ABSTRACT

Ultra-thin whitetopping is the technology to construct thin (50-100mm) Portland cement concrete overlays on distressed asphalt pavements. There have been several UTW projects completed in Canada, the first in Mississauga ON, with others in Brampton, Markham, Ottawa, Hamilton, and Vancouver. All projects have shown good to excellent performance thus far, indicating that this rehabilitation strategy can stand up to the harsh Canadian climate. The suitability of UTW rehabilitation for a particular site is dependant on several factors including existing asphalt thickness, volume of truck traffic, base and subgrade support, and pavement condition. UTW is beneficial in several ways especially for repairing roads and intersections experiencing problems with rutting or washboarding. This paper outlines the state-of-practice in Canada for UTW construction, with respect to traffic, materials, design, construction, and repair. The determination of load carrying capacity and measurement of performance of a UTW project is discussed as well as issues related to life cycle cost analysis. Several case studies on UTW projects in Canada are presented.

1. INTRODUCTION

Ultra-Thin Whitetopping is the newest innovation in asphalt pavement rehabilitation. This technology involves bonding a thin concrete layer, 50 to 100 mm thick, to an existing prepared surface of asphalt pavement. The concrete overlay utilizes closely spaced transverse and longitudinal joints to reduce tensile stresses caused by traffic loads and environmental conditions such as thermal stresses and curling due to temperature changes. Fibre-reinforcement is commonly specified in the concrete mixes to improve load transfer, durability, and shrinkage cracking resistance. The result is a bonded composite pavement structure, as shown in Figure 1, that can eliminate rutting or washboarding problems commonly found with asphalt pavements, particularly at intersections. Since the introduction of this technique to North America with the first UTW project in Kentucky in 1988, several hundred projects have been completed in North America 1. The outstanding performance of these UTW projects has led to increasing interest in the technique.

The first Canadian UTW project was constructed by the City of Mississauga in 1995. Since then, several more projects have been completed in the cities of Brampton, Markham, Hamilton, Ottawa, and Vancouver. Most of the projects have shown good to excellent performance thus far, indicating that this rehabilitation strategy can stand up to the harsh Canadian climate. The suitability of UTW rehabilitation for a particular site is dependant on several factors including existing asphalt thickness, volume of truck traffic, base and subgrade support, and pavement condition.
traffic, base and subgrade support, and pavement condition. UTW is beneficial for repairing roads and intersections experiencing problems with rutting, washboarding, cracks, and poor drainage. Other benefits include improved visibility, skid resistance, and elimination of potholes. One major additional benefit is that UTW can be more cost effective due to the minimal maintenance requirements, increased design life compared to an asphalt mill and replace option, minimal traffic disruption, and reasonable construction costs.

2. CONCRETE MIX DESIGN

The type of concrete mix for a particular UTW project is often selected based on traffic conditions, concrete strength and time requirements for opening to traffic. Many UTW projects have utilized fast track concrete mixes that typically contain higher cement content or high early-strength cement. In addition, fast track mixes can be adjusted to produce compressive strengths of at least 20 MPa in 24 hours and 28-day strengths in excess of 40 MPa. Synthetic fibres are often used in UTW mixes to provide additional strength and durability to the thin concrete layer. It has also been found that these fibres extend the time window for saw-cutting the joints by delaying early plastic shrinkage cracking. Additional information on fast-track concrete mix designs can be found in reference 2.

3. MECHANISTIC ANALYSIS

Design of UTW pavements is considerably different than the design procedures used for conventional whitetopping. Because of the unique properties of the UTW pavement system, conventional concrete pavement thickness design procedures, such as those of Portland Cement Association (PCA) and AASHTO, do not apply. The use of a conventional two-layer analysis, without consideration given to the pavement bonding, typically results in an over-estimation of the critical stresses and thickness requirements. By using a more realistic three-layer model that incorporates a degree of bond between the two pavement layers and adding a base layer with a specified k-value, more accurate stress computations will be achieved. As shown in Figure 2, which compares the two-layer and three-layer models, the stresses can be nearly cut in half by using this type of analysis.
3.1 Bond

The bond allows the concrete and asphalt to perform in composite action that essentially causes the layers to share the loads. Bonding shifts the neutral axis in the concrete downward, reducing the tensile stresses at the bottom of the concrete layer to sustainable levels. By doing this however, corner stresses are increased at the top of the concrete layer. If the neutral axis shifts low enough in the concrete, the critical load location will move from the edge to the corner. This type of stress can be decreased by having an adequately thick asphalt layer to provide support to the UTW slab.

3.2 Joint Spacing

Traditional concrete pavements are designed to absorb the energy of the applied loads by bending and thus are designed thick enough to resist the bending stresses. UTW pavements on the other hand, are designed with short joint spacings that allow the composite pavement to absorb the energy by deflection instead of bending. The short joint spacing reduces the moment induced in the slab by loads and minimizes stresses due to bending. This short joint spacing also minimizes stresses due to curling, warping and thermal expansion and contraction. Typical joint spacings that have shown to perform well in past UTW projects range between 0.6 and 1.8 m. It is recommended that the spacing be between 12 and 15 times the slab thickness in each direction. Joint spacing as low as 10 times the concrete thickness have also been used recently in Canada[2,5].

UTW projects require extra concrete thickness at the transition to the asphalt roadway in order to prevent early cracking of the transition slabs. Figure 3 shows the suggested transition detail for a transverse section of the overlay. This type of detail should also be used on longitudinal joints where traffic will frequently cross from the concrete over to the adjacent asphalt.

Figure 2: Stress distribution under 2-layer and 3-layer analyses.
3.3 Asphalt Thickness

After the asphalt surface has been prepared, there must be enough remaining asphalt thickness that, when combined with the bonded concrete, the composite section can carry the anticipated truck traffic. It is recommended that the minimum asphalt thickness after milling the deteriorated asphalt be equal to or greater than 75 mm. The thicker the remaining asphalt structure, the greater the number of trucks a UTW overlay can carry for the same concrete pavement thickness. This increased thickness provides a stronger pavement structure thereby reducing the concrete stresses.

4. CONSTRUCTION OF UTW PAVEMENTS

4.1 Preconstruction considerations

The following is a list of preconstruction activities that should be performed:
- Investigate the existing pavement structure by coring, giving special attention to utility cuts and road widening
- The selected milling depth should be sufficient to remove all wheel-rutted areas. Consideration must be made to the fact that additional milling may be required if locations of delamination, or debonded asphalt are observed. There must be at least 75 mm or more of sound asphalt thickness left after all milling to use this rehabilitation technique.
- Constraints such as elevation of adjacent pavement lane or curb and gutter
- Traffic routing and temporary asphalt ramping will need to be considered prior to paving

4.2 Construction

There are 4 fundamental steps for UTW construction:
- Prepare the asphalt surface by milling out deteriorated asphalt and cleaning the milled surface with compressed air or water blasting
- Place, finish, texture, and cure the concrete using conventional techniques
- Saw cut the joints early to prevent cracking
- Open to traffic

It is essential to prepare a good, clean asphalt surface to achieve a proper bond to the UTW. Milling is the most common and effective method. If water blasting is used for cleaning the milled surface, the surface must be allowed to dry before placing the concrete over it. This will ensure that the cement paste can penetrate the roughened asphalt surface and the w/c ratio of the concrete at the interface with the asphalt is not increased. Additional cleaning of the asphalt surface is required if traffic is allowed to travel on the milled surface prior to placement on the concrete overlay.
Paving UTW is no different than paving other concrete pavements except that the concrete layer is significantly thinner. Conventional slip-form and fixed-form paving processes, as well as hand-held vibrating screeds have all been successfully used in the past. Normal finishing and texturing procedures apply. Curing, however, is very critical due to the large surface area and thin concrete pavement. Curing compound should be applied at twice the normal rate (2.5 litre/m²) to prevent rapid loss of water due to evaporation, which can cause early plastic shrinkage cracking.

Joint sawing should be conducted with lightweight saws as early as possible. It is recommended that early entry sawing (also known as green cut) technology be used, Figure 4, and cutting should commence when the concrete is strong enough to support the equipment. Joints should be cut only 3 mm wide to prevent intrusion of incompressibles, and the saw depth should be between \( \frac{1}{4} \) and \( \frac{1}{3} \) the depth of overlay. Typically, joints are not sealed as performance to date has shown little or no benefit from sealant use. However, if working joints do open up significantly, they should be sealed to prevent incompressibles from causing joint spalling. The use of fibres will keep the joints tight and minimize water infiltration by up to 90 percent.

Figure 4: Saw-cutting UTW joints

5. REPAIR OF UTW PAVEMENTS

With UTW pavements, cracks in the small concrete slabs do not always necessitate the need for repair. Generally, repairs should be considered when panels are broken into 4 or more pieces, surface irregularities or settlement affect ride quality or if loose or missing concrete is evident. From past UTW projects, the most common distresses found over 6 or 7 years of service are low-severity corner and edge cracking.

The repair process is much like full-depth repair except that no load transfer devices are required. There are generally two methods for removing a damaged UTW slab:

1) break-up and clean out
2) lift-out method – (This involves removal of whole or large portions of slabs using a steel chain connected to lift pins.)

For either method, care must be taken not to disturb the underlying pavement and adjacent slabs. A good practice is to make a second saw cut 150 mm inside of the slab edge and remove the inside material first followed by the remaining 150 mm portions. Some asphalt will probably adhere to the bottom of the concrete because of the bond, so care must be taken to ensure a uniform foundation before replacing the concrete. If the asphalt layer is damaged after removal, and the remaining thickness is less than 75 mm
or the base beneath the asphalt is visible, all asphalt should be removed and replaced with a full-depth concrete slab (minimum 150 to 200 mm). Load transfer can be added by roughening up the edges of surrounding slabs with a lightweight jackhammer.

6. LIFE CYCLE COST ANALYSIS

A recent life cycle cost (LCC) analysis study was conducted in British Columbia to evaluate the relative effectiveness of Ultra-Thin Whitetopping versus traditional asphalt rehabilitation of deteriorated or rutted asphalt intersections. The study evaluated 150 intersections in the City of Surrey, B.C. for cost effectiveness of competing rehabilitation strategies using five different life cycle costing philosophies. They are:

1) Maximizing the net Road User Cost savings
2) Comparing direct agency costs to Road User Cost savings
3) Minimizing an agency’s direct agency costs
4) Maximizing the resulting pavement quality
5) Comparing direct agency costs to resulting pavement quality

The city of Surrey was selected for this study because it has a large quantity of data available on its road network.

Of the 150 intersections evaluated, the study determined that UTW was the most cost effective by all 5 philosophies in 36 intersections. UTW was not cost effective by any of the five philosophies for 41 intersections, and UTW was cost effective in the remaining 73 intersections by a few, but not all, of the philosophies. Cost effectiveness of UTW depends on existing asphalt thickness, amount of truck traffic, base and subgrade support conditions, and pavement condition. The most important factors are the existing asphalt thickness and amount of expected truck traffic.

The LCC study in Surrey, BC shows that UTW rehabilitation is extremely dependent on site conditions and traffic volume. If a particular site does not have the required minimum thickness of asphalt and a fairly high volume of truck traffic that will cause rutting of the asphalt, UTW may not be the most cost effective alternative for repair. However, if the site conditions do warrant UTW rehabilitation, the benefits can be substantial.

7. CANADIAN UTW INSTALLATIONS

To date there are twelve UTW installations in Canada. Table 1 summarizes key properties of the various installations and identifies their general performance. To date, all the installations have performed very well except for one under-designed installation in Brampton.

The first UTW installation in Canada took place in Mississauga, Ontario in 1995 to help solve a severe rutting problem at a heavily truck trafficked intersection. As part of the experiment with this new maintenance option the city had two lanes paved with polypropylene fibre-reinforced concrete and one lane paved with conventional OPSS 30 MPa concrete mix. During inspections two and five years after the UTW installation it was recorded that the two fibre-reinforced lanes had shown no visible distress while the non-fibre-reinforced lane had several very slight cracks with no movement along the cracks. In order to assess the performance difference between the sections, limited cores were taken in both the fibre-reinforced concrete (five cores) and non-fibre-reinforced concrete (three cores) lanes. These cores identified the UTW thickness which varied from 118 to 166 mm and the asphalt thickness which varied from 51 to 235 mm. Shear strength tests were also performed and showed that there was no bond between the UTW and underlying asphalt pavement in half of the cores and slight to 0.78 MPa in the other cores. The recommended minimum shear strength is 1.4 MPa. This lack of bond is probably due to no vibrators being used to consolidate the concrete, which would have helped the concrete flow better into the milled asphalt surface and thereby, establish a good bond. It was also observed from the cores that pavement distress is occurring in the areas where there was no bond between the concrete and asphalt pavement. This highlights the importance of obtaining the good bond between the two pavement types to ensure a lasting composite pavement.
<table>
<thead>
<tr>
<th>Project Details</th>
<th>Location</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Mississauga ON</td>
</tr>
<tr>
<td><strong>Type of Use</strong></td>
<td>Intersection</td>
</tr>
<tr>
<td><strong>UTW thickness mm</strong></td>
<td>100mm (design)*</td>
</tr>
<tr>
<td><strong>AC thickness, mm</strong></td>
<td>80mm (design)**</td>
</tr>
<tr>
<td><strong>Joint Spacing, m</strong></td>
<td>1.6m</td>
</tr>
<tr>
<td><strong>Synthetic fibre, kg/m³</strong></td>
<td>Two lanes: 1.6 kg/m³</td>
</tr>
<tr>
<td><strong>General Performance Poor/ Good/ Excellent</strong></td>
<td>Excellent (Lanes w/fibres have fewer cracks)</td>
</tr>
</tbody>
</table>

* Milling depth was increased in certain locations to remove debonded or delaminated asphalt
** Existing asphalt depth varied between different lanes in the intersection
† Curb lane shows signs of cracking due to insufficient thickness of residual asphalt, less than 75mm.
‡ The thin 50mm UTW section performs excellently in the left hand turn lane.
§ Cracks in transition slabs and at utility holes
The next four UTW installations were constructed in Brampton, Ontario. As identified in Table 1, these installations have performed very well with the exception of a portion of the 1999 UTW installation. The curb lane portion of the 1999 Brampton UTW installation had insufficient asphalt under the thin concrete overlay and is showing signs of cracking from the heavy loads operating on it. However, the thin 50 mm section in the left-hand turning lane of this same installation is performing extremely well.

The limited damage noted on the north bound UTW lane of the Campus bus stop in Ottawa appears to be due to insufficient UTW thickness, especially at the transition slab area adjoining the asphalt pavement. It should be noted a thickened edge was not used in this area due to insufficient asphalt thickness. In the future a thickened edge should be considered in these transition zones. Another problem has developed this spring with four or five of the UTW slabs adjacent to a manhole. It appears these UTW slabs have debonded from the underlying asphalt which is deflecting excessively under the bus loads. This may be due to a subgrade failure around the manhole area. It should be noted it was originally recommended using a 100 mm UTW installation in this location due to the high amount of bus traffic, but to meet the need of minimum 75 mm asphalt base after milling, only 75 mm of concrete could be placed in this location.

The Vancouver UTW bus stop is a demonstration project, which uses high volume synthetic fibre reinforced concrete. The unique aspect of this project is no joints are used in the installation as the high dosage of fibres are to used to prevent the need for the short joint spacing which is normally associated with UTW pavements. This installation also used a thickened edge to improve stiffness and strength of the UTW at the transition from asphalt to concrete pavement. A recent inspection of the installation revealed two transverse cracks have occurred in the pavement – one low severity crack extending part way across the slab and one moderate severity crack extending across the entire slab with two corner cracks formed off it. The moderate severity crack is over a utility cut and is most likely due to settlement of the fill around the utility.

8. **SUMMARY**

The recent UTW projects in Canada have provided extensive knowledge about the application of this rehabilitation strategy in the Canadian climate. Although the age of the UTW projects in Canada only range from one to six years, to date, with two exceptions, they have performed very well. The typical features of UTW are shown in table 2.

With every new UTW project, more knowledge is gained about design and construction requirements. If a site is selected for a UTW rehabilitation, it is critical that there be a minimum asphalt thickness of 75 mm or more. The use of fibres has shown to be successful in preventing early shrinkage cracking, extending the time window for saw-cutting joints, and increasing the fatigue characteristics of the pavement structure. Joint spacing should be 10-15 times the UTW thickness to prevent slab cracking due to curling stresses. Fast track concrete mix designs should be used to minimize traffic disruption. Special attention must be given to ensure that the asphalt surface is clean and does not have any debonding or delamination problems so that the UTW overlay will bond well. UTW technology is a viable strategy for rehabilitating distressed asphalt pavements. It is an alternative that restores safety to the roadway, has a competitive cost, and creates minimal traffic disruption. As long as the existing pavement and traffic conditions warrant the use of UTW, it can be a very cost effective rehabilitation strategy.

9. **REFERENCES**

1) American Concrete Pavement Association, “Concrete Information – Ultra-Thin Whitetopping”, IS100P, American Concrete Pavement Association, Skokie, IL, 1998.

Table 2. Typical UTW Features

<table>
<thead>
<tr>
<th>Applications</th>
<th>City streets; intersections, bus terminals, parking lots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>General Aviation Airfield taxiways, runways and aprons</td>
</tr>
<tr>
<td>Design Principles</td>
<td>Bonded composite pavement structure</td>
</tr>
<tr>
<td></td>
<td>Bonding reduces concrete stresses by shifting the neutral axis in the concrete downward and transferring load to the asphalt below</td>
</tr>
<tr>
<td></td>
<td>Closely spaced transverse and longitudinal joints allow slabs to absorb loads through deflection rather than bending and alleviate curling stresses</td>
</tr>
<tr>
<td>Pavement Structure</td>
<td>50 to 100 mm thick concrete overlay on top of milled asphalt (minimum 75 mm of remaining asphalt)</td>
</tr>
<tr>
<td></td>
<td>Joint spacing is 10 to 15 times the UTW thickness</td>
</tr>
<tr>
<td></td>
<td>Dowels and steel reinforcement are not used, joints are not sealed</td>
</tr>
<tr>
<td>Concrete Mix</td>
<td>Fast track concrete mixes are used</td>
</tr>
<tr>
<td></td>
<td>Strength of 20 MPa in 24 hours for opening road to traffic</td>
</tr>
<tr>
<td></td>
<td>Synthetic fibres, 19mm long, are specified to increase strength, durability, and prevent early shrinkage cracking, recommended dosage 2.7-5.3 kg/ m²</td>
</tr>
<tr>
<td>Construction</td>
<td>Slip-form or fixed-form paving operations</td>
</tr>
<tr>
<td></td>
<td>Asphalt surface must be clean in order to achieve a good bond</td>
</tr>
<tr>
<td></td>
<td>Early (green) saw-cutting of joints to prevent shrinkage cracking</td>
</tr>
</tbody>
</table>