1. Introduction

Whitetopping, a relatively thin concrete overlay placed atop distressed asphalt pavement, was introduced in the United States in 1918 and its use has continued through today [1]. Traditional whitetopping consists of full-depth concrete slab (90-255mm thick) designed with conventional design procedures, simply factoring in the current asphalt pavement as a base in an unbonded scenario [2]. In 1991, a new form of whitetopping, ultra-thin whitetopping (UTW), emerged, which relies on a bond with the distressed pavement to act as a composite, significantly decreasing the load-induced stresses imposed on the concrete and strains induced on the asphalt.

This technical note begins with a literature review to outline the theories behind UTW overlays and the prominent failure mechanism. Then, a case study in which an UTW overlay was used to restore the Spirit of St. Louis Airport after a major flood is presented. Lastly, a cost analysis study was conducted and compared to similar cost analyses.

2. UTW Theories

To ensure that an UTW pavement system will perform satisfactorily throughout its entire design life three factors are required: a bond between the existing asphalt pavement and the UTW overlay, short joint spacings, and appropriately thick layers of UTW overlay and existing asphalt [1, 3]. Other issues of extreme importance are the concrete mix design and the construction processes.

2a. Bond

Of all of the UTW overlay design and construction considerations, proper bond between the UTW and the asphalt is of utmost importance as, without it, the other design parameters are void. Without proper bond, the UTW and asphalt no longer act monolithically, leaving a structurally insufficient system which will underperform and
likely fail well before the end of its design life. Unlike the other design parameters (joint spacing, saw-cut width, overlay thickness, etc.), the bond is not definitively defined and high variability in the bond can occur. Once the bond is such that the tensile stress of the concrete/asphalt interface exceeds its tensile strength, debonding will occur.

A finite element analyses showed that along the free edge of the concrete slab the maximum tensile stress was decreased 66% in the bonded versus unbonded cases and near the corner of the concrete slab the maximum tensile stress was decreased 40% in the bonded versus unbonded cases [1]. Figure 2-1 is an illustration of the effects of bonding for these two scenarios. The key mechanism for such drastic changes in stress is the movement of the neutral axis downward as the system shifts from a two layer scenario to a composite, where they act monolithically. As the bond increases for the middle and edge cases, the neutral axis will move from the middle of the concrete overlay down towards the bottom of it, greatly decreasing the stresses imposed at the bottom face. For the corner case, the maximum tensile stress occurs at the top surface of the slab, as the corner behaves like a cantilever. The shift downward in the neutral axis will effectively increase the stress at the top surface but the effective stress will decrease even more due to the composite action, resulting in an overall less stress. If the neutral axis shifts far enough down in the concrete, the critical load can move from the edge to the corner, a realistic event as all field tests exhibit this behavior in the form of corner cracking [3].

![Figure 2-1. Effects of bonding on concrete stresses [3].](image-url)

2b. Joint Spacing

All pavement systems are designed to absorb the energy applied to them due to loading and environmental forces. In traditional concrete pavements, this energy is absorbed by way of bending, causing the design thicknesses to be relatively high. In UTW pavements, this energy is absorbed by way of deflection instead of bending, only possible because the concrete lies on an asphalt base. The short joint spacing will reduce the moment arm of an applied load, greatly reducing the applied moment, as well as minimizing stresses due to curling and warping, caused by environmental forces. The UTW sections effectively act as minipaver blocks (similar to the brick roads of the past) which transfer the load to a flexible pavement rather than absorbing the energy through their own bending [3]. This mechanism is illustrated in Figure 2-2.
Typical joint spacings reported lie between 0.6m and 1.5m and it is recommended that the maximum joint spacing for UTW overlays be between 12 and 15 times the slab thickness [4]. The objective of such short crack spacing is to absorb the energy in deflection and not bending, as aforementioned, to ensure that cracks only form at the joints, leading to a smooth pavement system for the entire design life [5].

2c. Thicknesses of UTW Overlay and Existing Asphalt

The thicker the existing asphalt pavement can be after milling, the thicker the overall cross section becomes, further shifting the neutral axis downward and leading to a greater load carrying capacity of the system. The thickness of the UTW layer is less crucial, as it is not designed to carry the load itself. In short, there needs to be sufficient UTW concrete thickness to protect the asphalt from excessive deformation and sufficient asphalt thickness to protect the UTW concrete from excessive stresses [3]. For an UTW overlay thickness of 100mm, if the asphalt thickness is doubled from 50mm to 100mm, the tensile stress in the concrete is more than halved, shown in Figure 2-3 [5]. An analysis similar to this should always be conducted to investigate the required UTW overlay thickness for the expected, surface prepared asphalt thickness.
2d. UTW Concrete Mix Design

As with any concrete pavement construction project, the concrete mix must be designed per the project requirements. UTW concrete mixes require the inclusion of a synthetic fiber, such as polypropylene fibers [3], not typical of normal concrete pavement mixes due to their high cost. Since the thickness of UTW is so much less than that of full-depth concrete pavements, its relative cost is easily justified due to its benefits, despite typical fiber dosages being roughly double the dosage used in industrial slabs [2].

Due to the relatively small thickness of UTW overlays, there would not be sufficient cover depth for a wire mesh reinforcement system to be utilized. The fibers used in UTW overlays can be substituted in place of a wire mesh system to provide multidirectional reinforcement which will absorb the energy due to of loading, shrinkage, impact, freeze-thaw, etc [2]. The increased ability to absorb energy will increase the postcrack integrity of the UTW panels and also decrease the permeability of the concrete [2, 3].

2e. Construction Practices

Excellent bonding between the UTW overlay and the existing asphalt is not possible without proper surface preparation. Typical surface preparation includes milling and cleaning of the surface in order to improve the roughness of the bond surface, promoting bond, although water or abrasive blasting are also used. Between preparation of the surface and placing of the UTW overlay, special attention should be paid to avoid dust, debris and dirt contamination from outside sources such as the wind and construction vehicle traffic. If the surface is cleaned the day before paving, air cleaning should be used to remove any subsequent contamination [3].

Placing, finishing and texturing an UTW overlay is no different than for conventional concrete pavement. Slip-form and fixed-form pavers can be used as well as handheld equipment such as vibrating screeds [3]. Curing procedures, however, are much more crucial for UTW overlays than for conventional concrete pavements. Because the UTW overlay is so thin, it has a surface-area-to-volume ratio making it especially susceptible to rapid moisture loss due to evaporation, leading to shrinkage cracking and more importantly, debonding [3, 5]. In an effort to prevent this, curing compound is applied at twice the typical rate to all exposed edges while not allowing the curing compound to contaminate any unpaved, surface prepared asphalt [1, 3].

Joints should be sawed into the UTW overlay at a depth of one-fourth to one-third of the total depth of the overlay, as early as possible and with a lightweight saw. Because tests have shown that the compact size of the slabs minimizes joint movement, the joints are not typically sealed [5]. To prevent incompressibles from causing damage to the joints, the cut width should be around 3mm wide [3]. The short joint spacing serves an indirect convenience, as they lead to easy rehabilitation of structurally insufficient slabs because the compactness allows individual slabs to be easily removed [5].
3. Failure Modes

According to a survey, corner cracking is the most common distress type in UTW overlays. Corner cracking can be a result of either wheel loading alone or in combination with another distress. For example, wheel loading and permanent deformation of layers below the corner and wheel loading and debonding of the whitetopping overlay from the existing HMA layer can both cause corner cracking [6]. The primary source of corner cracking is believed to be a loss in support due to permanent deformations in the support layers. Figure 3-1 illustrates how repeated loads can lead to permanent deformation in the HMA layer. This void will in turn cause a cantilever effect which increases the stresses in the surface of the UTW overlay until the fatigue limit is reached, resulting in cracking [6]. Other failure modes include joint or crack spalling, faulting, and mid-slab cracking but these are not discussed herein since they are relatively uncommon in UTW.

![Figure 3-1. Illustration of the development of a corner crack for UTW overlays [6].](image)

4. UTW Overlays at the Spirit of St. Louis Airport

The first use of UTW overlays at an airport in the United States was in 1994 at the Spirit of St. Louis Airport, which accommodates over 1,000 takeoffs and landings daily. In an effort to relieve traffic from Lambert Airport, a six-acre asphalt apron, designed for light aircraft, was often overloaded with medium-sized planes (DC-9s, B-727s, etc). This overloading caused severe deterioration and after being submerged in over 9 feet of water in the Great USA Flood of 1993, the apron was deemed unusable. Several rehabilitation plans were proposed including complete reconstruction and overlaying with asphalt or concrete. In the end, a feasibility study favored whitetopping and a complete rehabilitation was made in 1994 by utilizing a whitetopping/UTW mixture.
The whitetopping/UTW mixture was necessary to address challenges of designing for both heavy and light aircraft. The 45,000 square-yard area was divided into three types of areas: a heavy-load area for up to 120,000 pound aircrafts which consisted of a 10-inch PCC whitetopping and comprised 15,000 SY of the apron, a medium-load area for up to 70,000 pound aircrafts which consisted of an 8-inch PCC whitetopping and comprised 7,200 SY of the apron, and a light-load area for up to 12,500 pound aircrafts which consisted of a 3.5-inch UTW overlay and comprised 14,000 SY of the apron.

The UTW overlay was placed atop a 3.5-inch asphalt and 6-inch to 7-inch subbase with joint spacings of 4-foot, 2-inches. The minimum flexural strength was specified at 675psi and the fiber dosage was 3 pounds per cubic yard of polypropylene fibers for the UTW PCC. The existing asphalt surface was rotomilled and air blasted in preparation for the overlay, which was placed using a slipform paver that could adapt to the varying overlay thicknesses. The joints were often cut at night, to keep the project on schedule, and then sealed with silicon to prevent jet fuel from eroding the asphalt base. A minimum of 1 gallon per 100 square feet of curing compound was placed to aid in the curing process [7].

Load testing was conducted both the spring and fall after construction and strains were recorded at the center and edges of test slabs. Results included that center loading and joint loading produced similar pavement responses, spring and fall test results displayed little difference despite quite different temperature gradients, and strains observed under free edge loading were considerably greater than center or contraction joint strains. Surface profile measurements showed that negligible vertical movement occurred for either the spring or fall case, despite significant temperature gradients, which is likely due to the short joint spacing. The interface shear strength (cores sampled in the spring) was found to be more than adequate for a bonded composite pavement system, further substantiated by the excellent long term performance as after 6 years of service, only 18 of the more than 7,200 UTW panels exhibited any form of distress (typically corner cracking) and non of these warranted repair or effected serviceability. All of the joint sealants and joints were also found to be in very good condition after 6 years [8].

5. Cost Analysis

A simple cost analysis was performed to compare rehabilitating a distressed asphalt pavement with either an UTW or an asphalt overlay. For concrete, the total cost including material, labor and equipment is $144/CY and for asphalt, the total cost including material, labor, and equipment is $70/CY [9]. As previously discussed, any UTW overlay is between 2 and 4 inches thick so at 3 inches, the total cost is approximately $36/yd$^2$ and an asphalt overlay thickness is between 1.5 and 2.5 inches [10] so at 2 inches, the total cost is approximately $12/yd^2$. These numbers agree well with a similar cost comparison conducted by the Tennessee DOT which showed the costs of an UTW overlay at $32.00/yd^2$ and the cost of a HMA overlay at $8.00/yd^2$ [2].
The UTW overlay has a higher initial cost but if this comparison takes place in a scenario in which the asphalt requires replacement every two years due to extensive rutting and shoving, then the 10 year life cycle cost of the asphalt overlays would be around $60/yd$^2$ and only $35/yd^2$ for the UTW overlay, showing it to be cost effective. A TDOT study indicated that the concrete is the more cost-effective of the two if it lasts at least two to four times as long as the HMA (approximately 8 to 12 years), which is believed to be probable by the TDOT [2]. In Iowa, a more comprehensive cost comparison study (considerations included that UTW overlays require less time to construct and that UTW overlay repairs last much longer than conventional asphalt rehabilitation techniques) on UTW overlays showed that this system costs up to 50% more than a HMA overlay, but the concrete pavement can easily last twice as long as HMA [11].

UTW overlays have proven to be a low-cost, effective, and fairly simple rehabilitation solution. Once constructed, UTW overlays require little maintenance with no seasonal weakening, and repairs can be performed on single panels, keeping the maintenance costs down. UTW overlays can also provide cost benefits in other areas; for example, their surfaces reflect lights, unlike asphalt pavements, leading to cooler pavements and reduced lighting costs [11].

6. References