Technical Paper

ISSN 1997-1400 Int. J. Pavement Res. Technol. 8(4):267-275

Evaluation for UTBWC on SR-11 as Pavement Preservation Treatment: A Case Study

Yigong Ji[1+], Tommy Nantung[1], and Bill Tompkins[2]

Abstract: State highway agencies are facing immense pressure to maintain roads at acceptable levels for drivers amidst challenging financial and economic situations. Pavement preservation has been sought as a potential alternative for managing the pavement assets. This paper aims to present the functional and structural benefits of the Ultrathin Bonded Wearing Course (UTBWC) applications as a pavement preservation strategy on highway sections in Indiana. To achieve this goal, comprehensive monitoring and data analysis were performed using the Pavement Condition Rating (PCR), Structural Number (SN), and International Roughness Index (IRI) for in situ performance evaluation on UTBWC and the four control sections (SR-58, SR-69, SR-68, and SR-145). The cost study indicated that UTBWC would be deemed cost-effective if it could provide more than 3.6 years of service life, and resurfacing would be deemed cost-effective if it could provide more than 3 years of service life. The study results demonstrate that UTBWC is not as cost effective as resurfacing; however UTBWC can still address pavement distresses and can extend pavement life in general.

DOI: 10.6135/ijprt.org.tw/2015.8(4).267

***Key words**: International roughness index; Pavement condition rating; Structural number; UTBWC.*

Introduction

State highway agencies are facing immense pressure to maintain roads at acceptable levels for drivers amidst challenging financial and economic situations. In recent years, pavement preservation has been sought as a potential alternative for managing pavement assets due to the belief that it could provide a cost-effective solution for maintaining infrastructural conditions and meeting user expectations. Pavement preservation consists of applying preventative maintenance to a roadway before it has deteriorated to an unacceptable level; preservation maintains structural integrity and extends the service life of roadways, decreasing costly rehabilitation. Dean and Baladi [1] found out that for the pavement projects that received certain types of treatment in the past, knowledge of the relationships between the before- and after-treatment distributions of the pavement's surface condition and distress was crucial to the establishment of a future cost effective strategy for pavement treatment.

Ultrathin Bonded Wearing Course (UTBWC) is one of these promising applications. It is a pavement treatment in which a polymer modified emulsion membrane is applied to existing pavement, then immediately covered with a thin course of open-graded hot mix asphalt (HMA). The emulsion membrane seals the existing surface and produces high binder content at the interface of the existing roadway surface and the gap- or open-graded mix all in one pass. The gap-graded and open-graded mixes provide an open surface texture to allow water to flow through the surface. This mixture can be used to correct the profile of a roadway and to provide adequate frictional properties to polished pavement that may be structurally sound. After its introduction in the United States in the early 1990s, projects were initiated in Alabama, Mississippi, and Texas in 1992. Hanson [2] reported on one of the initial U.S. UTBWC applications in Pennsylvania in which the International Roughness Index (IRI) went from 2746.4 to 1905 mm/km (173 to 120 in./mile) following application of the UTBWC. The IRI at this site rose to 138 within 5 years of placement of the wearing course. After reviewing five projects in Pennsylvania, Texas, and Alabama, Hanson [2] concluded that it provides a surface with excellent macro texture qualities, good aggregate retention, and excellent bonding of the very thin surfacing to the underlying pavement. In a North Carolina study [3], it was found that a treatment could extend the life of PCC (Portland cement concrete) pavements that are already more than 30 years old by 6 to 10 years. Nationwide research [4] has shown that UTBWC reduces deterioration caused by weathering, oxidation, traffic and provided good skid resistance, reduced rolling noise, reduction of hydroplaning, and back spray from roadway. UTBWC does not increase the structural capacity of the pavement.

The Indiana Department of Transportation (INDOT) maintains more than 25,000 lane miles of state highway pavement, which has led INDOT to change its emphasis from construction to preservation of highways. Meanwhile, facing staff and budget shrinkages and the need to increase pavement quality and life-cycle performance [5], INDOT is finding that pavement preservation offers an alternative way to improve performance with a decreased budget; therefore, pavement preservation is receiving a new level of attention. Accordingly, INDOT is actively establishing an effective pavement preservation program that includes mill and fill, UTBWC, microsurfacing, and chip sealing that are applied in a cost-effective and efficient manner. Lee et al. [6] provide treatment guidelines for the INDOT pavement preservation program based on literature reviews and a review of current practices in Indiana. A complete copy of the INDOT specification for UTBWC is available on the

[1] INDOT Office of Research and Development, 1205 Montgomery Street, West Lafayette, Indiana 47906, USA.

[2] INDOT Highway Management, 100 N. Senate Ave, Indiana, 46204, USA.

[+] Corresponding Author: E-mail yji@indot.in.gov

Note: Submitted December 3, 2014; Revised May 4, 2015; Accepted May 5, 2015.

Joint Transportation Research Program website (https://engineering.purdue.edu/JTRP). Ong et al. [7] developed a framework for pavement preservation implementation within the state of Indiana. Therefore, it is necessary for INDOT to initiate a case study to identify all kinds of pavement preservation strategies that may affect the long-term performance of a pavement. In 2009, INDOT began experimenting with UTBWC on SR-11. After 3 years' monitoring, the assessment on UTBWC in conjunction with two control and two milling/filling sections has been completed. For each project, the distresses on the pavement will be described and the results of the pavement condition survey before placement of the UTBWC will be shown. Survey results and other test results following the preservation treatment will be used to assess the effectiveness of the UTBWC for that project.

Objectives and Scope

The purpose of this study was (1) to document the materials and the construction procedures utilized in the construction of the UTBWC in Indiana; and (2) to evaluate the performance of UTBWC surface treatment on SR-11 in Jackson County, Indiana for a period of 3 years.

For comparison purposes, a control section was established to assess the performance of the mill and fill and no treatment at all. The primary concern was to identify UTBWC that could improve pavement performance of asphalt pavement by positively affecting the Pavement Condition Rating (PCR), Structural Number (SN), and International Roughness Index (IRI). The surface roughness and condition of these sections have been monitored on a yearly basis.

Test Site Selection

Pavement preservation is a method by which roads are treated before significant failure has occurred. It enhances pavement performance by using a variety of cost-effective surface treatments that extend pavement life. Choosing the right treatment can make the best use of funds and provide smooth, safe roads while avoiding costly reconstruction and extended road closures. Surface treatments are preventive and corrective maintenance; therefore, the site should have sound structure. These treatments must be carefully selected and applied before the pavement sustains structural damage. INDOT personnel, including materials, design, planning and programming, and maintenance staff, were involved in the selection.

For comparison purposes, four projects were established to assess the pavement performance. The first project was a UTBWC treatment on existing full-depth asphalt pavement. The second and third involved resurfacing a full-depth asphalt pavement. The remaining two projects involved full-depth asphalt pavement without any treatment. For each project, the distresses on the pavement will be described and the results of the pavement condition survey before placement of the UTBWC will be shown. Survey results and other test results following the preservation treatment will be used to assess the effectiveness of the UTBWC. Fig. 1 shows the locations for five projects.

INDOT design specification [8] categorizes the traffic volume for pavement thickness design. In general, these pavements are categorized as medium traffic; that is, 57 < AADTT < 570 (or 0.3 million ESALs < Traffic < 3 million ESALs. Therefore, this paper assumes that the traffic has no significant effects on the pavement performances.

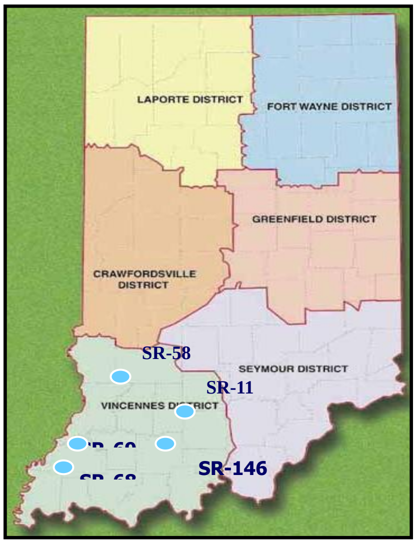

Fig. 1. Project Location Map.

SR-11—UTBWC Section

The SR-11 section is located in Jackson County, Indiana. It is a two-lane highway with a 254 mm (10 in.) thick asphalt and is approximately 12.9 km in length. Weigh in motion (WIM) data from INDOT show that the traffic volume through the test sections in 2006 was approximately 3,000 vehicles per day with about 5% trucks. The section was treated in 1999 with Partial 3-R (Resurfacing, Restoration, and Rehabilitation), it was because the threshold values of Partial 3-R could not reach full 3-R and because of constraints in construction time, pavement conditions, and cost. In 2009, The IRI was 2000.25 mm/km (126 in./mi.) on the northbound (NB) lane and 1889.13 mm/km (119 in./mi.) on the southbound (SB) lane. Before placement of the UTBWC, the PCR was 75. A site visit showed low to medium severity block cracking, longitudinal wheel path cracking, and transverse cracks over most of the length of the project. Centerline joint openings with medium severity were also found. Some areas of the surface showed signs of aging and oxidation.

SR-68 and SR-145—No Treatment Section

SR-68 is located in Warrick County, Indiana, and is between SR-57 and SR-6. This site is approximately 14.1 km in length. The two-way average daily traffic in the area is 1691 with 4% truck traffic. The thickness of HMA is 20.32 cm (8 in.). The section consists of one lane in each direction. The construction took place during the summer of 1997. Eleven years after construction, cracking appeared on the pavement surface. Slight to moderate oxidation showing hairline cracks for most of the road, including minor raveling for one of the sections, was observed. In some sections, some minor, low to medium severities have shown up. Longitudinal cracking also developed on some of the test sections. Low severity longitudinal and some low to medium severity block cracking were noted in some areas. On the eastbound (EB) lane, there was one section with some minor, low to medium severity transverse cracks.

SR-145 is approximately 27.3 km in length. This two-lane highway lies between SR-64 and SR-56 in Crawford and Orange counties, Indiana. The thickness of 27.94 cm (11 in.) of full-depth asphalt pavement was constructed in 1997. Traffic is estimated at more than 1550 ADT per day with 8% trucks. After 11 years in service, there were some transverse, longitudinal block cracks observed on the pavement. The crack severity was generally low to moderate, including low severity longitudinal cracks and signs of minor rutting. The surface was aged and oxidized. Very little raveling had occurred. Water was seeping out of a longitudinal construction joint in the center yellow line.

SR-58 and SR-69—Mill and Fill Section

SR-58 is located in Greene and Lawrence counties, Indiana. The 9 in. of full-depth asphalt is 12.2 km in length. It was reconstructed in 1993. Traffic is estimated at more than 2,481 ADT per day with 8% trucks. The first site visit was in January 2008. Medium to high severity fatigue cracks and signs of rutting in some area were found. The surface was aged and oxidized and showed raveling.

SR-69 is located in Posey County, Indiana. The 38.1 cm (15 in.) of full-depth asphalt is 3.2 km in length. It was reconstructed in 1993. Traffic is estimated at more than 3,500 traffics per day with 8% trucks. The first site visit was in January 2008. Low to medium severity longitudinal cracks and signs of rutting were found. The surface has medium transverse, moderate raveling, and block cracking.

Construction Activities

SR-11 UTBWC

The UTBWC on SR-11 was constructed in October 2009 and was completed in March 2010. Since the construction spanned the whole winter, the day temperature could be as low as 30°F on some days. (It should be noted that the UTBWC usually should not be applied when the temperature of the pavement or air is below 60°F. The first step of surface preparation is to restore the pavement’s structural integrity and functional performance characteristics through patching and crack sealing. At the same time, thermoplastic road markings must be removed prior to placing a UTBWC.) On SR-11, the polymer modified emulsion membrane was sprayed by a metered mechanical pressure spray bar at a temperature of 48.9–82.2℃ (120–180°F) with a target emulsion shot rate of 0.108–0.153 L/m^2 (0.12–0.17 gal/yd^2); it was accurately and continuously monitored during the spray in order to provide a uniform application across the entire width to be overlaid. (The engineer may make adjustments to the spray rate based on the existing pavement surface conditions and the recommendations of the polymer modified emulsion membrane supplier.) The contractor used machines to mix and place the UTBWC materials, which consisted of gap graded course aggregate hot mix asphalt over a heavy asphalt emulsion layer. The gradation of the job mix formula (JMF) for the mixture is given in Table 1. Trial 3 is decided to put in use. PG 70-28 asphalt cement was used for coating the mixture. Maximum size of the aggregate is 9.5 mm, and it is always 100% crushed. The HMA concrete was applied at a temperature of 143.3–165.6℃ (290–330°F) and laid over the polymer modified emulsion membrane immediately after its application. Rolling of the wearing course consisted of three passes with a steel double drum asphalt roller of a minimum weight of 10 tons. Rolling immediately followed the placement of the UTBWC. The thickness of the UTBWC is 18 mm (0.7 in.).

Table 1. Job Mix Formula for SR-11.

	Source		
Sieve (mm)	Trial 1	Trial 2	Trial 3
½ " (12.5 mm)	100	100	100
½ " (12.5 mm)	100	100	100
⅜" (9.5 mm)	82	100	100
4 (4.75 mm)	16	94	100
8 (2.36 mm)	3	61	91
16 (1.18 mm)	3	44	76
30 (0.6 mm)	2	33	51
50 (0.3 mm)	2	27	15
100 (0.15 mm)	2	23	5
200 (0.075 mm)	1.5	18.6	3.5

The quality control process for the ultrathin bonded HMA mixtures should generally follow the INDOT specifications [6]:

1. Strip testing: Based on the strip test, the emulsion spray is calibrated and the target application rate should be determined;
2. UTBWC application: Paver should spray emulsion, apply overlay, and level surface all in one pass;
3. Rolling: A 10-ton steel double drum roller with two passes is adequate. Rollers should run only in static mode; and
4. Curing: To avoid tracking, applied emulsion should be sufficiently cured before traffic is permitted.

SR-58 and SR-69 Mill and Fill

Thin HMA mill and fill is a process that improves surface condition by milling the existing pavement with minor deterioration to a certain depth and then filling it with a new HMA mixture to the original surface elevation or slightly higher. HMA mill and fill and HMA overlay are considered the pinnacles of pavement preservation treatments. They may be used to (a) extend pavement life; (b) improve riding quality; and (c) correct surface defects. This thin HMA overlay effectively addresses most of the functional deficiencies that may occur on an existing HMA pavement. Therefore, it is best placed on pavements in relatively good condition and where there are no signs of significant structural deterioration.

The purpose of mill and fill at SR-58 and SR-69 is to mill the existing pavement with minor deterioration to a certain depth and then fill it with a new HMA mixture to the original surface elevation or slightly higher. Mill and fill on SR-58 and SR-69 consisted of milling a 1 in. (25 mm) thickness of HMA off the entire road and constructing a 1.5 in. (38 mm) thick layer of new HMA surface over the road and shoulders. INDOT specifies that the asphalt binder is

PG 64-22 and the aggregate sizes for HMA are dense grade (DG) ⅜ in. (9.5 mm), following the pavement preservation guidelines [6]:

1. Preparation: Clean existing pavement of all loose materials;
2. Milling: Mill the existing surface. (The typical milling depth is 1.0 in. (25.4 mm) and the minimum is scarification.);
3. Tack coating: Place a light tack coat on the vertical faces and base of the milled area (prior to filler);
4. Filling: Fill with HMA mixture in uniform lifts. (The typical filling thickness is 1.5 in. (38.25 mm)); and
5. Rolling: Compact by rolling with a minimum of three passes.

Annual Evaluation

A study conducted a pavement condition survey [9] annually for these five sections (SR-11, SR-58, SR-68, SR-69, and SR-145). During the survey, after construction, the first 100 m (330 ft.) section of every mile (1.6 km) was evaluated for transverse, longitudinal, and fatigue cracking, as well as bleeding, patching, and sealing. Pavements were visually inspected to assess conditions within each test section and ranged from good to very poor in both 2010 and 2011, following the first visit in 2009.

The SR-11 site visit after construction showed that pavement surface overall is in good shape after the UTBWC treatment; few of the several low to moderate transverse cracks over the length of the project, which appeared to be a reflection of underlying distress, extend the entire pavement width. Particularly, transverse cracks appeared in an area close to Reference Point (RP) 34, which has a pipeline underneath. It was also found that low severity transverse cracking in the middle of two wheel paths at RP 33 was evident. No stripping or delamination has occurred, and the pavements had no premature failure. The UTBWC appeared to be adhering well to the existing HMA pavement surface.

In the site visit in June 2011, low severity and low extent transverse cracking were found throughout the project. The transverse cracks are still there in the shallow culvert underneath. Slight bleeding/flushing in the wheel path was found during this visit at the east junction of SR-11 and County Road 200M, which may be due to deceleration or acceleration of traffic. The existing HMA pavement surface had no stripping or delamination in other places, which shows that the bond between the old and new surfaces is in good shape.

Control Sections

Control section pavement management system (PMS) network data for IRI and FWD was used as a baseline. SR-68 showed that low to moderate cracking had continued to develop on all of the sections, and crack intensities were progressing more rapidly than expected. Compared to the 2008 visit, oxidation and raveling with moderate severity was observed in 2009 and 2010. Longitudinal cracking and block cracking had also developed on some of the test sections. However, there was no sign of degrading. SR-145 showed that crack severity was still generally low to moderate at in 2009. Cracks were not sealed with emulsion in some areas. The wide openings served as entrances for water to enter the pavement, and therefore caused the asphalt near the cracks to deteriorate in 2012. The deterioration of the joint, in turn, further accelerated the pavement deteriorations. This apparently accelerated the cracks. In some places, cracks were sealed with an asphalt-rubber crack sealant and conventionally with emulsion; this seemingly helped to prevent the cracks from becoming severe. SR-58 and SR-69 were resurfaced with mill and fill in late September 2008 and May 2009. The overall appearance of the resurfacing was good. There was no sign of degrading at the 2009 site visit and very little transverse cracking at the 2010 site visit.

Test Method and Procedures

After completion of the comprehensive in situ monitoring, a thorough field data analysis was performed, including pavement structure analysis (SN), PCR, and IRI each year.

Structural Evaluations

The Structural Number (SN) represents the overall structural requirement needed to sustain the design's traffic loadings. It is an abstract number that expresses the structural strength of a pavement required for given combinations of soil support (resilient modulus of subgrade, MR), total traffic (ESALs), terminal serviceability and environment [10, 11]. FWD tests were conducted in 2009, 2010, and 2011 in order to evaluate structural adequacy. Tests were conducted in the driving lanes in both directions at 100 meter intervals. Based on previous INDOT studies and experiences, a minimum of 16 testing locations per mile is adequate to provide statistically sound analysis. Three drop load levels consisting of 31.3 kN, 40.0 kN, and 48.9 kN (7 kip, 9 kip and 11 kip) were used. Only the 40 kN (9-kip) load level was used for the analysis. To determine the SN for the total layer (HMA, base, and subbase), the relationship between the effective modulus (E_p) and the effective SN (SN_{eff}) was calculated as follows [11]:

$$SN_{eff} = 0.0045 D \sqrt[3]{E_p} \tag{1}$$

where, SN_{eff} = effective SN; D = total thickness of all pavement layers above the subgrade (inches); and E_p = effective modulus of pavement layers above the subgrade (psi).

Pavement Roughness

Pavement roughness has long been used as one of the primary indicators of pavement condition. It is the principal measure of public satisfaction within the highway system; thus, the as-built roughness of a pavement immediately after construction is a key measure of the road quality. To evaluate pavement roughness, the IRI was computed; the higher the IRI, the rougher the roadway. The IRI is determined by measuring the profile of the road and passing it through an algorithm or filter known as the quarter-car model. Roughness measurements were made with an inertial profiler (IP) system, which is a vehicle-mounted, laser-based inertial pavement profile measuring system. The roughness results from the IP system were derived from the pavement profile, which is measured at intervals of approximately 100 mm.

Pavement Conditions

The PCR is based on a visual inspection of the condition of the pavement by trained raters [9, 12]. The rater measures pavement distresses in terms of severity and extent and then deduction points are subtracted for each type, extent, and severity of distress from a perfect condition of 100 points. The distresses included in the ratings are alligator cracking, edge cracking, block/transverse cracking, reflective cracking, rutting, raveling, bleeding, ride quality, and patching. To determine the PCR of asphalt pavement, each distress and weighting factor is set, and every distress has a distress weight. For each distress there is a severity (high, medium, or low) and an extent (occasional, frequent, or extensive). Each severity corresponds to a weighting factor between 0 and 1, and each extent also has a weighting factor between 0 and 1. The distress weight is multiplied by the distress's severity and weighting factors in order to obtain the deducted value for a given distress. Then the PCR for a pavement is obtained through the procedure where the sum of all distress deductions is subtracted from 100.

Comparative Statistics

This study included investigation of UTBWC and some control sections. Nondestructive testing was conducted on trial sections of the highway. The detailed investigation concentrated primarily on analysis of the pavement data collected pre- and post-construction of the UTBWC and on four control sections. For each project, the distress on the asphalt will be described, and the results of the pavement condition survey will be shown. Survey results and other test results following the preservation treatment will be used to assess the effectiveness of UTBWC in pre- and post-construction. Evaluation of pavement surface conditions and nondestructive testing of pavement included measuring IRI, surface deformation (rutting), transverse cracking, longitudinal cracking, and friction number.

To assess the effectiveness of UTBWC, two types of methods were used for overall statistical analysis in this paper. One is analysis of variance (ANOVA) testing, which makes a comparison between the mean values and variances in each testing year. The other type of method is based on the T-test, which provides confidence intervals (CI) that provide designers with more reliable design parameters, as well as mean and standard deviations.

Structural Number (SN)

Nationwide research has shown that UTBWC does not increase the structural capacity of the pavement; however, the use of UTBWC on old pavements as a wearing course could be considered. Evaluation of the SR-11 UTBWC project should be continued on a yearly basis in order to have a better understanding of UTBWC structural performance. FWD testing for SR-11 was performed to determine the pre- and post-construction strength of the pavement structure in April 2009, June 2010, and July 2011. A total of 129 FWD tests were carried out on the NB pavement surface. The summary of analysis is presented in Table 2. The SN ranged from 2.65 to 2.90 with a mean of 2.78 in April 2009 (pre-construction). The SN ranged from 2.78 to 3.19 with a mean of 2.99 in June 2010 (post-construction). An ANOVA was carried out to compare the SN differences between these two and found that the results were no statistically different, indicating that the pavement structure after UTBWC was similar to the pavement structure before UTBWC ($F = 0.89 < Fcrit = 3.88$, $P = 0.34$). On the other hand, the mean SN in 2010 was 2.99, whereas the mean SN in 2011 was 2.81, meaning it decreased 0.18 in structural capacity. However, the ANOVA also showed that there was no statistical difference in the strength of the pavement structure between 2009 and 2010 ($F = 0.93 < Fcrit = 3.90$, $P = 0.33$).

In the SB lane, a total of 128 FWD tests were performed on the pavement surface. In June 2008, the SN ranged from 2.62 to 2.88 with a mean of 2.75 (pre-construction). Similar to the NB lane, SN values of SB at pre- and post-construction were not significantly different ($F = 0.85 < Fcrit = 3.88$, $P = 0.03$). There was no difference ($F = 0.19 < Fcrit = 3.88$, $P = 0.66$) between 2009 and 2010.

Table 3 listed SN annual variations for SR-58 and SR-69. FWD testing was performed to determine the SN at the pre- and post-resurfacing construction of SR-58. A total of 121 FWD tests were carried out on the pavement EB surface. Before resurfacing (June 2008), the mean of the SN was 2.24 with a range between 2.19 and 2.29. After resurfacing (October 2009), the SN jumped to a range of 2.53 to 2.67 with a mean of 2.59. The SN values kept constant with 2.53 after 1 year (July 2010). An ANOVA was carried out to compare the SN results for the UTBWC and found that the results were statistically different between 2008 and 2009 ($F = 59.04 > Fcrit = 3.88$, $P = 0.01$), indicating that the pavement structure after resurfacing was slightly stronger than the pavement structure before resurfacing. SN values between 2009 and 2010 were not statistically different, indicating that the SN still keeps constant. The same is true in the years of 2010 and 2011.

Table 2. Summary Statistic of SN at SR-11 UTBWC.

	Northbound			Southbound		
	Before construction April 2009	After construction June 2010	One year after Construction July 2011	Before construction April 2009	After construction June 2010	One year after Construction July 2011
Mean	2.78	2.99	2.81	2.75	2.94	2.88
Standard Deviation	0.69	1.15	1.00	0.70	1.07	1.04
Interval Lower Limit with CI 95%	2.65	2.78	2.64	2.62	2.73	2.69
Interval Upper Limit with CI 95%	2.90	3.19	2.99	2.88	3.12	3.02

Note: CI: Confidence Intervals

Table 3. Summary Statistic of SN at SR-58 and SR-69 Resurfacing.

Road	SR-58				SR-69			
Year	June 2008	Oct 2009	Jul 2010	Aug 2011	June 2008	Oct 2009	Oct 2010	Sep 2011
Mean	2.24	2.59	2.53	2.61	5.71	6.62	5.89	5.88
Standard Deviation	0.24	0.41	0.35	0.35	0.77	0.47	0.50	0.49
Interval Lower Limit with CI 95%	2.19	2.53	2.48	2.48	5.22	6.48	5.77	5.67
Interval Upper Limit with CI 95%	2.29	2.67	2.60	2.60	5.90	6.76	6.01	6.00

FWD testing was performed to determine the SN at the pre- and post-resurfacing construction of SR-69. A total of 110 FWD tests were carried out on the pavement EB surface. Before resurfacing (June 2009), the mean of the SN was 5.71 with a range between 5.22 and 5.90. After resurfacing (October 2009), the SN jumped to a range from 5.77 to 6.01 with a mean of 6.62. The SN values decreased to 5.77 after 1 year (July 2010). An ANOVA was carried out to compare the SN results for the UTBWC and found that the results were statistically different between 2008 and 2009 ($F = 6.60 > Fcrit = 3.96$, $P = 0.01$), indicating that the pavement structure after resurfacing was slightly stronger than the pavement structure before resurfacing. SN values between 2009 and 2010 were not statistically different, indicating that the SN still keeps constant. The same is true in the years of 2010 and 2011.

An ANOVA was carried out to compare the SN during a 3-year period on SR-145 and SR-68. It was found that the results were not statistically different, indicating that the pavement structure did not deteriorate significantly in capacity.

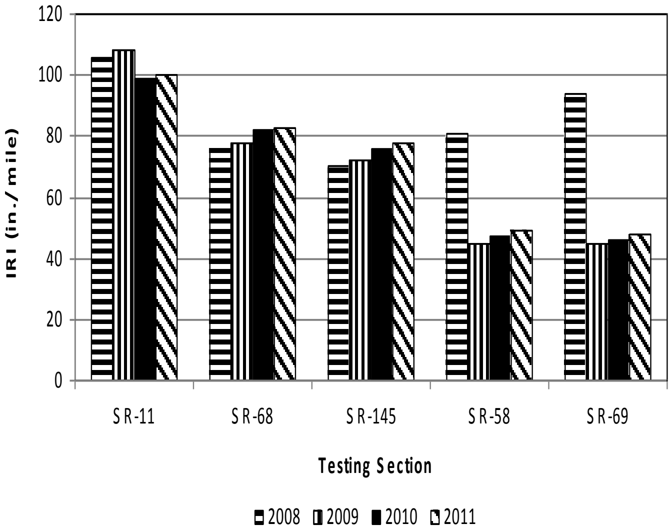

Fig. 2. IRI Growth with Time (1 in./mi. = 15.875 mm/km).

IRI

Shortly before and after placement of the UTBWC, INDOT carried out testing of roughness every 100 m. Testing was also carried out annually after construction completion. The other four control sections were tested as well. Fig. 2 shows the graph of the IRI plotted against time. The average IRI for SR-11 went from 1714 to 1571 mm/km (108 to 99 in./mile), an improvement in IRI of 9 in./mile, indicating a 9% decrease in IRI on average. In the post-UTBWC curves from 2010 and 2011, no consistent trend of increasing or decreasing IRI between these two test cycles is noted. The measurements taken 1 year after construction indicated that sections were exhibiting good ride characteristics with 1587.5 mm/km (100 in./mi.). As expected, values before and after construction were significantly different in ANOVA analysis. The testing in 2010 and 2011 show no difference when compared with data collected after UTBWC using ANOVA.

Annual testing shows that SR-58 has a lower IRI in 2009 than in 2008. This section was milled and filled in 2009 to correct the profile. This decreased the value by half and greatly improved the smoothness of the pavement. As expected, ANOVA results show that IRIs in 2008 and 2009 were not significantly different ($F = 223.36 > Fcrit = 3.93$, $P = 0.00$); however, the difference between 2009 and 2010 was significant. The same conclusion can be made for SR-69.

However, the average IRI values for SR-68 increased from 1238.25 mm/km (78 in./mi.) in 2008 to 1301.75 mm/km (82 in./mi.) in 2009. Similarly, SR-145 increased 4 points from 1190.63 mm/km (72 in./mi.) in 2008 to 1206.5 mm/km (76 in./mi.) in 2009. These two testing sites in 2009 show no difference when compared with data collected in 2008 using ANOVA.

The IRI values for SR-11, SR-58, and SR-69 are shown in detail in Figs. 3 and 4, respectively. Fig. 3 shows that, on average, NB declines 8 points while SB declines 20 points. As expected, UTBWC can improve smoothness and enhance the frictional properties of structurally sound polished pavements. However, Fig. 4 shows that resurfacing in both lanes reveals substantial decreases in IRI values with the construction of resurfacing. There is an outstanding improvement in the rideability of the surface when compared with the original surface. Also, on the basis of practical experience, the IRI values for SR-11 seemed to be quite satisfactory when compared with those for resurfaced pavements, although the IRI values for the resurfacing layer were narrower than those for the UTBWC surface, indicating less variability in the resurfacing.

Rutting

The rutting depths were measured in the summer seasons each year in the left and right wheel paths with a 1.2 m (4 ft.) straightedge. Fig. 5 shows a summary of rut depth measurements for each test section. Before UTBWC, SR-11 had a rut depth of 0.14 in. in 2008 and 2009; after treatment, rut depths in UTBWC decreased to 0.10 in. in September 2010, then kept the same value of 0.10 in. in August 2011. UTBWC can be utilized to correct rutting and preserve pavements. The HMA rut depths for SR-68 and SR-145 constantly increased by 0.0254 cm (0.01 in.) per year. The SR-58 and SR-69 resurfacing section decreased dramatically after resurfacing. This

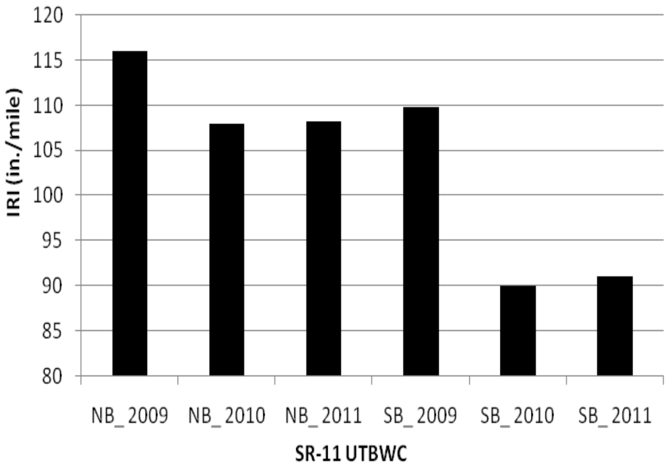

Fig. 3. IRI Growth with Time in SR-11 UTBWC Section (1 in./mi. = 15.875 mm/km).

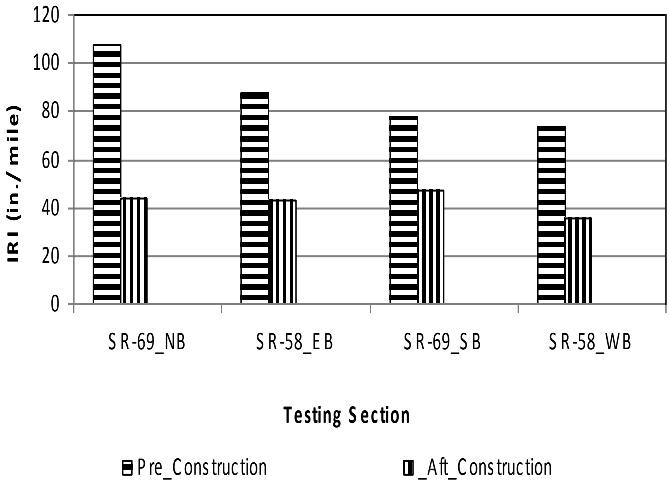

Fig. 4. IRI Growth with Time in Resurfacing Section (1 in./mi. = 15.875 mm/km).

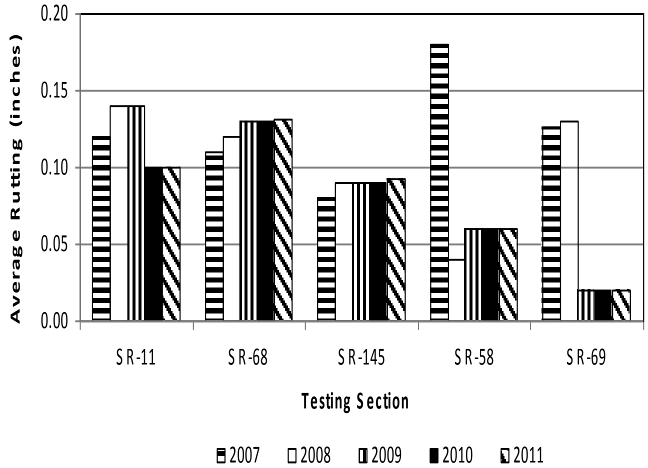

Fig. 5. Average Rutting by Year (1 in. = 25.4 mm).

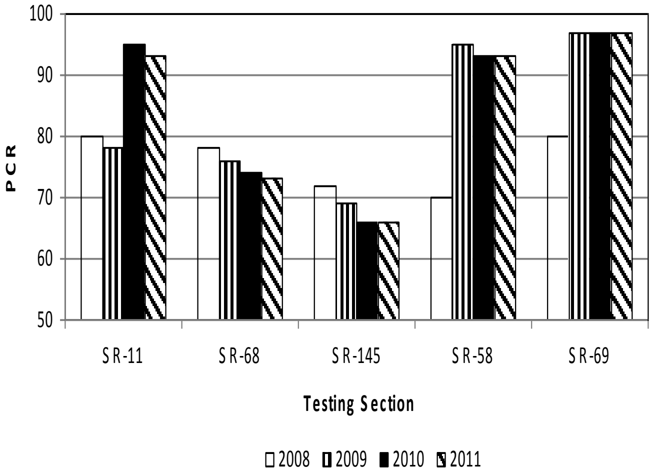

Fig. 6. Average PCR by Year.

decrease in rut depths could be attributed to the milling of the aging and distressed surface and filling the new wearing course. In general, the amount of rutting for all of these sections is within the normal range (less than 6.35 mm (0.25 in.)). Apparently, resurfacing has more advantages than UTBWC.

PCR

To assess the effectiveness of the UTBWC, the PCR from the UTBWC treated section was compared with the PCR from the control sections (without treatment and resurfacing). Fig. 6 shows PCR data from 2008 to 2011. A PCR value of 60 is often regarded as the point at which rehabilitation is necessary. In general, the average change of PCR on the UTBWC section from 2009 to 2010 is 19% while the change on the resurfacing section over the same time period is 24%. Specifically, a significant jump in PCR occurred following placement with mill and fill or UTBWC. The PCR on SR-11 increased from 75 to 95 and on SR-58 from 70 to 95. The PCR for the UTBWC and resurfacing sections shows that they are in good condition as categorized by INDOT. On the other hand, the no treatment sections kept declining steadily and the control section (without treatment) deteriorated more than 1.25 times faster than the UTBWC section. This indicates that the preservation was successfully rejuvenating aged pavement. The average performance of SR-58 appears to be significantly better than the other no-preservation sections. However, this performance is similar to SR-11 with its UTBWC treatment. PCR deterioration trends indicate that the performance of all pavement sections declined, with average rates of 3 and 2.8 points per year, respectively. Specifically, the SR-58 and SR-69 resurfacing appeared to be significantly better than the other three in averages. SR-11, SR-68, and SR-145 were the worst scenarios, exhibiting rapid PCR drops. The overall appearance of the UTBWC was good, but the PCR has continued to decline slightly since then, from 95 to 93 in 2010. SR-68 decreased from 78 to 76 to 74 over 3 years. The average rates of decline in the PCR for the pavement are 3.5 and 3.2 points per year, respectively.

It should be noted that some inconsistency of FWD (falling weight deflectometer), IRI, and rutting is due to different operators performing the testing, the variability in the vehicle alignment in testing sections, seasonal effects on pavement structure and smoothness, slight variations in locating the starting and ending points for testing and for locating the project limits, and the variability in FWD testing stations.

Cost Comparison: UTBWC, No Preservation, and Conventional Resurfacing

Performance data can help quantify the cost-effectiveness of pavement management (PM) treatments. Long-term evaluation concerns how well a treatment is able to sustain its effectiveness over time. This effectiveness of PM treatments is determined through treatment service life, increase in average pavement condition, and area bounded by the performance curve. For each measure of effectiveness, the pavement performance indicators used are the IRI, rutting, and PCR.

The UTBWC on SR-11 provided an increase of 8% SN (approximately 0.8 to 1.5 years of structure service life), 9% for the IRI (approximately 3 to 4.5 years of service life), 2 to 4 years (on the basis of rutting), and 12% PCR (approximately 5 to 7 years of service life). The construction cost of the UTBWC was $6.60/yd^2. The construction cost of the SR-58 conventional hot mix resurfacing (mill and fill) project was $5.60/yd^2; its cost was approximately 20% less than the cost of UTBWC treatment. Previous studies show that UTBWC and resurfacing can extend service life. However, this study shows that resurfacing provides a more cost-effective service for old pavement as measured by IRI, SN, and PCR. Particularly, in the case of SR-58, resurfacing could provide an estimated additional 1 to 2 years (on the basis of structural service life), approximately 8 to 10 years (on the basis of the IRI), 10 to 15 years (on the basis of rutting), and 6 to 8 years (on the basis of the PCR). The sections with no preservation have no increase in service life.

Life-cycle cost of pavement depends on the pavement's service life. A 10-year service life is a reasonable estimation for pavement preservation. The maintenance costs were not available and were therefore not included in the analysis. The equivalent uniform annual cost (EUAC) values are introduced in the comparison. Therefore, construction costs for all treatments mentioned were converted to EUAC for different service lives between 1 and 10 years in order to see clearly the effectiveness of UTBWC. A life-cycle analysis was conducted based on an interest rate of 8%. Another assumption made was that the full-depth pavement of 20.32 cm (8 in.) would only last up to its 20-year design life due to lack of maintenance. The construction cost per lane mile for each treatment is plotted in Fig. 7.

The data in Fig. 7 show that the pavement service lives for the treatments are expected to vary. The minimum investment for the pavement is set as a baseline for a 20-year service life, which is the initial pavement construction cost. The baseline was drawn out to discover whether the service lives for UTBWC and resurfacing would be as cost-effective as a service life of 20 years without any preservation treatment. The intersections of the horizontal line and the cost curves indicate that UTBWC is cost-effective if it can provide more than 3.6 years of additional service life, and resurfacing is cost-effective if it can provide more than 3 years of additional service life. Considering cost as well as performance, UTBWC may not be an economical alternative to conventional resurfacing because the cost of UTBWC is 20% higher than the cost of resurfacing. It is also found that pavement preservation is a more cost-effective tool than no treatment on the pavement, which could result in total reconstruction in the future.

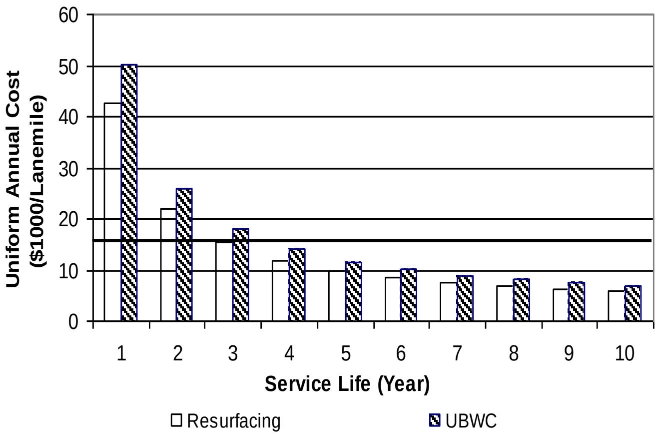

Fig. 7. Equivalent Uniform Annual Costs with Different Service Lives. (US $1,000/lane mi. = US $625/lane km)

Conclusions

This study evaluated the effectiveness of UTBWC as a form of pavement preservation. Based on the analysis of the data, the following conclusions were made:

- The overall performance of the UTBWC sections has been very good. UTBWC can be considered as a low-cost preventive maintenance treatment that retards deterioration of the pavement, maintains or improves the functional and structural condition of roadways, and extends the pavement's service life.
- UTBWC can be utilized to correct rutting and improve smoothness. It is well suited as a preventive maintenance treatment to extend the life of sound pavement. Its function is to increase the PCR and IRI. However, it is not as effective as resurfacing in reducing rutting.
- UTBWC does not increase the structural capacity of the pavement; however, it can rejuvenate the aged pavement surface and appears to slow the progress of reflective cracking.
- Compared to UTBWC, mill and fill can more effectively address rutting, increase ride quality, and show the largest improvement in PCR. Therefore, it can offer the longest functional service.
- With the curves of performance developed in this study, results suggest that the performance life of a treatment is 3 to 4 years for UTBWC and 6 to 8 years for resurfacing.
- The cost analysis indicated that UTBWC is cost-effective if it can provide more than approximately 3.5 years of service life, and resurfacing is cost-effective if it can provide more than approximately 3 years of service life.
- UTBWC effectiveness is influenced by pavement structural capacity, construction, the time at which preservation was performed after pavement deterioration, and traffic volume. If applied properly, UTBWC may show better results and can be considered as an alternative to conventional resurfacing.

Acknowledgments

This project was made possible by the sponsorship of the Indiana Department of Transportation (INDOT). The authors would like to thank Dr. Dwayne Harris, Mr. Todd Shields, and Design Engineer Maricor (Joy) Colglazier for their valuable assistance in the course of performing this study.

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