**MnROAD Lessons Learned**

Thin and Ultra-thin Concrete Overlays

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**History at MnROAD**

Thin and ultra-thin concrete overlays (also known as whitetopings) are a pavement rehabilitation option that has been increasing in popularity in the U.S. over the past 15 years. One area of deficiency in the use of ultra-thin and thin concrete overlays is the lack of a rational design method. While several local (1,2) and industry (3,4) design methods have been formulated, few are based on mechanistic-empirical research born out of actual field performance. Fortunately, the Minnesota Road Research Project (MnROAD) has contributed significantly to the understanding of the field performance of thin and ultra-thin concrete overlays.

In 1997, three thin (TWT) and three ultra-thin (UTW) concrete overlay test sections were constructed on the interstate portion of the MnROAD facility. The objective in locating these thin concrete surface layers on the interstate was to accelerate traffic related distresses. In 2004, after enduring over 6 million concrete equivalent single axles loads (CESALs), the UTW test sections needed to be replaced due to severe surface distresses. Later that year, four new thin concrete overlay test sections were constructed in their place. Table 1 summarizes the experimental designs studied at the MnROAD facility.

The following sections highlight the lessons learned from the testing and monitoring of the MnROAD concrete overlay test sections.

**Table 1. Thin (TWT) and ultra-thin (UTW) concrete overlay designs at the MnROAD project. All sections are subject to interstate traffic.**

<table>
<thead>
<tr>
<th>Cell #</th>
<th>Type</th>
<th>PCC thickness (in)</th>
<th>HMA thickness (in)</th>
<th>Panel size (ft)</th>
<th>Sealed joints</th>
<th>Fiber reinforcement type</th>
<th>Year Start-End</th>
</tr>
</thead>
<tbody>
<tr>
<td>92</td>
<td>TWT</td>
<td>6</td>
<td>7</td>
<td>10 x 12*</td>
<td>Y</td>
<td>Polypropylene</td>
<td>1997-present</td>
</tr>
<tr>
<td>93</td>
<td>UTW</td>
<td>4</td>
<td>9</td>
<td>4 x 4</td>
<td>Y</td>
<td>Polypropylene</td>
<td>1997-2004</td>
</tr>
<tr>
<td>94</td>
<td>UTW</td>
<td>3</td>
<td>10</td>
<td>4 x 4</td>
<td>Y</td>
<td>Polypropylene</td>
<td>1997-2004</td>
</tr>
<tr>
<td>95</td>
<td>UTW</td>
<td>3</td>
<td>10</td>
<td>5 x 6</td>
<td>Y</td>
<td>Polyolefin</td>
<td>1997-2004</td>
</tr>
<tr>
<td>96</td>
<td>TWT</td>
<td>6</td>
<td>7</td>
<td>5 x 6</td>
<td>Y</td>
<td>Polypropylene</td>
<td>1997-present</td>
</tr>
<tr>
<td>97</td>
<td>TWT</td>
<td>6</td>
<td>7</td>
<td>10 x 12</td>
<td>Y</td>
<td>Polypropylene</td>
<td>1997-present</td>
</tr>
<tr>
<td>60</td>
<td>TWT</td>
<td>5</td>
<td>7</td>
<td>5 x 6</td>
<td>Y</td>
<td>None</td>
<td>2004-present</td>
</tr>
<tr>
<td>61</td>
<td>TWT</td>
<td>5</td>
<td>7</td>
<td>5 x 6</td>
<td>N</td>
<td>None</td>
<td>2004-present</td>
</tr>
<tr>
<td>62</td>
<td>TWT</td>
<td>4</td>
<td>8</td>
<td>5 x 6</td>
<td>Y</td>
<td>None</td>
<td>2004-present</td>
</tr>
<tr>
<td>63</td>
<td>TWT</td>
<td>4</td>
<td>8</td>
<td>5 x 6</td>
<td>N</td>
<td>None</td>
<td>2004-present</td>
</tr>
<tr>
<td>(14)</td>
<td>TWT</td>
<td>6</td>
<td>Var.</td>
<td>6 x 6*</td>
<td>Y/N</td>
<td>None</td>
<td>To be Built 2008</td>
</tr>
</tbody>
</table>

* Test Cell 92 contains doweled transverse joints. Some joints to be doweled in Cell 14.
Effect of Panel Size and Thickness

Panel size and thickness can have a major effect on the performance of a thin concrete overlay. As the panel thickness decreases, so should the overall panel size. This ensures that the panels will have less of a tendency toward curling up, and instead simply deflect downward under heavy loading. To test this theory, the UTW test sections at the MnROAD facility studied two panel sizes and two thicknesses. Test cells 93 and 94, consisting of 4 foot by 4 foot panels, both demonstrated corner cracking in locations near the wheelpaths. The concentration of heavy loads near the edge of the thin panels exceeded their load capacity. Cell 93, with a concrete surface thickness of 4 inches, exhibited approximately 75% less cracks than the 3 inch thick Cell 94. Photo 1 shows the typical crack pattern experienced by smaller panel sizes in Cells 93 and 94.

Test Cell 95 (3 inch PCC), with the larger 5-foot long by 6-foot wide panels, also experienced about 75% less cracking than the 3 inch thick, 4 by 4 foot panels, in Cell 94. Surface distress in test Cell 95 occurred mostly in panels near the driving lane shoulder. See Photo 2. Cracking in Cell 95 was caused mainly by debonding of the thin concrete overlay from the hot-mixed asphalt (HMA) layer. Once a crack initiated, repetitive heavy traffic loading propagated further cracking, eventually resulting in a large area of distress.

Based on the performance of the UTW test sections at MnROAD, it is recommended that panel size should be chosen to keep channelized wheel loadings away from the edges of ultra-thin panels. Also, there is a significant difference in performance between a 3 and 4 inch concrete surface layer for the same panel size. It needs to be reemphasized that MnROAD provides accelerated traffic loading, and that typical UWT and TWT applications are located on lower volume roadways.

The thin concrete overlay test Cells 92 and 97, with their larger 10 foot long by 12 foot wide panel size, both experienced minor longitudinal cracking in several panels. The tendency of the larger panels to crack into 6 foot wide panels, supports current theory that a panel size of 6 foot by 6 foot is optimal for most thin concrete overlays. In fact, test Cell 96, with 5 foot long by 6 foot wide panels, demonstrates the best performance of the original concrete overlay test cells constructed in 1997.
Reflective Cracking
Besides corner cracking, the phenomenon of reflective cracking was noticed at MnROAD for test sections with a concrete layer thickness less than 5 inches. This behavior was evident in both the original UTW test sections (Cells 93-95), and the 4 inch thick TWT test Cells 62 and 63 constructed in 2004. Currently thinking is that the underlying HMA becomes stiff enough in the wintertime to exceed the strength of the bonded thin concrete overlay.

Interlayer bonding
The performance of ultra-thin concrete overlays relies heavily on the composite action between the older HMA and the new concrete layer. Steps are taken during construction to enhance bonding of the layers through the techniques of HMA milling and careful surface cleaning. Understanding the strength and longevity of the layer bonding will be critical to forming rational design methods for UTW and TWT.

Forensic examination of core samples and test pits at MnROAD showed clear evidence that debonding of the ultra-thin white topping from the hot-mix asphalt layer led to cracking, and eventually surface distress(5). Photos 3 and 4 show a core sample demonstrating significant loss of interlayer bond. Debonding between the layers always occurred near panel edges or cracks, likely due to asphalt stripping and/or freezing and thawing action from the increased amount of available moisture.

Photos 3 and 4. Sample location (left photo) and bottom view (right photo) of Core “F”, showing loss of bond between the UTW and HMA layers. Core shown upside down.

Load Testing
Besides exposure to live interstate traffic and Minnesota’s extreme weather, the MnROAD test sections are periodically load tested by specific test vehicles (MnROAD truck) and nondestructive devices (FWD). Results of this testing can be found in references 6-9. Notable results include strain measurements indicating composite action between the layers, and the observation that as temperatures increase in the HMA layer (and therefore resilient modulus decreases), the strains measured in the concrete layer increase(9).

Joint Faulting
Test Cell 97, which has large panels and undoweled transverse joints, has recently demonstrated significant joint faulting. Forensic cores, taken recently, indicate overdosing or settlements of fibers, causing weakness near the joints and bottom of the concrete panels. Adjoining Test Cell 92 has dowels and is not experiencing the joint faulting, despite the same fiber concrete mix.
Fibers in Concrete Mix
The original UTW and TWT test sections at MnROAD had concrete surface layers containing synthetic fibers. These fibers were inserted to strengthen the concrete, reduce shrinkage cracking, and provide reinforcement across cracks. The small polypropylene fibers in the MnROAD test sections seemed to provide little benefit to the performance of the concrete layer. The larger polyolefin fibers did not prevent cracking, but did appear to have the ability to retain small broken pieces of concrete. Reference 5 contains further information on the performance of the fiber-reinforced mixes in the MnROAD UTW and TWT test sections. Given their less than satisfactory performance, and substantially higher initial cost, non-structural fiber reinforced mixes have not been used in the newer TWT test cells at MnROAD.

Best Design for Interstate Traffic
As previously mentioned, MnROAD TWT test Cell 96 demonstrates the best performance under interstate traffic loads. The design consists of 6 inch thick concrete over 7 inches of HMA, with 5 foot by 6 foot panels. This closely simulates the national trend toward “6 inch (thick) by 6 foot by 6 foot (panel)” designs for higher volume roads.

Future Plans
The original thin concrete overlay test sections at MnROAD are approaching their 11th year in operation. In addition, the test cells constructed in 2004 continue to be monitored and load tested. A new thin concrete overlay will be built over one of the original MnROAD full-depth HMA cells in 2008. A six-state sponsored pooled fund study to develop a rational design method for thin and ultra-thin concrete overlays has just begun. MnROAD performance data will provide a large basis for that study.

References