (mean crack width ≤ 0.24-in.)
- moderate (mean crack width > 0.24-in. and ≤ 0.75-in.)
- high (mean crack width ≥ 0.75-in.)

Rutting classification:
- low (mean rut depth ≤ 0.47-in.)
- moderate (mean rut depth > 0.47-in. and ≤ 0.98-in.)
- high (mean rut depth ≥ 0.98-in.)

Distress Survey

Results and Discussion

- Rheological properties of tack coats
- Surface texture depths
- Effect of tack coat type on ISS
- Effect of pavement surface type on ISS
- Effect of residual application rate on ISS
- Effect of service time on ISS
- Analysis of FWD test results
- Density test results
- Relationship between ISS and FWD center deflections
- Short-term performance of test sections

Results
**Relationship between ISS vs. Rheology Test Results**

![Graph showing the relationship between ISS and rheology tests with R² values]  

**Rheological Properties of Tack Coats**

<table>
<thead>
<tr>
<th>Project</th>
<th>Tack-Coat Type</th>
<th>Percent Residue, %</th>
<th>Saybolt Furol Viscosity, s</th>
<th>Penetration, dmm</th>
<th>Softening Point, °C</th>
<th>Performance Grade</th>
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<td>29.2</td>
<td>53.3</td>
<td>50.3</td>
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</table>

**Surface Mean Texture Depths**

<table>
<thead>
<tr>
<th>Pavement Surface Type</th>
<th>Field Project</th>
<th>Surface MTD, mm</th>
<th>Average MTD, mm</th>
<th>Measured Range, mm</th>
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</thead>
<tbody>
<tr>
<td>Missouri HMA</td>
<td>Missouri</td>
<td>1.62</td>
<td>1.77</td>
<td>2.14-1.38</td>
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<tr>
<td></td>
<td>Louisiana</td>
<td>1.56</td>
<td></td>
<td></td>
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<td></td>
<td>Tennessee</td>
<td>1.92</td>
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<td></td>
<td>Nevada</td>
<td>1.83</td>
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<tr>
<td>New HMA</td>
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<td>0.87</td>
<td>0.91</td>
<td>0.95-0.84</td>
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<tr>
<td></td>
<td>Florida</td>
<td>0.96</td>
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<tr>
<td>Existing HMA</td>
<td>Missouri</td>
<td>0.99</td>
<td>0.97</td>
<td>0.96-0.95</td>
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<tr>
<td></td>
<td>Florida</td>
<td>0.96</td>
<td></td>
<td></td>
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<td>PCC</td>
<td>Missouri</td>
<td>1.26</td>
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<td></td>
<td>Oklahoma</td>
<td>1.61</td>
<td>1.49</td>
<td>1.67-1.25</td>
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</tbody>
</table>
Effect of Tack Coat Type on ISS

MISSOURI PROJECT

- NTSS-1HM (PG 94-10)
- SS-1H (PG 64-22)
- Milled HMA
- New HMA
- Existing HMA
- PCC

A A A A

Interface Shear Strength, psi

All tack coat material were compared at 0.05 gsy residual application rate

Effect of Tack Coat Type on ISS

MISSOURI PROJECT

- New HMA
- Existing HMA
- HMA PCC

Interface Shear Strength, psi

All tack coat material were compared at 0.02 gsy residual application rate

Effect of Tack Coat Type on ISS

LOUISIANA PROJECT (LA 1053)

- New HMA (0.99 mm)
- PG 94-4
- PG 70-22
- PG 70-16
- PG 88-10

Interface Shear Strength, psi

All tack coat material were compared at 0.05 gsy residual application rate
Effect of Tack Coat Type on ISS

**Summary:**
- All test sections met 40 psi threshold except
  - PCC surface in Missouri project
  - SS-1 tack coat on LA 30 project
- NTSS-1HM tack coat exhibited higher ISS than SS-1H
- CBC-1H showed similar ISS when compared with SS-1H

**Effect of Tack Coat Type on ISS**

**Effect of Surface Type on ISS**

- ISS was largely dependent on
  - Type of pavement surface (HMA versus PCC)
  - Pavement surface texture (milled versus non-milled)
Effect of Residual Application Rate on ISS

**LOUISIANA PROJECT (LA 1053)**

New HMA

<table>
<thead>
<tr>
<th>Tack Coat Material</th>
<th>Residual Rate, gsy</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 94-2</td>
<td>0.01</td>
</tr>
<tr>
<td>PG 70-20</td>
<td>0.05</td>
</tr>
<tr>
<td>PG 64-22</td>
<td>0.04</td>
</tr>
</tbody>
</table>

**FLORIDA PROJECT**

Existing HMA

<table>
<thead>
<tr>
<th>Tack Coat Material</th>
<th>Residual Rate, gsy</th>
</tr>
</thead>
<tbody>
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<td>CRS-1HBC</td>
<td>0.02</td>
</tr>
<tr>
<td>SS-1H</td>
<td>0.04</td>
</tr>
</tbody>
</table>

**OKLAHOMA PROJECT**

PCC

<table>
<thead>
<tr>
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<th>Residual Rate, gsy</th>
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<tbody>
<tr>
<td>CBC-1H</td>
<td>0.03</td>
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<tr>
<td>SS-1H</td>
<td>0.07</td>
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</table>

ISS improved with the increase in residual application rate for all tack coat and pavement surface types.
Effect of Service Time on ISS

MISSOURI PROJECT

Effect of Service Time on ISS

LOUISIANA PROJECT (LA 1053)

Effect of Service Time on ISS

FLORIDA PROJECT

Effect of Service Time on ISS

Pavement Layer Bond Quality

11/20/2019
**Effect of Service Time on ISS**

**NEVADA PROJECT**
- Milled HMA

**OKLAHOMA PROJECT**
- PCC

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**Summary:**
- All test sections met 40 psi threshold except PCC surface in Missouri project.
- ISS increased with service time due to tack coat curing.
- Curing effect is more pronounced with:
  - non-tracking rapid setting tack coat materials on new HMA surfaces
  - increase in the residual application rate
Analysis of FWD Test Results

Density Test Results

Relationship between ISS and FWD Deflection

- Densification of overlays was primarily attributed to the
  - densification effect of HMA overlays due to in-service trafficking
  - improved interface bonding with service time

- Indicates surface deflection depends on
  - the interface bonding between pavement layers
**Conclusions**

- **Effect of tack coat type on ISS**
  - Non-tracking rapid setting tack coats with stiff base asphalt (NTSS-1HM) exhibited the highest ISS, and slow setting resulted in the lowest

- **Effect of pavement surface type on ISS**
  - ISS was largely dependent on
    - Type of pavement surface (HMA versus PCC)
    - Type of pavement surface texture (milled versus non-milled)
    - Milled surface yielded the highest ISS, followed by new HMA, existing HMA, and PCC surface types
    - Higher surface roughness provided greater shear resistance

- **Effect of residual application rate on ISS**
  - ISS improved with the increase in residual application rate for all tack coat types and pavement surface types
Conclusions

- **Effect of service time on ISS**
  - ISS increased with service time due to tack coat curing
  - Curing effect is more pronounced with
    - non-tracking rapid setting tack coat materials on new HMA surfaces
    - increase in the residual application rate

- **Falling weight deflectometer test results**
  - Mean center deflection decreased with service time
  - Densification of overlays was attributed to
    - in-service trafficking
    - improved ISS

- **Short-term pavement performance**
  - ISS values correlated well with short-term performance
  - No rutting and surface cracking
  - Few test sections with ISS < 40 psi showed low to moderate cracking

Recommendations

- **AASHTO TP 114 test**
  - Quality control and quality assurance testing of tack coat construction
  - Evaluation of interface-bonding condition of in-service pavements

- **Use of minimum ISS threshold criterion (40 psi)**
  - As the specification for satisfactory pavement performance