Applications, Design & Construction of Ultra-thin Whitetopping

Dr. Julie M. Vandenbossche, P.E.
- University of Pittsburgh-
Whitetopping

Conventional
(no bond)

Ultra-thin
(bond is key!)
Definitions

Thin Whitetopping (TWT)  
Bond is not required

Ultra-Thin Whitetopping (UTW)  
Bond \textit{is} required

- PCC Overlay
- Existing HMA

Existing HMA

> 100 to 200 mm

50 to 100 mm
Definitions

Thin Whitetopping (TWT) > 100 to 200 mm

Ultra-Thin Whitetopping (UTW) 50 to 100 mm

Bond is not required

Bond is required
How does UTW work?

Bonded

Unbonded

Compression

Tension

0

NA

Compression

Tension

0

NA

NA
How does UTW work?

Joint Spacing

Long

Short
When to consider UTW

- HMA thickness $\geq$ 75 mm
- No stripping/raveling
- No excessive bottom-up fatigue cracking
Keys to UTW Performance

- Adequate (HMA and soil) support layers
- PCC-HMA bond (*essential*)
- Slab size / joint spacing
- Concrete material selection
- Design Inputs
  - Traffic, layer thickness, climate, etc.
Ultra-Thin Whitetopping

Since 1990, over 300 UTW projects have been constructed.
Ultra-Thin Whitetopping

Since 1990 about 1 million SY placed - It is not experimental anymore

Over 835,000 m²

Jerry Voight - ACPA
Appropriate applications
Applications for UTW

- Streets
- Intersections
- Bus pads
- GA airports
- Parking lots
Stopping Areas...
Chicago Bus Stops

- Building more than 1000 concrete bus stops (approximately 30 x 3 m)
- Cobblestone/asphalt base costly to remove
- Thickness constrained from 90 to 140 mm
- Increase strength
- Use structural fibers
UTW Commercial Projects
Lancaster, PA
Rt 30 & 896
Lancaster, PA
Rt 30 & 896
Whitetopping - Advantages

Structural

- Improved structural capacity
- Low maintenance
- Reacts structurally as if on strong base course
- Concrete slabs bridge problems asphalt cannot
Whitetopping - Advantages

Construction

- Can place on pavement in poor condition.
  - Little or no pre-overlay repair needed.
- Avoid reconstruction problems.
  - Minimal rain delays.
  - Maintain traffic on existing surface.

Randy Riley
Whitetopping - Advantages

Safer

- Visibility
- Decreased stopping distances
- Non-rutting
- Less work zone reconstruction
  - less accidents

Asphalt

Concrete

Randy Riley
Typical Distresses
Typical Distresses

- Transverse Cracking
- Corner Breaks & Transverse Cracking
- Corner Breaks
Typical Distresses

(1.5 ft x 1.8 m Panels)
Findings from instrumented UTW
Minnesota Test Sections

- 102 mm - 1.2 m x 1.2 m Panels (polypropylene fibers)
- 76 mm - 1.2 m x 1.2 m Panels (polypropylene fibers)
- 76 mm - 1.5 m x 1.8 m Panels (polyolefin fibers)
- 152 mm - 1.5 m x 1.8 m Panels (polypropylene fibers)
- 152 mm - 3 m x 3.7 m Panels (polypropylene fibers)
- 152 mm - 3 m x 3.7 m Panels (polypropylene fibers & dowels)
Sensor Installations Prior to Paving

Thermocouples

Moisture Sensors

Static Strain Sensors
Performance after 4 years

Interstate highway with 25,000 ADT, 12-13% trucks
83% of the distress occurred in the driving lane.
73 % of the distress occurred in the driving lane.
76 mm - 1.5 m x 1.8 m Panels

75 % of the distress occurred in the driving lane.
**Whitetopping Crack Summary**

<table>
<thead>
<tr>
<th>Cell</th>
<th>Panels Cracked (%)</th>
<th>Corner Cracks</th>
<th>Trans. Cracks</th>
<th>Long. Cracks</th>
</tr>
</thead>
<tbody>
<tr>
<td>102- 1.2x1.2m</td>
<td>7</td>
<td>14</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>76- 1.2x1.2m</td>
<td>40</td>
<td>165</td>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>76- 1.2x1.2m *</td>
<td>8</td>
<td>18</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>152- 1.2x1.2m</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*All transverse cracks in 78 mm 1.2 x 1.2m section are reflective cracks.*
Longitudinal Joint Layout

1.2x1.2m Panels

1.5x1.8m Panels

4’ x 4’ Panels

5’ x 6’ Panels
U.S. -169, N. Mankato, MN (10/’98)
Debonding

- Debonding at Interface
- Delamination Between Lifts
- Raveling

U.S. 169, N. Mankato, MN 10/’98
Debonding

Debonding at Interface

Delamination Between Lifts

Raveling

SP208 near Sao Paulo

U.S. 169, N. Mankato, MN 10/’98
Temperature effects
Temperature Characterization
(Thermocouple Data)

76-mm Overlay

Frequency

Gradient, °C / cm
# Temperature Characterization

(Thermocouple Data)

<table>
<thead>
<tr>
<th>Overlay Thickness</th>
<th>Temperature Gradients, °C/cm</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max. Negative</td>
<td>Max. Positive</td>
<td>95% of the Time</td>
</tr>
<tr>
<td>76 mm</td>
<td>-0.82</td>
<td>+1.23</td>
<td>-0.40 to +0.80</td>
</tr>
<tr>
<td>102 mm</td>
<td>-0.61</td>
<td>+0.81</td>
<td>-0.35 to +0.60</td>
</tr>
<tr>
<td>152 mm</td>
<td>-0.63</td>
<td>+0.96</td>
<td>-0.25 to +0.45</td>
</tr>
</tbody>
</table>

The mean gradient is approximately -0.2 °C/cm for all three overlays.
1.5 m x 1.8-m Panels

FWD Testing at Lane/Shoulder Joint
(July 1999)

Estimated Traffic, ESALS

- Top
- Bottom
1.5 m x 1.8-m Panels

FWD Testing at Lane/Shoulder Joint
(July 1999)

Resilient Modulus of AC, MPa

- Top
- Bottom
Temperature and applied load

Asphalt Resilient Modulus (MPa)

Asphalt Temperature (°C)

23 13 3 -7

Microstrain

40 kN FWD load in wheelpath for 76 mm 1.52-m x 1.83-m panels
ISLAB 2000 FEM

Principal Stresses

Modeling Assumptions:
- 76-mm 1.2 x 1.2m Panels
- Fully bonded
- 0.80 °C/cm gradient
- 356 kN Tandem axle load

1. HMA temp. greatly influences stress (strains)
2. Temperature gradients have little influence on stress (strains)
Lessons learned?

- **Must obtain a good bond**
- Initial condition of existing HMA
- HMA layer must have adequate structure
- Evaluate original structure (depth of HMA layers, condition of HMA...)
- Fibers help keep cracks tight
- Joint layout
Designing UTW
UTW Design

Joint Spacing

1. 12 to 18 times pavement thickness
2. Keep longitudinal joints out of wheelpath
UTW Design

Concrete mixture design.....

- Typical Higher Cement Content
  - Fast track type construction
- Low Water / Cement Ratio
- Synthetic Fibers
- Durable, Quick Opening to Traffic
Macro vs Micro Fibers

**Macro-Fibers**

Diameters: 0.2 to 0.8 mm
(0.008 - 0.03”)

Materials: Steel, Synthetic

**Micro-Fibers**

Diameters: < 0.1 mm
(< 0.004”)

Materials: Polypropylene, Steel, Carbon, ...

Typically a 20% increase in the cost of the mix.

Adapted from Jeff Roesler
Sample mix designs...

<table>
<thead>
<tr>
<th></th>
<th>Polypropylene</th>
<th>Polyolefin</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>w/c</strong></td>
<td>0.38</td>
<td>0.41</td>
</tr>
<tr>
<td><strong>Cement (kg/m³)</strong></td>
<td>386</td>
<td>386</td>
</tr>
<tr>
<td><strong>Fly Ash (kg/m³)</strong></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>FA (kg/m³)</strong></td>
<td>1285</td>
<td>762</td>
</tr>
<tr>
<td><strong>CA (kg/m³)</strong></td>
<td>1773</td>
<td>1052</td>
</tr>
<tr>
<td><strong>Fibers (kg/m³)</strong></td>
<td>2</td>
<td>15</td>
</tr>
</tbody>
</table>
UTW Design

HMA condition assessment ..

- Values chosen for design:
  - Poor \((E_{AC} = 700 \text{ MPa})\)
    - fatigue cracked, old
  - Fair \((E_{AC} = 2,500 \text{ MPa})\)
    - rutting, no structural damage
  - Good \((E_{AC} = 4,000 \text{ MPa})\)
UTW Design Equations

Effective radius of relative stiffness...

\[ l_e = \left( \frac{I_e}{(1 - 0.15^2)k} \right)^{0.25} \]

\[ NA = \frac{(E_c t_{PCC})^2}{2} + E_b t_{BIT} \left( t_{PCC} + t_{BIT} \right) \]

\[ I_e = \left( \frac{E_h^3}{3!} \right) e = \frac{(E_c t_{PCC})^3}{12} + E_c t_{PCC} \left( NA - \frac{t_{PCC}}{2} \right)^2 + \frac{(E_b t_{BIT})^3}{12} + E_b t_{BIT} \left( t_{PCC} - NA + \frac{t_{BIT}}{2} \right)^2 \]
Determining total stress...

\[ \log(\sigma_{18}) = 5.025 - 0.465 \log(k) + 0.686 \log(L/l_e) - 1.291 \log(l_e) \]

Based on 2-D Finite element with 36% stress increase (partial bond)

\[ \sigma_T = 28.037 - 3.496(\text{CTE} \times \Delta T) - 18.382(L/l_e) \]

\[ \sigma_{\text{Total}} = \sigma_{18} + \sigma_T \]

Superposition assumes slab and HMA remain in contact
UTW Design Equations

PCC strength characterization...

Beams:
150x150x530mm
Span: 450mm
L/150 = 3 mm

\[ \text{MOR} = \frac{P_1L}{bd^2} \]
\[ f_{150}^{150} = \frac{P_{150}^{150}L}{bd^2} \]
\[ R_{150}^{150} = \frac{f_{150}^{150}}{\text{MOR}} \times 100 \]

FIG. 3 Example of Parameter Calculations for First-Peak Load Equal to Peak Load (Not to Scale)
UTW Design Equations

Stress Ratio...

\[ R_{150}^{150} = \frac{f_{150}^{150}}{\text{MOR}} \times 100 \quad (\text{ASTM C1609-07}) \]

\[ R_{150} \text{ values} = 20\% \]

\[ \text{Stress Ratio (SR)} = \frac{\sigma_{\text{Total}}}{(1+R_{150}) \times \text{MOR}} \]
UTW Design Equations

Fatigue ...

\[ R^* = 1 - \frac{(1 - R) \cdot P_{cr}}{0.5} \]

\[ \log N_{PCC} = \left[ - \frac{SR_{total}^{10.24} \log(R^*)}{0.0112} \right]^{0.217} \]
### UTW Design Procedure

**Load-Carrying Capacity Calculator**

This website calculates the load-carrying capacity of an ultra-thin wearing course (UTW) pavement in terms of the total number of loads that can be carried during its service life. The calculations are based on an engineering analysis that includes life-cycle analysis and correlation to OPM performance data. For more information, see ACPA publications 31502P - Ultra-thin Wear Courses.

#### Unit of Measure

<table>
<thead>
<tr>
<th>Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Loadable Category</strong></td>
<td>This is the loadable category, which affects the service life of the pavement.</td>
</tr>
<tr>
<td><strong>Thickness</strong></td>
<td>The thickness of the UTW, which affects the load-carrying capacity.</td>
</tr>
<tr>
<td><strong>Joint Spacing</strong></td>
<td>The joint spacing between the slab parts, affecting the load distribution.</td>
</tr>
<tr>
<td><strong>Flexural Strength</strong></td>
<td>The average flexural strength of the pavement, affecting its load capacity.</td>
</tr>
<tr>
<td><strong>Asphalt Concrete</strong></td>
<td>The thickness of the existing asphalt concrete, affecting the load distribution.</td>
</tr>
</tbody>
</table>

#### Other Inputs

- **k-value** (psi, weight) - This is the subgrade/subbase k-value, which affects the load-carrying capacity.

---

UTW Design

- **Traffic**
  - Category A – Low truck volume
  - Category B – Medium truck volume
- **Average** Flexural Strength
  - Third-point loading (ASTM C78)
- Composite k-value of all layers below HMA
**UTW Design**

- Composite k-value of all layers below HMA

<table>
<thead>
<tr>
<th>Subgrade</th>
<th>k, pci (MPa/m)</th>
<th>Combined thickness of base and subbase, in. (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td></td>
<td>4 (100)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 (200)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12 (300)</td>
</tr>
<tr>
<td>Poor</td>
<td>75 (20)</td>
<td>90 (24)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120 (32)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>150 (41)</td>
</tr>
<tr>
<td>Fair</td>
<td>100 (27)</td>
<td>118 (32)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>152 (41)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>186 (51)</td>
</tr>
<tr>
<td>Good</td>
<td>150 (41)</td>
<td>168 (46)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>208 (56)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>250 (68)</td>
</tr>
<tr>
<td>Excellent</td>
<td>200 (54)</td>
<td>217 (59)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>260 (71)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>310 (84)</td>
</tr>
</tbody>
</table>
Construction
UTW Construction

- **Milling**
  - Use when rutting > 25mm
  - Removes between 25 and 76mm
    - Can shave off top of ruts
- **Used with inlays**
  - Limited vertical clearances
  - Single lane replacement
  - Runway keelways
Ref. “Resurfacing and Patching Concrete Pavement with Bonded Concrete”, Highway Research Board, Volume 35, 1956
Ref. Unpublished Research, David Whitney, Department of Civil Engineering, University of Texas at Austin

Randy Riley
Surface Preparation

- Clean surface
  - Sweeper
  - Compressed air

Adapted from Randy Riley
Heat/Energy is Absorbed into Black Leveling Surface

Heat/Energy is Reflected by Whitewashed Surface

-10° C
Paving

- Mist surface
- Place concrete
  - Paver
  - Clarey screed
**Loss % Varies by Depth**

<table>
<thead>
<tr>
<th>Expected Loss</th>
<th>Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% @ 25 cm</td>
<td>= 0.0% @ 75 cm</td>
</tr>
<tr>
<td>3% @ 25 cm</td>
<td>= 10% @ 75 cm</td>
</tr>
<tr>
<td>5% @ 25 cm</td>
<td>= 16.7% @ 75 cm</td>
</tr>
<tr>
<td>8% @ 25 cm</td>
<td>= 26.7% @ 75 cm</td>
</tr>
</tbody>
</table>
UTW Jointing

- Apply curing compound
- Saw joints
- Seal joints (optional)
THANK YOU

ANY QUESTIONS??