Sustainable Pavement Rehabilitation: Thin Bonded Wear Course with High Taconite and Recycled Asphalt Shingles Mix

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St. Paul, MN
Outline

- Thin Bonded Overlays / Wearing Courses
- Yosemite Avenue Project
- Sustainability Evaluation of the Project
- Laboratory Characterization of Field Samples
- Summary
Historically thin asphalt overlays were treated as means of pavement preservation
- Current usage is more driven by pavement rehabilitation
  - Capping mixes on reclaimed and recycled (FDR, CIR, FIR) layers
  - Surface improvement overlays
  - Mill and fill

Thin overlays / wear courses can have significant pavement rehabilitation benefits
- Sealing pavement surface
- Skid resistance and smoothness
- Improved thermal cracking performance
- Maintain clearance and profiles
- Ability to recycle
- Noise benefits
- Life cycle extension
- Construction and material quality
Thin Asphalt Overlay – Cost Effectiveness

- Life Cycle Cost Analysis
  - Wolters and Thomas, 2010
Thin Asphalt Overlays / Wear Courses

- Typical thicknesses: < 1.5 inch
  - Ultra Thin < 1 inch

- Requires some mix design innovations
  - Use of performance tests
  - Number of provisional specifications

- Different placement approaches
  - Traditional HMA placement
  - Thin bonded asphalt course Placed using Spray-paver
Thin Bonded Asphalt Wear Course Construction

- Single Pass Paving Process: Spray Paver
- Range of HMA types
- High application rate of uniform Tack Coat (3-5 times > conventional)

Benefits
- No Tack Coat Tracking
- Improved Bonding
- Provides Waterproofing
- Rapid Construction (30 to 120 ft/min)
Outline

Thin Bonded Overlays / Wearing Courses

Yosemite Avenue Project

Sustainability Evaluation of the Project

Laboratory Characterization of Field Samples

Summary
City of Duluth Field Study

Project: Yosemite Avenue (N-W Duluth)
- Low volume residential street

Typical City Rehabilitation
- Mill existing asphalt
- Regrade (and reclaim) base
- Wear Course: 1.5 inch
- Non-Wear (Binder) Course: 2 inch

Three 1000 ft. test sections
- Section-1: Traditional Approach (Control section)
- Section-2: 1 inch thin bonded wear course
- Section-3: \( \frac{3}{4} \) inch thin bonded wear course
Yosemite Avenue

Prior to Rehabilitation
Design Philosophy

Design Needs:
- High Friction Surface (Ice and Snow)
- High Cracking Resistance
  - Prevent low temperature cracking
- Moderate load carrying capacity
  - Garbage trucks, occasional delivery trucks etc.
- Smooth Surface (Bike friendly)

Approach
- Thin bonded wear course on surface (High performance sustainable mix)
  - Provide high toughness (crack resistant) layer
  - Excellent water proofing
  - High friction
- Non-wear courses
  - 2.5 – 3 inch regular hot-mix
  - High stiffness and load carrying capacity
Section-1 (Control)

- Traditional Wearing Course (1.5 inch)
- Binder Course (2 inch)
- Reclaimed Base (~ 6 inch)
- Subgrade

Section-2

- Bonded Thin Wearing Course (1 inch)
- Binder Course (2.5 inch)
- Reclaimed Base (~ 6 inch)
- Subgrade

Section-3

- Thin Bonded Wearing Course (0.75 inch)
- Binder Course (2.75 inch)
- Reclaimed Base (~ 6 inch)
- Subgrade

Section-2:
- Thin Bonded Wearing Course
- Engineered Emulsion Tack Coat – 0.08 gal/sq. yd.

Section-3
- Thin Bonded Wearing Course
- Engineered Emulsion Tack Coat – 0.20 gal/sq. yd.
Materials in Thin Wear Course Mix

**Taconite Tailings:**
- By-product from taconite mining operations at Minnesota Mesabi Iron Range (MMIR)
- Annual production = 125 Million Tons
  - Most of this ends up in land-fills around mines
- MnDOT and UMD-NRRI have conducted significant feasibility research on use of tailings in HMA

**Recycled Asphalt Shingles**
- Rich in Asphalt Binder (18-40%)
- Annual Availability = 10 Million Tons
Mix Design for Yosemite Avenue

Number of recent studies have proposed various volumetric limits for 4.75 mm mixes (more research is underway)

Started with six aggregate blends that met the AASHTO specifications for gradation
  – Bailey method approach was utilized to optimize the aggregate packing

Focused on VMA and VFA at 4% Air void level
  – Reduced to three gradations for asphalt content trails

The design with highest taconite tailings content (45.5%), 5% recycled shingles and VMA above 16.0% was chosen
# Thin Overlay Mix Design – Yosemite Avenue

## Aggregate Percentages

<table>
<thead>
<tr>
<th>Taconite Tailing</th>
<th>BA Sand</th>
<th>Crusher Fines</th>
<th>Dust</th>
<th>RAS</th>
<th>Design Asphalt Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45.5</td>
<td>24.5</td>
<td>29.0</td>
<td>1.0</td>
<td>5.0</td>
<td>7.7</td>
</tr>
</tbody>
</table>

## Aggregate Blend for NMAS = 4.75mm

![Aggregate Blend Graph](image-url)
Yosemite Avenue: Control and Non Wear Course

Constructed in August 2011
MnDOT 2360 Mix
30% RAP
Yosemite Avenue: Bonded Wear Course

Paving Date: 9/19/2012
Hail in afternoon and rain during paving
Spray paver construction
Outline

- Thin Bonded Overlays / Wearing Courses
- Yosemite Avenue Project
- Sustainability Evaluation of the Project
- Laboratory Characterization of Field Samples
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## Pavement Sustainability Rating Systems

<table>
<thead>
<tr>
<th>Rating System Attributes</th>
<th>Sustainable Rating Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PaLATE</td>
</tr>
<tr>
<td>Based on Point System (Qualitative Approach)</td>
<td>-</td>
</tr>
<tr>
<td>Quantitative Input: Roadway Design, Construction, Maintenance, and Cost</td>
<td>ü</td>
</tr>
</tbody>
</table>
**PaLATE Results**

Focus on energy demands and CO\(_2\) emissions:
- Material Production
- Transportation and Construction

Comparison between traditional asphalt mix (with 30\% RAP) and the Taconite-RAS mix

### Energy Demand (MJ / inch-mile placed)

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Mat. Prod.</th>
<th>Transp. &amp; Const.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Mix</td>
<td>744,577</td>
<td>20,598</td>
<td>765,175</td>
</tr>
<tr>
<td>Taconite+RAS Mix</td>
<td>599,820</td>
<td>34,608</td>
<td>634,428</td>
</tr>
</tbody>
</table>

### CO\(_2\) Emissions (kg/ inch-mile placed)

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Mat. Prod.</th>
<th>Transp. &amp; Const.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Mix</td>
<td>32,373</td>
<td>1,540</td>
<td>33,913</td>
</tr>
<tr>
<td>Taconite+RAS Mix</td>
<td>30,230</td>
<td>2,587</td>
<td>32,817</td>
</tr>
</tbody>
</table>
Lab Testing of Field Samples

Mix Volumetrics
- Loose Mix and cored samples were collected and tested by Golder Associates
- Marshall flow and stability tests were also conducted by Golder Associates

Portable Bond Test
- Evaluation of bond between wear course and underlying layers
- Cored samples were provided to Road Science for testing using the Portable Bond Tester (PBT)

Disk Shaped Compact Tension (DCT) Fracture Energy Test
- Provides measure of the cracking resistance of the mix
- Has been shown to correlate very well against low temperature cracking amount
Mix Volumetrics

- Air Void Level (Core samples) = 4.3%
- Nuclear Gage = 8 – 13%
  - Very thin lift, gage not calibrated to this type of mix
- Total Asphalt Content = 7.9% (with tack coat)
  - Plant Mix = 7.7%
- Voids in Mineral Aggregate (VMA) = 19.3%
- Voids Filled with Asphalt (VFA) = 77.7%
- Percent crushed = 95%
- Marshall Stability = 11,972 N (2,690 lb.)
  - Usually required limit for heavy traffic is 8,000 N
- Marshall Flow = 11.6 (0.25 mm / 0.001 inch)
  - For heavy traffic: 8 - 14
Portable Bond Test Equipment

- Equipment and test under evaluation
- Use in lab or in field
- Portable, battery powered, weight ~25#
- Data acquisition, captures load and travel
- 0.5 mm/min rate of travel
- 2 inch diameter specimens on road or in larger core
- 500 lb. load capacity
## Portable Bond Tester Results

<table>
<thead>
<tr>
<th>Section</th>
<th>Time (Days after construction)</th>
<th>Bond Energy J/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (0.08 gal/yd²)</td>
<td>42</td>
<td>24.8</td>
</tr>
<tr>
<td></td>
<td>57</td>
<td>45.2</td>
</tr>
<tr>
<td>3 (0.20 gal/yd²)</td>
<td>37</td>
<td>33.6</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>42.5</td>
</tr>
<tr>
<td></td>
<td>57</td>
<td>39.0</td>
</tr>
</tbody>
</table>

- All cores were obtained within 2 days of paving
- Testing of additional cores is planned
Disk-Shaped Compact Tension (DCT) Test

- ASTM D7313
- Loading Rate:
  - Crack Mouth Opening Displacement
  - CMOD = 1.0-mm/min
- Measurements:
  - CMOD
  - Load

Fracture Energy Results for the Taconite-RAS Mix

Test Temperature = -24°C
Recommended Minimum = 400 J/m²
Outline

- Thin Bonded Overlays / Wearing Courses
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Summary

The current mill and fill approach used for rehabilitation of low volume roads can be improved to extend the maintenance dollars.

Use of thin bonded wear course provides good opportunity to improve the performance of roadways:
- Good friction
- Waterproofing
- Cracking resistance

Combining thin bonded wear course with high taconite and RAS mix can yield sustainable results:
- Lower material costs and environmental impacts (Tailings and RAS)
- Reduced thicknesses of underlying non-wear courses
- Average cost difference between control section and the thin bonded wear course section ~ 9%
Summary (cont.)

- Few cracks in all test sections due to base settlement
  - No thermal cracks so far
- Longitudinal joint on control section is cracking
Thank you for your attention!!!

Questions?

Acknowledgements:
Ø City of Duluth
Ø LRRB Local Operational Research Assistance (OPERA) Program
Ø Minnesota Department of Transportation
Ø Road Science
Ø UMD Natural Resources Research Institute (NRRI)
Ø Golder Associates
Thin Overlay – Asphalt Mix Considerations

Open/gap graded and SMA mixes
- Requires high quality aggregate
- High air void content
- Good friction and drainability

Dense graded mixes
- Significant effort on development of gradation and volumetric criteria for 4.75 mm mixes
- High surface smoothness
- Good pavement sealing and may add surface cracking benefits
Thin Overlay – 4.75 mm Mix Designs

Significant research has been undertaken in recent years

James et al. (2007)
- Proposed gradation and volumetric requirements
  
  *Gradation Control*
  - 9.5 mm  95 – 100%
  - 4.75 mm  90 – 100%
  - 1.18 mm  30 – 54%
  - 0.075 mm  6 – 12%

  *Volumetrics*
  - Min. 16% VMA
  - VFA: 75 – 78% (high traffic), 75 – 80% (low traffic)
  - Dust proportion 0.9 – 2.2
# Thin Overlays: 4.75 mm Mix Design

AASHTO M 323 Specifications:

<table>
<thead>
<tr>
<th>Design ESALs (Millions)</th>
<th>( N_{\text{des}} )</th>
<th>FAA Depth from Surface</th>
<th>( N_{\text{ini}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( \leq 100 \text{ mm} )</td>
<td>( \geq 100 \text{ mm} )</td>
</tr>
<tr>
<td>&lt;0.3</td>
<td>50</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.3 to &lt;3.0</td>
<td>75</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>3.0 to &lt;10</td>
<td>75</td>
<td>45</td>
<td>40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Min.</th>
<th>Max.</th>
<th>( V_a = 4.0% )</th>
<th>D:B Ratio: 0.9 to 2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 mm</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.5 mm</td>
<td>95</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.75 mm</td>
<td>90</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.18 mm</td>
<td>30</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.075 mm</td>
<td>6</td>
<td>12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Thin Overlays - 4.75 mm Mix Design**

**NCAT Study (West et al., 2011)**
- Major modification from AASHTO specification: Use of $V_{be}$ instead of VMA and VFA
- This modification is based on performance tests

<table>
<thead>
<tr>
<th>Design ESAL Range (Millions)</th>
<th>$N_{des}$</th>
<th>Minimum FAA</th>
<th>Minimum SE</th>
<th>Minimum $V_{be}$</th>
<th>Maximum $V_{be}$</th>
<th>$%G_{mm@N_{ini}}$</th>
<th>D:B Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.3</td>
<td>50</td>
<td>40</td>
<td>40</td>
<td>12.0</td>
<td>15.0</td>
<td>$\leq 91.5$</td>
<td>1.0 to 2.0</td>
</tr>
<tr>
<td>0.3 to ≤ 3.0</td>
<td>75</td>
<td>45</td>
<td>40</td>
<td>11.5</td>
<td>13.5</td>
<td>$\leq 90.5$</td>
<td>1.0 to 2.0</td>
</tr>
<tr>
<td>3.0 to ≤ 30</td>
<td>100</td>
<td>45</td>
<td>45</td>
<td>11.5</td>
<td>13.5</td>
<td>$\leq 89.0$</td>
<td>1.0 to 2.0</td>
</tr>
</tbody>
</table>

**Gradation Limits**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 mm</td>
<td>---</td>
<td>100</td>
</tr>
<tr>
<td>9.5 mm</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>1.18 mm</td>
<td>30</td>
<td>55</td>
</tr>
<tr>
<td>0.075 mm</td>
<td>13</td>
<td>6</td>
</tr>
</tbody>
</table>

**Effective binder amount**
**Thin Overlays – 4.75 mm Mix Designs**

**Texas (Scullion et al., 2009): CAM**

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Fine Mixture (% Passing by Weight or Volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2&quot;</td>
<td>–</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>98.0–100.0</td>
</tr>
<tr>
<td>#4</td>
<td>70.0–90.0</td>
</tr>
<tr>
<td>#8</td>
<td>40.0–65.0</td>
</tr>
<tr>
<td>#16</td>
<td>20.0–45.0</td>
</tr>
<tr>
<td>#30</td>
<td>10.0–30.0</td>
</tr>
<tr>
<td>#50</td>
<td>10.0–20.0</td>
</tr>
<tr>
<td>#200</td>
<td>2.0–10.0</td>
</tr>
</tbody>
</table>

- 2 – 4% Air Voids
- Design is based on performance tests
  - Hamburg and Texas Overlay Tester
**Thin Asphalt Overlays: MnROAD**

- Two test sections in Cell-6
- Mix consists of significant quantities of Taconite tailings

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Proposed AASHTO Criteria</th>
<th>MnDOT SPWEB440F Special</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix Size</td>
<td>4.75 mm NMAS</td>
<td>4.75 mm NMAS</td>
</tr>
<tr>
<td>Binder Type</td>
<td>PG 64 -34 (polymer modified)</td>
<td></td>
</tr>
<tr>
<td>Binder Content</td>
<td>7.4%, Pbe=6.9</td>
<td></td>
</tr>
<tr>
<td>Aggregate Blend</td>
<td>55% Taconite tailings (Mintac)</td>
<td>10% Taconite tailings (Ispat)</td>
</tr>
<tr>
<td></td>
<td>35% Man-sand (Loken)</td>
<td></td>
</tr>
<tr>
<td>Target Gradation</td>
<td>30%–55% passing 1.18 mm Sieve</td>
<td>51% passing 1.18 mm Sieve</td>
</tr>
<tr>
<td></td>
<td>6-13% passing 0.075 mm Sieve</td>
<td>7.7% passing 0.075 mm Sieve</td>
</tr>
<tr>
<td>Aggregate Properties</td>
<td>FAA = 45 (min)</td>
<td>FAA = 47</td>
</tr>
<tr>
<td></td>
<td>SE = 45 (min)</td>
<td>SE = 83</td>
</tr>
<tr>
<td></td>
<td>Nat.Sand=15(max) if FAA&lt;45</td>
<td>N/A</td>
</tr>
<tr>
<td>Air Voids</td>
<td>4.0%-6.0% (Ndes=75 gyrations)</td>
<td>V_{se}=3.9% at N_{des} =75 gyrations</td>
</tr>
<tr>
<td></td>
<td>89.0 max (%G_mm @ N_uni)</td>
<td>Not reported</td>
</tr>
<tr>
<td>Volumetric Properties</td>
<td>V_{ve} 11.5-13.5</td>
<td>V_{se}=16.4</td>
</tr>
<tr>
<td></td>
<td>VMA 16.0 min. (note 1)</td>
<td>VMA=20.3</td>
</tr>
<tr>
<td></td>
<td>VFA 65-78 (note 1)</td>
<td>VFA 80.8</td>
</tr>
<tr>
<td></td>
<td>D:B ratio 1.5-2.0</td>
<td>D:B ratio =1.1</td>
</tr>
<tr>
<td>Moisture Susceptibility</td>
<td>TSR=0.82 @ V_3 = 9.0%</td>
<td></td>
</tr>
</tbody>
</table>