EFFECTIVENESS OF ASPHALT PENETRATING SEALERS IN EXTENDING NEW ASPHALT PAVEMENT LIFE

The Office of Pavement Engineering
Ohio Department of Transportation

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Numerous methods are being employed for asphalt pavement preservation, including rejuvenator emulsions, asphalt emulsion fog seals, and a variety of non-structural surface treatments (including slurry and micro surfacing technologies). To make the most of maintenance budgets, some agencies are using asphalt penetrating sealers as an alternative to reduce the detrimental impact of weathering or aging of wearing surfaces for older and new asphalt pavements or overlays of existing flexible pavements. Applying a penetrating sealer to a new surface within a few weeks after it has been placed has several benefits to the HMA wearing surface. It can restore the original asphalt properties that were lost during the production process and seal the pavement for improving on the durability of the surface course, reducing the permeability at the surface.

Asphalt penetrating sealers have been used by Federal, State, county, and municipal agencies over the past 15 years, and their use has been based on past performance. However, there are diverse opinions regarding the success of this technology. Once a product has been used, a pavement engineer's opinion can vary from the project being totally successful or completely ineffective. Little data exists based on quantitative data from multiple projects. The issue or gap in the technology, especially in Ohio, is quantifying the cost-effectiveness on the use of these materials. Thus, the purpose of this project was to collect the data to quantify the cost-effectiveness of these asphalt penetrating sealers. In other words: Are these surface treatments or penetrating sealers cost-effective? The purpose of this report is to document the surface condition of test and control sections along four projects before and immediately after application of three penetrating sealer products, as well as over a four year monitoring period to determine the added service life, if any, between treated and untreated surfaces.</td></tr>
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The ARA project team recognizes and appreciates the services provided by the Ohio Department of Transportation. These services included: providing traffic control during the field work, coordination with the contractors responsible for the placing the asphalt concrete overlays, providing the skid resistance testing, and providing results from the annual distress surveys in accordance with Ohio Department of Transportation procedures. The ARA team would also like to acknowledge and recognize the Ohio Technical Panel members that provided guidance on completing the project activities. These individuals included: Aric Morse, Brad Young, Matt Parrill, Fred Humphrey, and Robin Fogt.

Three companies provided the penetrating sealers, as well as applying those materials to the surface of the asphalt concrete overlay on four projects. The three companies or material providers included: Ohio Pavement Systems, Inc., Asphalt Systems, Inc., and Pavement Technology Inc.

ARA also recognizes the participation and assistance of Burns Cooley Dennis, Inc. (BCD) for assisting in the field testing effort. The ARA field team consisted of the following individuals: Lax Premkumar was involved in the density testing and coring, Mark Stanley completed the distress surveys, Joe Sebright completed the sand patch tests, and Kevin Williams (with BCD) completed the field water permeability tests.

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NOTATIONS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
COV	Coefficient of Variation
DOT	Department of Transportation
EAPC	Equivalent Annual Pavement Costs
FHWA	Federal Highway Administration
HMA	Hot Mix Asphalt
JMF	Job Mix Formula
JPCP	Jointed Plain Concrete Pavement
JRCP	Jointed Reinforced Concrete Pavement
LCC	Life Cycle Cost Analysis
LTPP	Long Term Pavement Performance
M&R	Maintenance and Rehabilitation
NCAT	National Center for Asphalt Technology
ODOT	Ohio Department of Transportation
PCR	Pavement Condition Rating
RFP	Request for Proposal
SN	Skid Number

Effectiveness of Asphalt Penetrating Sealers in Extending New Asphalt Pavement Life

1. INTRODUCTION

1.1 Background

Numerous techniques and materials are being used to preserve asphalt pavements, including: rejuvenator emulsions, asphalt emulsion fog seals, and a variety of non-structural surface treatments (including slurry and micro surfacing technologies). Many studies over the years have quantified the benefit of pavement preservation programs. Montana conducted a study and found roadway sections with preservation treatments exhibited 3 to 5 years of additional service life as a result of retaining improved asphalt properties over a longer period of time in comparison to segments without preservation treatments (Von Quintus and Moulthrop, 2007). The Montana study included chip seals and surface seals; penetrating sealers were not included.

Aging or weathering of hot mix asphalt (HMA) wearing surfaces cost agencies millions of dollars each year in maintenance and repair (M&R) costs to keep pavements serviceable by removing (milling) and replacing the wearing surface. Aging can result in surface distress in the forms of raveling and surface cracking. Reducing the amount of aging of the wearing surface can save taxpayers millions of dollars by extending the service life of the wearing surface and reducing the number of roadway closures needed for M&R activities. Some agencies spray an asphalt penetrating sealer on the wearing surface to reduce the detrimental impact of weathering or aging of wearing surfaces for older and new asphalt pavements or overlays of existing flexible and rigid pavements.

Studies on the effect of spraying sealers on the surface of existing weathered HMA surfaces date back to the 1970s. Robert Boyer with the Asphalt Institute (2000) reported many of these earlier studies concluded that sealers or rejuvenators do extend the service life of pavements. Some of these earlier studies were completed for the California Department of Transportation (DOT), New Mexico DOT, Texas DOT, and the Department of Naval Facilities Engineering Command

and Air Force, primarily for extending the service life of airfields. Few studies, however, have been completed since the 1990s.

Penetrating sealers have been used mostly on weathered or existing HMA surface layers. Using penetrating sealers on new construction does not seem to be logical. It is well known, however, that the greatest change in asphalt composition takes place during the production and placement of HMA. In addition, surface mixtures with higher air voids, gap-graded or coarse-graded aggregate blends can be susceptible to accelerated weathering because of higher permeability. Applying a penetrating sealer to a new surface within a few weeks after it has been placed can have several benefits. As reported by Boyer (2000), rejuvenating sealers can restore some of the original asphalt properties that were lost during the production process and seal the pavement for improving the durability of the surface course—reducing the permeability at the surface.

Asphalt penetrating sealers have been used by Federal, State, county, and municipal agencies over the past 15 years, and their use has been based on past performance. Boyer reported, however, there are clear-cut opinions regarding success of a rejuvenator product. Once a rejuvenator product has been used, a pavement engineer's opinion appears to be that the project was either totally successful or completely ineffective. Most of these opinions are not based on quantitative data from multiple projects. Boyer and others have hypothesized that the diverse attitudes stem from proper and improper application of a product, rather than the performance of the product itself. The issue or gap in the technology, especially in Ohio, is quantifying the cost-effectiveness of penetrating sealers.

The Ohio Department of Transportation (ODOT) and other agencies recognize the potential benefit of increasing the average service life of their roadways to reduce life cycle costs (LCC)—making the limited tax dollars go further in maintaining and managing their roadway network. The Ohio Request for Proposal (RFP) Solicitation #2013-18 reported that over the last 30 years, ODOT has investigated the benefits of using various asphalt penetrating sealers (sometimes referred to in the literature as rejuvenators) to restore the surface properties and/or protect the wearing surface from aging or weathering.

The cost for applying asphalt sealers is relatively inexpensive, varying from $0.50 to $0.75 per square yard. Extending the service life even for a limited number of years can reduce LCCs. However, results observed to date in Ohio have been mixed. The materials sprayed on the wearing surface provide no increase to the structural capacity of the pavement. One possible reason for these mixed results could be related to structural adequacy of the existing pavement and construction defects (segregation, moisture damage, etc.), as well as with the performance of the penetrating sealers themselves.

ODOT sponsored this project to evaluate three products: (1) Replay (supplied by Ohio Pavement Systems Inc.), (2) Reclamite (supplied by Pavement Technology Inc.), and (3) Bio-Re-Stor (supplied by Asphalt Systems Inc.). The three penetrating sealers were tested in a controlled study to measure their effectiveness to extend the life of recently placed HMA wearing surfaces and delay the need for maintenance and rehabilitation. The purpose of this project was to collect the data to quantify the cost-effectiveness of asphalt penetrating sealers in Ohio.

1.2 Research Objective

The objective of this study was to provide an answer to ODOT's question: Are surface treatments or penetrating sealers cost-effective? To answer that question, the following goals were accomplished:

1. Determine if penetrating sealers extend the asphalt pavement life, and if so, quantify the added service life.
2. If penetrating sealers do extend pavement service life, is the cost to apply the materials to the wearing surface cost-effective?
3. If penetrating sealers are cost-effective, quantify and make recommendations for applying the sealers in terms of selecting projects with features that will provide the best value to ODOT.

1.3 Scope of Work – Project Tasks

The following lists the activities for accomplishing the project objectives and goals listed above.

- Task 1—Coordinate with ODOT District 7 personnel and review the projects ODOT selected for this study.
- Task 2—Observe sealer application and measure pre and post-application surface properties.
- Task 3—Monitor the surface of the project annually (distress/condition surveys and sand patch tests)
- Task 4—Measure and evaluate friction or skid number measured prior to and after sealer application.
- Task 5—Perform water permeability tests.
- Task 6—Determine the cost-effectiveness of the penetrating sealers, if additional service life is found from task 3.
- Task 7—Provide recommendations for future data collection plans, if needed.
- Task 8—Prepare report that documents all activities of the project.

This report provides a summary of all activities and test results completed within the study.

2. PROJECTS: TEST SECTIONS AND CONTROL SECTIONS

Three penetrating sealers were placed along four project locations. Figure 1 shows the equipment used to apply the sealers to selected areas or test sections within each of the four project locations. One of the construction projects (designated as SR-292) was grouped into two different areas: defined as location A and location B.

Biorestor Sealer Application

Replay Sealer Application

Reclamite Sealer Application

Figure 1. Distributors or Equipment for Applying the Penetrating Sealers

All projects included in this study consisted of a mill and overlay rehabilitation strategy. Table 1 lists the beginning and ending mile posts for each section of the four projects, while the following sections of this chapter describe each project.

Table 1. Beginning and Ending Mile Posts for each Section of the Four Projects

Project		Section Designation	Mile Post	
			Beginning	Ending
US-40; Westbound Lanes	Springfield, OH (Sept. 4, 2012)	Control	18.237	18.573
		Biorestor	17.864	18.199
		Reclamite	17.118	17.453
		Replay	17.491	17.826
US-40; Eastbound Lanes	Springfield, OH (Sept. 5, 2012)	Control	17.118	17.453
		Biorestor	17.491	17.826
		Reclamite	18.237	18.573
		Replay	17.864	18.199
SR-292, Location A, Westbound and Eastbound Lanes	East Liberty, OH (Oct. 24, 2012)	Control	1.523	1.858
		Biorestor	1.150	1.485
		Reclamite	2.307	2.642
		Replay	1.896	2.231
SR-292, Location B, Northbound and Southbound Lanes	East Liberty, OH (Oct. 25, 2012)	Control	8.157	8.492
		Biorestor	7.373	7.708
		Reclamite	7.746	8.081
		Replay	7.000	7.335
SR-47; Westbound and Eastbound Lanes	Sidney, OH (June 4, 2013)	Control	13.629	13.729
		Biorestor	13.443	13.591
		Reclamite	12.825	12.973
		Replay	13.011	13.158

2.1 US 40—Springfield, OH

The segment along US 40 included in this study is a four-lane divided highway, and is classified as a rural principle arterial. Figure 2 shows the general location of the project, while Figure 3 shows the layout of the test and control sections. The penetrating sealers were applied to the wearing surface of all lanes in both directions on September 4 and 5, 2012. All testing prior to and after sealer application, however, was confined to the outside lanes. The existing pavement along this segment of US-40 is a jointed plain concrete pavement (JPCP) that had been previously overlaid. The rehabilitation strategy for this project included milling the surface to a depth of about 0.75 inches, and placing a 0.5-inch 448 HMA leveling course followed by a 1.25-inch 446 HMA overlay.

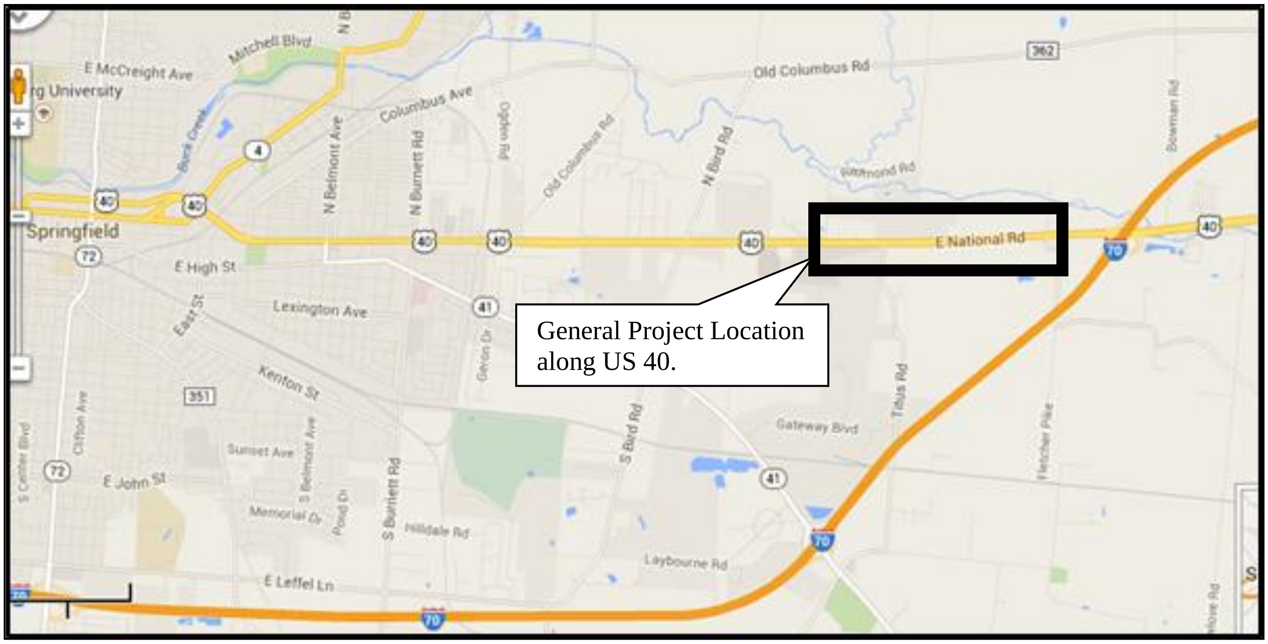


Figure 2. General Location of Project along US-40; Springfield, Ohio

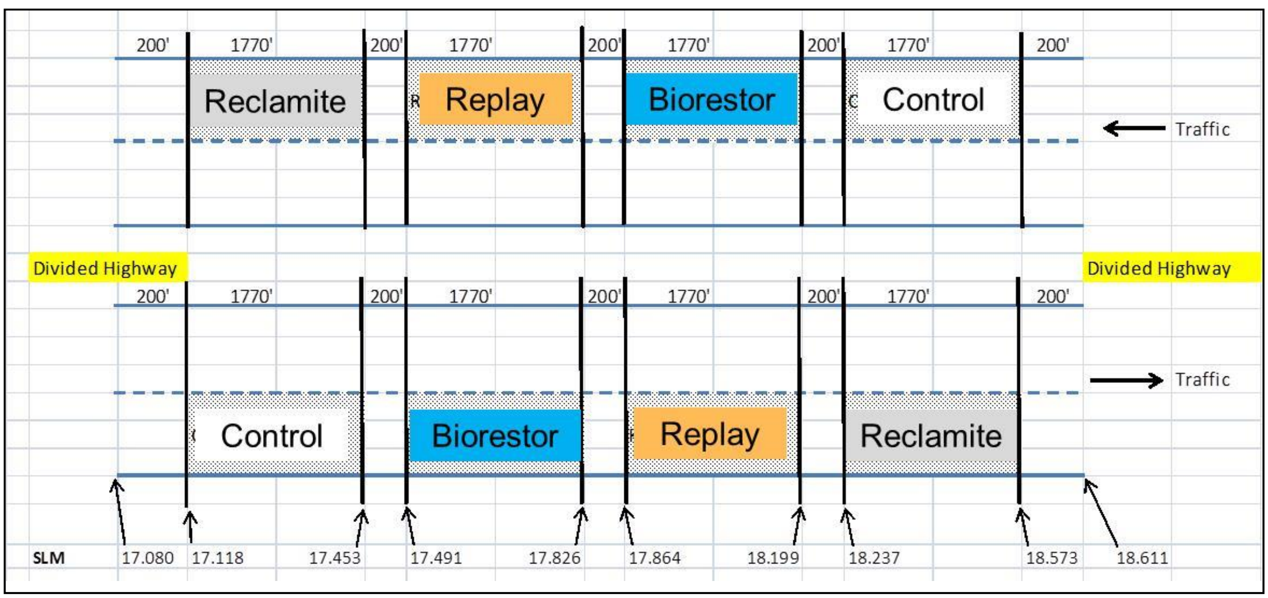


Figure 3. Test Section Layout, US-40; Springfield, Ohio

2.2 SR-292 Location A—East Liberty, OH

Two segments of SR-292 were included in the study; defined as location A and B. Location A was located in an area parallel to US-33 just southwest of East Liberty and carries more traffic than location B. This segment is a two-lane roadway and is classified as a rural minor arterial. Penetrating sealers were applied to the wearing surface in both directions on October 24, 2012. All testing prior to and after sealer application was confined to the westbound lane. Figure 4 shows the general location of the project, while figure 5 shows the layout of the test sections. The existing pavement along location A of SR 292 is a flexible pavement. The rehabilitation strategy included milling the existing surface to a depth of about 1.75 inches and replacing the milled surface with a 0.75-inch 448 leveling course and 1-inch 448 HMA overlay.

2.3 SR-292 Location B—East Liberty, OH

Location B along SR-292 is a two-lane roadway, and carries less traffic than location A. This segment is located in a rural area northwest of East Liberty, and is classified as a rural secondary collector. Figure 6 shows the general location of the project, while figure 7 shows the layout of the test sections. The penetrating sealers were applied to the wearing surface in both directions on October 25, 2012. All testing prior to and after sealer application was confined to the northbound lane. The existing pavement along this segment of SR-292 is a flexible pavement and the rehabilitation strategy for this segment was the same as for location A.

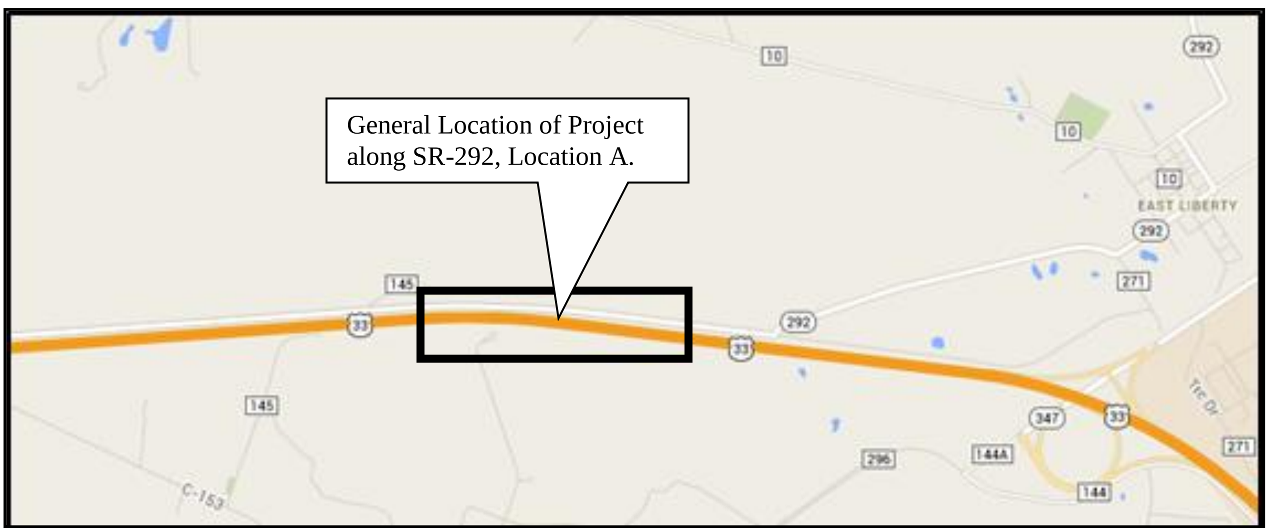


Figure 4. General Location of Project along Location A of SR-292; East Liberty, Ohio

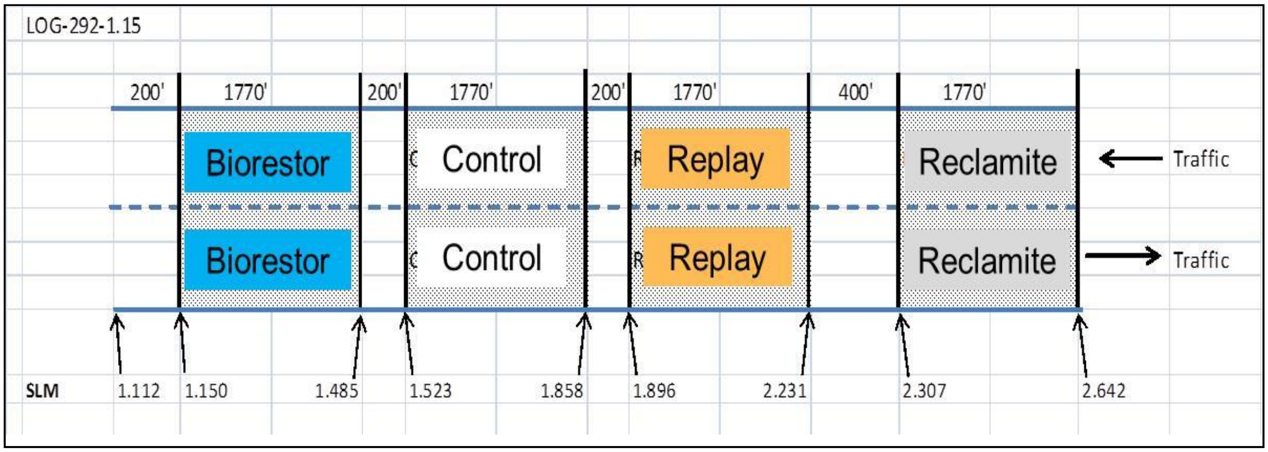


Figure 5. Test Section Layout along Location A of SR-292; East Liberty, Ohio

2.4 SR-47—Sidney, OH

The segment along SR-47 included in this study is a four-lane roadway located west of Sydney, OH. This segment of SR-47 is a heavily travelled urban roadway with left and right turn lanes because of multiple intersecting streets and driveways. This location is in a commercial area, and of the four projects, carries the highest level of traffic with a lot more turning movements. Figure 8 shows the general location of the project, while figure 9 shows the layout of the test sections.

The penetrating sealers were applied to the wearing surface in all lanes in both directions, including the center-turn lane on June 4, 2013. All testing prior to and after sealer application, however, was confined to the outside lanes. The rehabilitation strategy for SR-47 was the same as for SR-292. One major difference between this project and the other three is the HMA overlay mixture included a stiffer asphalt mixture because of the heavier traffic volumes and many more turning movements. In addition, the penetrating sealers were applied to the wearing surface later than for the other three projects because of construction issues and difficulties outside the scope of this project, so only three years of monitoring data were collected for this project.

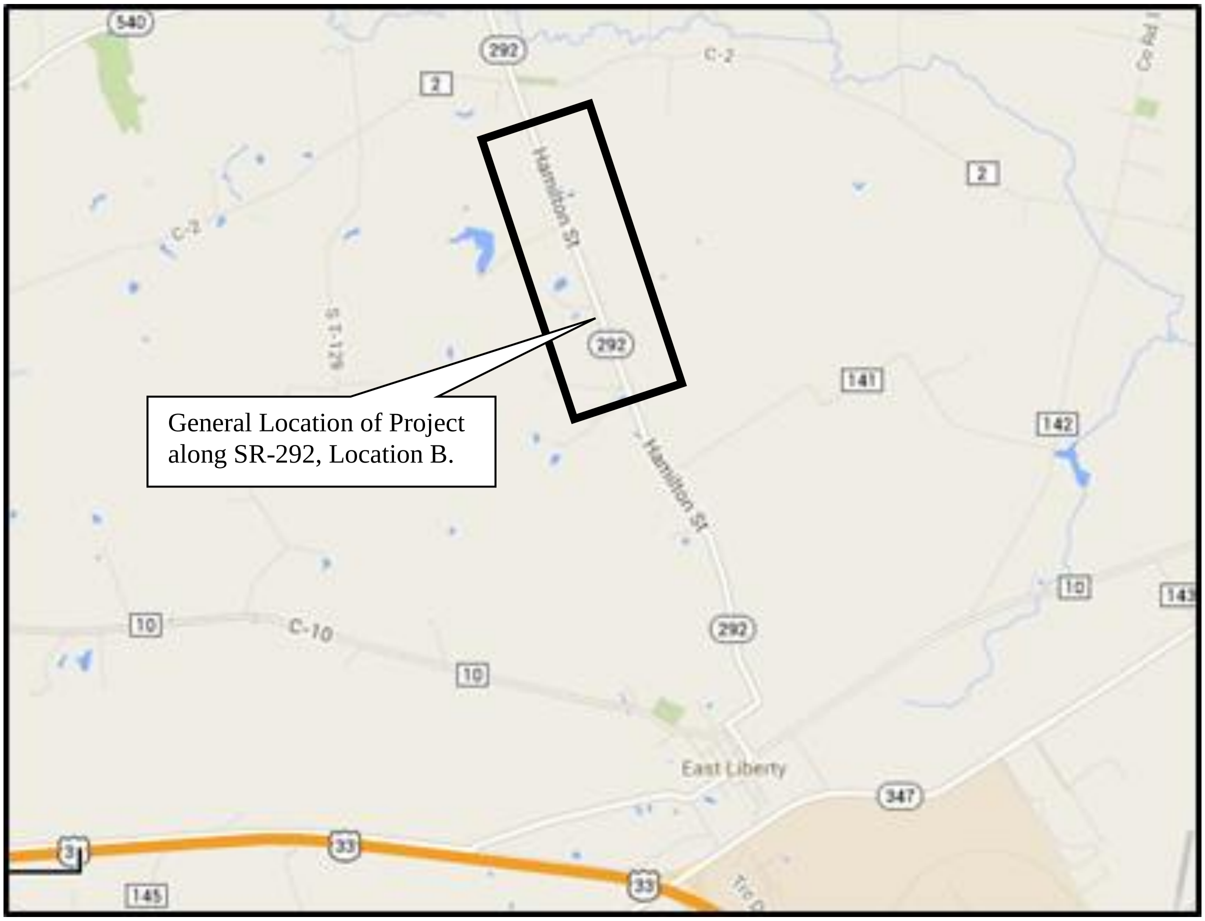


Figure 6. General Location of Project along Location B of SR-292; East Liberty, Ohio

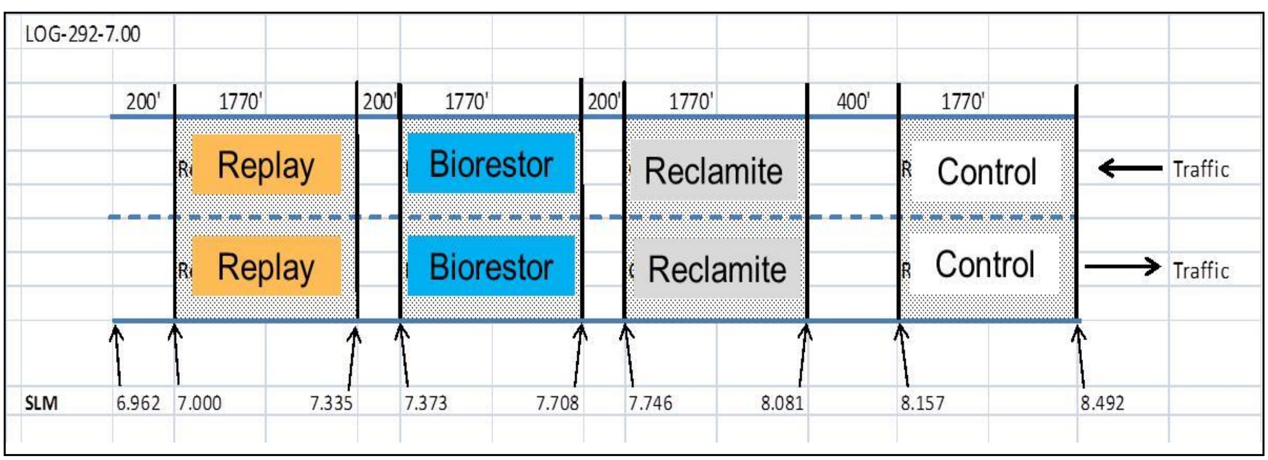


Figure 7. Test Section Layout along Location B of SR-292; East Liberty, Ohio

Figure 8. General Location of Project along SR-47; Sidney, Ohio

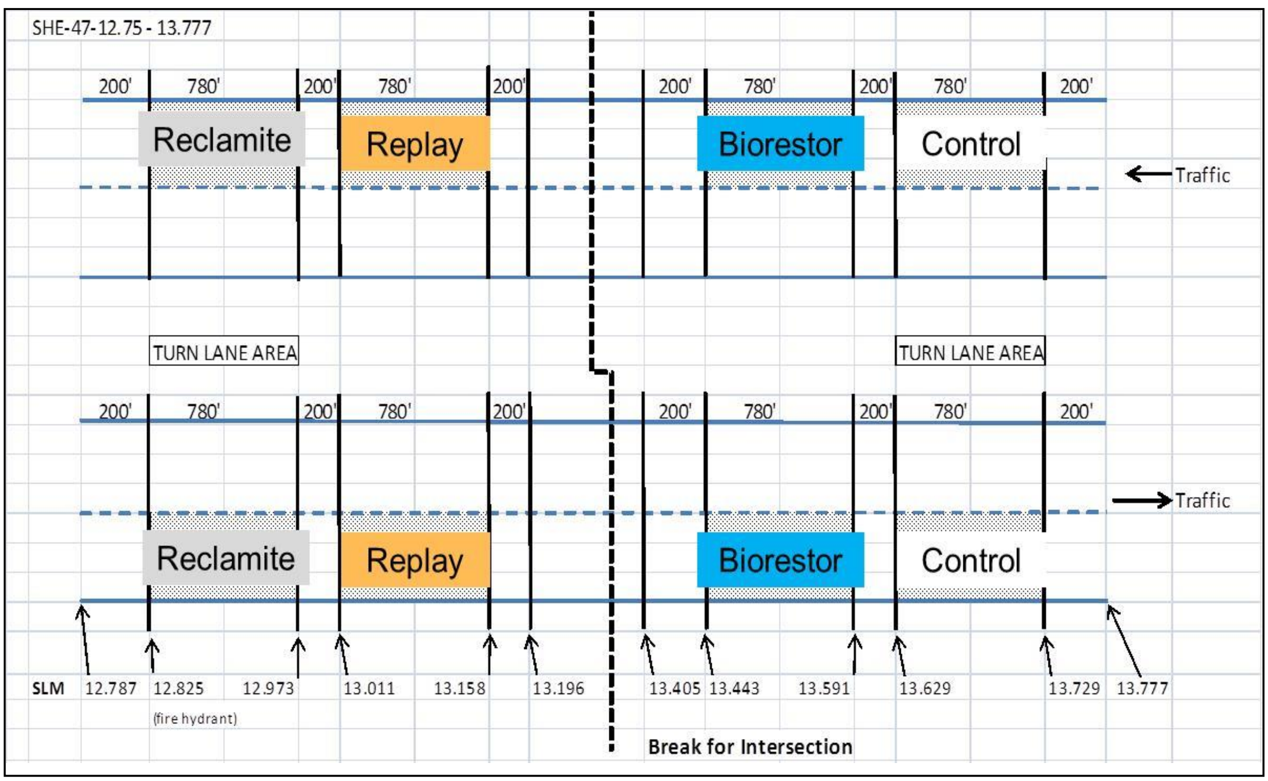


Figure 9. Test Section Layout along SR-47; Sidney, Ohio

2.5 Summary of HMA Mixture Design and In Place Properties

Table 2 provides a summary of the HMA job mix formula (JFM), while table 3 provides the average in place properties. As shown, the HMA mixtures are similar between the projects except for SR-47. The HMA mixture placed along the SR-47 project included stiffer asphalt (PG76-22) because of the heavier traffic levels and more turning movements along this segment for SR-47.

Table 2. HMA Job Mix Formula

Property		**Project**		
		US-40	**SR-292 A and B**	**SR-47**
Mixture Type		446, Type A	448E, Type 1	301/302, Type A
Mixture Size, mm		9.5	9.5	12.5
Aggregate Type		#8 Limestone; Limestone Sand; Natural Sand; RAP	#8 Limestone; Limestone Sand; Natural Sand; RAP	#67 & 9M Stone; Manufactured Sand; RAP
Gradation, percent passing sieve size	19.0 (3/4)	100	100	100
	12.5 (1/2)	100	100	96
	9.5 (3/8)	98	94	82
	4.75 (#4)	59	55	60
	2.36 (#8)	40	35	34
	1.18 (#16)	27	23	21
	0.60 (#30)	18	14	14
	0.30 (#50)	11	9	9
	0.15 (#100)	7	6	5
	0.075 (#200)	4.0	4.5	3.6
Total RAP Content, percent		10	20	15
Total Asphalt Content, percent		6.2	6.3	5.8
Asphalt Grade		PG70-22 with SBS	PG70-22 with SBS	PG76-22 with SBS
Design Air Voids, percent		4.0	3.5	4.0
Maximum Theoretical Density		2.457	2.441	2.500

Table 3. HMA In Place Properties

Property		Project			
		US-40	**SR-292/A**	**SR-292/B**	**SR-47**
Gradation, percent passing sieve size	12.5 (1/2)	100	99.5	98.7	NA*
	9.5 (3/8)	97.6	91.3	92.2	NA
	4.75 (#4)	59.3	55.1	54.5	NA
	2.36 (#8)	39.4	34.7	35.6	NA
	1.18 (#16)	26.3	22.3	21.8	NA
	0.60 (#30)	17.4	14.1	12.7	NA
	0.30 (#50)	10.3	8.9	6.8	NA
	0.15 (#100)	6.6	5.7	4.2	NA
	0.075 (#200)	3.9	3.9	2.9	NA
Total Asphalt Content, percent		6.05	6.20	6.27	NA
Lab Air Voids, percent		3.8	3.8	4.1	NA
Maximum Specific Gravity		2.466	2.468	2.442	NA
Voids in Mineral Aggregate		15.4	15.9	17.6	NA
** NA – Not available for this project.*					

3. TEST RESULTS: PRE AND POST SEALER APPLICATON

3.1 Sealer Residual Application Rate

The application rate of each sealer was measured for each test section. The procedure used for measuring the application rate was similar to the one used for placing tack coats or emulsions for seal coats. Six one-foot square pads were placed near the beginning and end of each test section. Figure 10.a shows the pads in place prior to sealer application.

a. Pads in place prior to sealer application.

b. Pads removed after sealer application.

Figure 10. Test Pads used to Measure the Amount of Residual Sealer

The tare weight of each pad was measured and the pads numbered and placed on the HMA surface using double-sided tape. After the sealer was applied to the surface, each pad was removed and sealed in plastic bags. The pads were removed from the plastic bags and weighed after drying to determine the weight of the residual material. Figure 10.b shows an area after the six pads were removed.

Table 4 summarizes the residual application rates for each test section, which was product dependent. The suppliers determined the application rate for each sealer. The greatest residual rate was calculated for the Reclamite test sections followed by the Replay sections. The lowest residual rate was calculated for the Biorestor sections.

Table 4. Sealer Residual Application Rates

Project	Residual Application Rate, gal./sy.		
	Biorestor	**Replay**	**Reclamite**
US-40; Westbound Lanes	0.00793	0.0147	0.0174
US-40; Eastbound Lanes	0.00713	0.0131	0.0159
SR-292; Westbound Lanes, Location A	0.00991	0.0103	0.0472
SR-292; Northbound Lanes, Location B	0.00396	0.0119	0.0242
SR-47; Westbound Lanes	0.00436	0.0103	0.0190
SR-47; Eastbound Lanes	0.00357	0.00951	0.0178
NOTE: The suppliers of each product or penetrating sealer decided on the application rate for their sealer along each project.			

3.2 Condition Surveys

Distress/condition surveys were completed in accordance with the Federal Highway Administration (FHWA) Distress Identification Manual (FHWA-RD-03-031, dated June 2003) prior to spraying the sealers, and annually throughout the monitoring period. This manual was developed under the Long Term Pavement Performance (LTPP) program and is typically used in pavement research-related studies. Cracking and defect maps were prepared for each test sections after sealer application. Specific attention was given to the condition of the longitudinal and transverse construction joints and interior lane areas that were placed within the test section areas.

No distresses were observed prior to and immediately after sealer application along the test sections with the exception of the US 40 project. A few reflection cracks from the existing JPCP were already observed in a few locations in the Reclamite test section in the eastbound lane. Other surface defects observed in localized areas included: truck to truck segregation and crushed aggregate along some of the test sections. Table 5 identifies pertinent surface condition defects for future reference that could have an impact on the performance of the individual test sections. Photographs were taken prior to sealer application showing the condition of the wearing surface or HMA overlay, as well as any feature that might have an effect on the long term performance of the HMA overlay.

Table 5. HMA Overlay Surface Defects, if any, Identified Prior to Sealer Application

Project	Lane/Direction	Test Section	Surface Defect or Issue
US-40; Springfield, OH	Westbound, Outside Lane	Control	None, uniform surface.
		Biorestor	None, uniform surface.
		Replay	Localized truck to truck segregation.
		Reclamite	Crushed aggregate near the beginning of section and where cross-street intersects US-40.
	Eastbound, Outside Lane	Control	None, uniform surface.
		Biorestor	Localized truck to truck segregation.
		Replay	None, uniform surface.
		Reclamite	A few transverse hairline cracks and not full lane width, just starting to occur.
SR-292, Location A, East Liberty, OH	Westbound Lane	Control	Limited area where vibratory roller rolled on the cold side of joint near the center of the section, crushing the aggregate along the longitudinal joint; also screed mark.
		Biorestor	None, uniform surface.
		Replay	Localized area along longitudinal joint where vibratory roller rolled on cold side of joint, crushing the aggregate along the longitudinal joint.
		Reclamite	Minor crushed aggregate, localized area near beginning of section.
SR-292, Location B, East Liberty, OH	Northbound Lane	Control	None, uniform surface.
		Biorestor	Use of screed extensions – macro surface texture near mailboxes.
		Replay	Localized area with crushed aggregate.
		Reclamite	None, uniform surface.
SR-47, Sidney, OH	Westbound, Outside Lane	Control	None, uniform surface. Two transverse joints.
		Biorestor	None, uniform surface. One transverse joint.
		Replay	None, uniform surface. One transverse joint.
		Reclamite	None, uniform surface. Two transverse joints.
	Eastbound, Outside Lane	Control	Localized segregation or macro-surface texture.
		Biorestor	None, uniform surface.
		Replay	None, uniform surface. One transverse joint.
		Reclamite	One transverse joint and localized area with crushed aggregate.

3.3 Sand Patch Tests

Sand patch tests were conducted in accordance with ASTM E 965-96 (last updated in 2006) before and after sealer application. Figure 11 shows the sand patch test. Five tests were performed within each test section at locations randomly selected along each test section. Table 6 summarizes the mean test results prior to and after sealer application. The average coefficient of variation (COV) for the calculated texture depth within a test section was 5.0 percent suggesting a uniform surface texture.

Figure 11. Sand Patch Test

In summary, the SR-47 surface consistently had the lower texture depth followed by the US-40 and SR 292/A projects. The SR 292/B project consistently had the greater texture depth, both prior to and after sealer application. The texture depth for all treated sections after applying the sealer consistently decreased in comparison to the values prior to applying the sealer, except for one of the Biorestor sections along the US 40 project (see figure 12). More importantly, the texture depth was lower for all treated sections after spraying the sealer in comparison to the control or untreated sections, except for the eastbound lane of the SR 47 project (see table 6). The higher sealer application rates, however, did not decrease the texture depth (see figure 13).

Table 6. Texture Depth from Sand Patch Test Prior to and After Sealer Application, mm

Project	Lane	Condition	Type of Penetrating Sealer			
			Control	Biorestor	Replay	Reclamite
Prior to Sealer Application						
US-40	WB	Before	0.261		0.289	0.244
US-40	EB	Before	0.268	0.247	0.256	0.318
SR-292-A	WB	Before	0.319	0.34	0.329	0.328
SR-292-A	EB	Before				
SR-292-B	NB	Before	0.415	0.396	0.344	0.458
SR-292-B	SB	Before				
SR-47	WB	Before	0.155	0.164	0.177	0.172
SR-47	EB	Before	0.135	0.153	0.164	0.197
After Sealer Application						
US-40	WB	After	0.261	0.193	0.184	0.235
US-40	EB	After	0.268	0.26	0.224	0.249
SR-292-A	WB	After	0.319	0.282	0.278	0.262
SR-292-A	EB	After				
SR-292-B	NB	After	0.415	0.289	0.284	0.308
SR-292-B	SB	After				
SR-47	WB	After	0.155	0.126	0.148	0.131
SR-47	EB	After	0.135	0.144	0.16	0.184

3.4 HMA Mat Density Tests

A non-nuclear density gauge was used to measure the in place density of the HMA at random and at biased locations along each test section (see figure 14.b). In most cases, five readings were taken at a single location or point. One reading was measured at the center of the outline for the gauge and four additional readings were made within each quadrant of the gauge outline. The average density reading was used to represent the specific area tested. Density tests were taken at each sand patch and field permeability test location.

Cores were drilled and recovered for developing a calibration factor for the non-nuclear density gauge (see figure 14.a). At least three 6-inch-diameter cores were recovered from each test section. These cores were used to measure the bulk and maximum specific gravity of the HMA mat for comparing the density between the different test sections of the same project and roadway. The bulk specific gravity was performed in accordance with AASHTO T 166 and the maximum specific gravity in accordance with AASHTO T 209. In summary, the SR-47 HMA overlay had slightly higher density, while the two SR-292 overlays had the lower density. The following lists the average density of the cores and resulting density adjustment factors for the non-nuclear density gauge.

Project	Density of Cores, pcf		Density Gauge
	Average	Standard Deviation	Adjustment Factor*
US-40	144.4	1.87	0.94
SR-292/A	143.4	1.49	0.98
SR-292/B	142.9	2.57	0.99
SR-47	146.5	3.39	1.05

** Adjustment Factor = Density of core divided by the average density reading from the non-nuclear density gauge at the core location.*

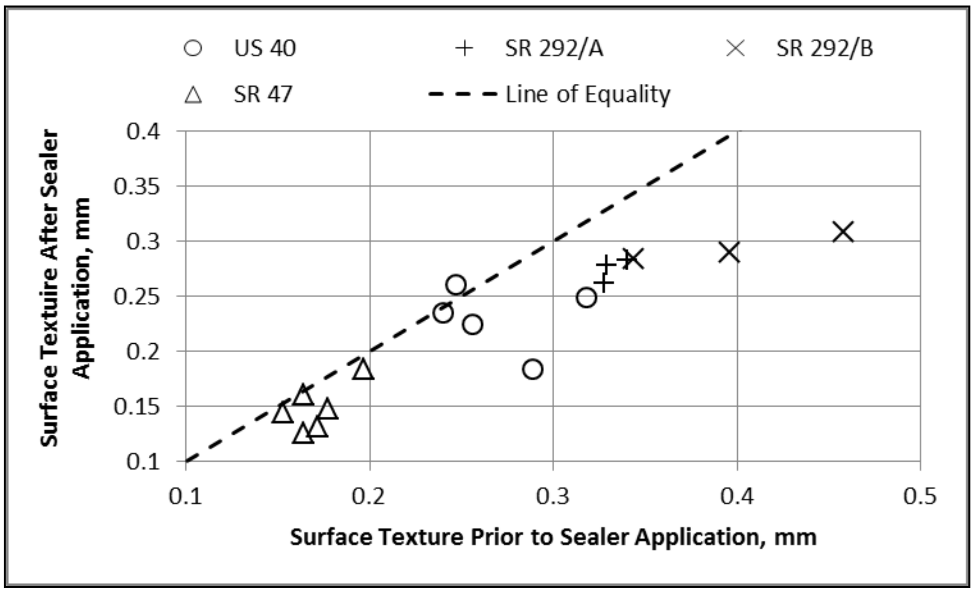


Figure 12. Surface Texture of the Individual Treated Sections; Prior to Spraying the Wearing Surface versus Post Sealer Applicaton

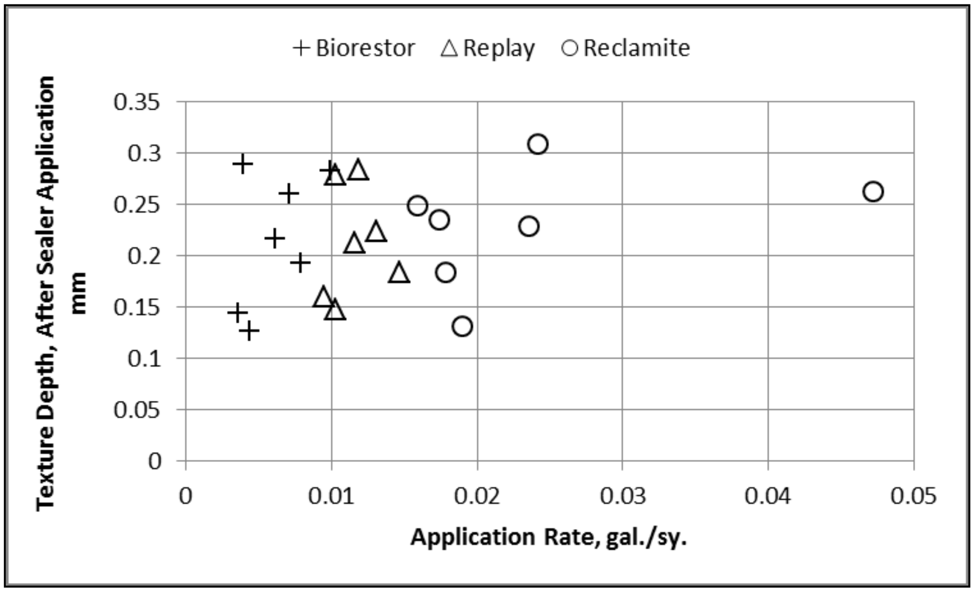
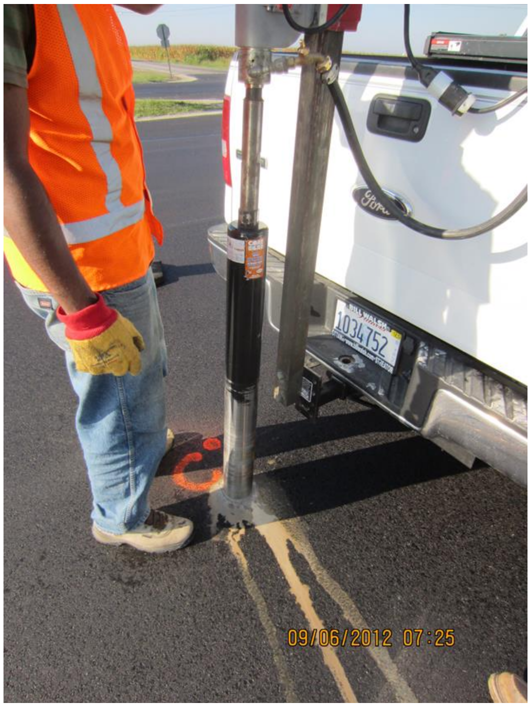


Figure 13. Surface Texture after Sealer Application of the Individual Treated Sections Compared to Sealer Application Rate



a. Coring the HMA Overlay

b. Non-Nuclear Density Gauge

Figure 14. HMA Density Tests; Cores and Non-Nuclear Density Gauge

Table 7 summarizes the average adjusted density measured within each test section prior to and after sealer application. The average COV for the density readings within a test section was 2.9 percent, suggesting a uniform mixture.

Table 7. HMA Mat Densities Measured Prior to and After Sealer Application with Non-Nuclear Density Gauge, pcf

Project	Lane	Condition	Type of Penetrating Sealer			
			Control	Biorestor	Replay	Reclamite
Prior to Sealer Application						
US-40	WB	Before	145.5	144.0	143.4	145.5
US-40	EB	Before	140.3	143.6	146.5	144.9
SR-292-A	WB	Before	144.0	140.6	143.7	144.9
SR-292-A	EB	Before				
SR-292-B	NB	Before	145.1	139.2	143.1	141.5
SR-292-B	SB	Before				
SR-47	WB	Before	144.4	148.1	144.6	146.7
SR-47	EB	Before	144.7	146.8	144.8	150.6
After Sealer Application						
US-40	WB	After	145.5			
US-40	EB	After	140.3	146.3	143.4	142.6
SR-292-A	WB	After	144.0	144.1	139.8	143.8
SR-292-A	EB	After				
SR-292-B	NB	After	145.1	141.9	141.9	144.1
SR-292-B	SB	After				
SR-47	WB	After	144.4	146.8	144.8	150.6
SR-47	EB	After	144.7	152.7	145.0	146.2

Air voids were calculated from the non-nuclear density readings using the maximum specific gravity measured in accordance with AASHTO T 209. Table 8 summarizes the average in place air voids calculated within each test section prior to and after sealer application. It is generally considered good practice for the average air voids to be below 8 percent. As shown, about 10 percent of the test sections exhibited air voids above 8 percent, while only one section was above 9 percent.

Table 8. HMA In Place Air Voids Calculated Prior to and After Sealer Application, percent

Project	Lane	Condition	Type of Penetrating Sealer			
			Control	Biorestor	Replay	Reclamite
Prior to Sealer Application						
US-40	WB	Before	5.44	6.41	6.78	5.44
US-40	EB	Before	8.80	6.66	4.83	5.86
SR-292-A	WB	Before	6.52	8.68	6.71	5.88
SR-292-A	EB	Before				
SR-292-B	NB	Before	4.76	8.65	6.12	7.16
SR-292-B	SB	Before				
SR-47	WB	Before	7.45	5.10	7.32	5.97
SR-47	EB	Before	7.25	5.90	7.18	3.48
After Sealer Application						
US-40	WB	After	5.44			
US-40	EB	After	8.80	4.95	6.78	7.33
SR-292-A	WB	After	6.52	6.46	9.19	6.65
SR-292-A	EB	After				
SR-292-B	NB	After	4.76	6.90	6.90	5.41
SR-292-B	SB	After				
SR-47	WB	After	7.45	5.90	7.18	3.48
SR-47	EB	After	7.25	2.13	7.05	6.31

Density readings were taken transversely across the HMA mat. Figure 15 shows the 8 test points equally spaced (except at the edges of the mat) transversely across the HMA mat. Table 9 summarizes the average density readings made along the transverse line, while figure 16 shows the transverse density profiles for each project and area.

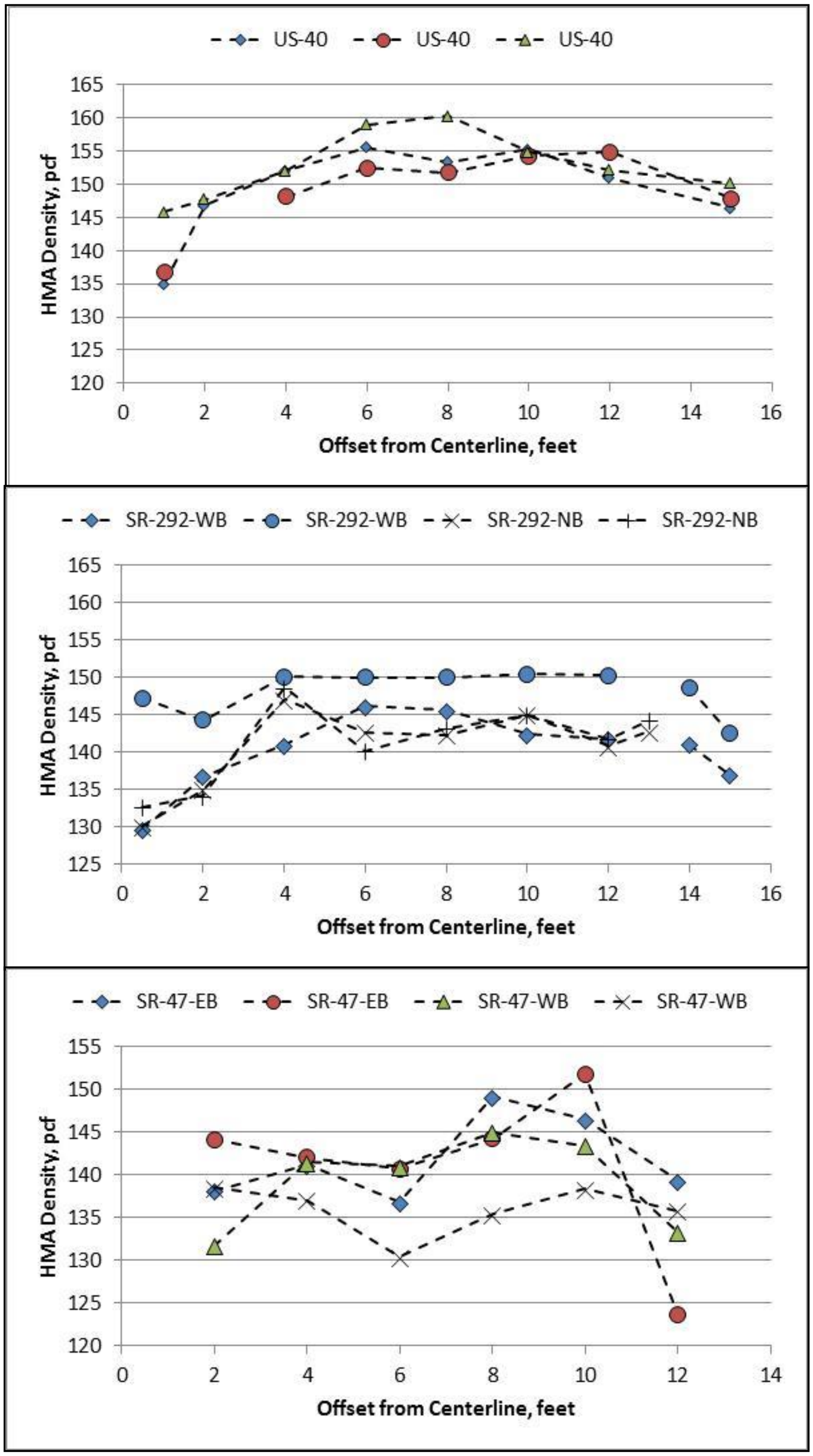
Figure 15. Test Point Layout for Measuring the Transverse Density Profile

Table 9. Mat Densities Measured with Non-Nuclear Density Gauge across the Mat (along a Transverse Line), Prior to Sealer Application; pcf

	Offset from Centerline, ft.									
Project	**1**	**2**	**4**	**6**	**8**	**10**	**12**	**15**		
US-40	135	146.8	152	155.5	153.3	155.2	150.9	146.4		
US-40	136.7		148.1	152.4	151.7	154.2	154.8	147.8		
US-40	145.8	147.7	152	159	160.3	154.8	152.1	150.1		

	Offset from Centerline, ft.									
	0.5	**2**	**4**	**6**	**8**	**10**	**12**	**13**	**14**	**15**
SR-292-WB	129.7	136.8	141	146.2	145.6	142.4	141.8		141.1	137
SR-292-WB	147.2	144.3	150.1	150	150	150.4	150.3		148.7	142.5
SR-292-NB	130.1	135	147.1	142.7	142.3	145	140.8	142.8		
SR-292-NB	132.7	134.2	148.7	140.2	143.2	145	141.8	144.3		

	Offset from Centerline, ft.									
		2	**4**	**6**	**8**	**10**	**12**			
SR-47-EB		138.1	141.2	136.8	149.1	146.5	139.3			
SR-47-EB		144.1	142	140.7	144.2	151.8	123.6			
SR-47-WB		131.7	141.5	141	145	143.4	133.3			
SR-47-WB		138.5	137	130.4	135.4	138.4	135.8			



(a) US-40 Project; Springfield: Typical transverse density profile across the mat.

(b) SR-292 Project, Location A and B, East Liberty: Typical transverse density profile across the mat.

(c) SR-47 Project, Sidney: Atypical transverse density profile across the mat – consistently lower densities measured at the mid-point of the paver (beneath the gear box) relative to the interior portion of the mat.

Figure 16. Transverse Density Profiles along Each Project and Area

3.5 Field Permeability Tests

Field permeability tests were performed at four random locations along each test section prior to and after sealer application. Two tests were performed at each location about 6 inches apart, and in many cases, the tests were repeated to confirm a test result. The National Center for Asphalt Technology (NCAT) water-based permeability device was used to measure the permeability of each test location. Figure 17 shows the field permeability device and test. Air-based permeability tests using the Kentucky device were initially planned but dropped from the study because that device was no longer available.

Figure 17. Field Permeability Test

Table 10 summarizes the mean permeability for each test section prior to and after sealer application.. The field permeability was found to be highly variable between the test sections, as well as between projects both prior to and after sealer application. The average COV for the permeability values within a test section was 56 percent, suggesting a lot of variability at the top of the wearing surface. Many of the tests were repeated to confirm the test values. On the average, the US-40 and SR-47 projects with the higher traffic levels had the lower permeability, while the two SR-292 projects with the lower traffic levels had the higher permeability.

Table 10. HMA Permeability Measured Prior to and After Sealer Application; 10^{-5} cm./sec.

Project	Lane	Condition	Type of Penetrating Sealer			
			Control	Biorestor	Replay	Reclamite
Prior to Sealer Application						
US-40	WB	Before	70	70.3	2.5	4.33
US-40	EB	Before	388	109	11.7	33.3
SR-292-A	WB	Before	191.8	472.8	489.2	363.7
SR-292-A	EB	Before				
SR-292-B	NB	Before	319.5	669.3	485.7	1915.7
SR-292-B	SB	Before				
SR-47	WB	Before	86.8	123.3	360.3	289.3
SR-47	EB	Before	43.8	102.7	87.3	155
After Sealer Application						
US-40	WB	After	70	2.75	18.2	5.67
US-40	EB	After	388	76.2	17.5	4.2
SR-292-A	WB	After	191.8	764.8	40	347.3
SR-292-A	EB	After				
SR-292-B	NB	After	319.5	361.8	26.6	1104
SR-292-B	SB	After				
SR-47	WB	After	86.8	81.3	308.7	235.8
SR-47	EB	After	43.8	71.2	16.7	136.7

As stated in the Introduction, it was reported or hypothesized that spraying sealers on the wearing surface shortly after HMA placement will increase durability and reduce permeability of the wearing surface. Figure 18 includes a comparison of the permeability prior to and after spraying the sealers. As shown, the permeability did decrease after spraying the sealer on the HMA wearing surface, except for three test sections along the US 40 and one section along SR 292/A. A more important observation from figure 18:

- For permeability values less than 100x10-5 cm./sec.; no consistent decrease was found between the values measured prior to and after sealer application.
- For permeability values greater than 100x10-5 cm./sec.; only a slight decrease was observed after sealer application.

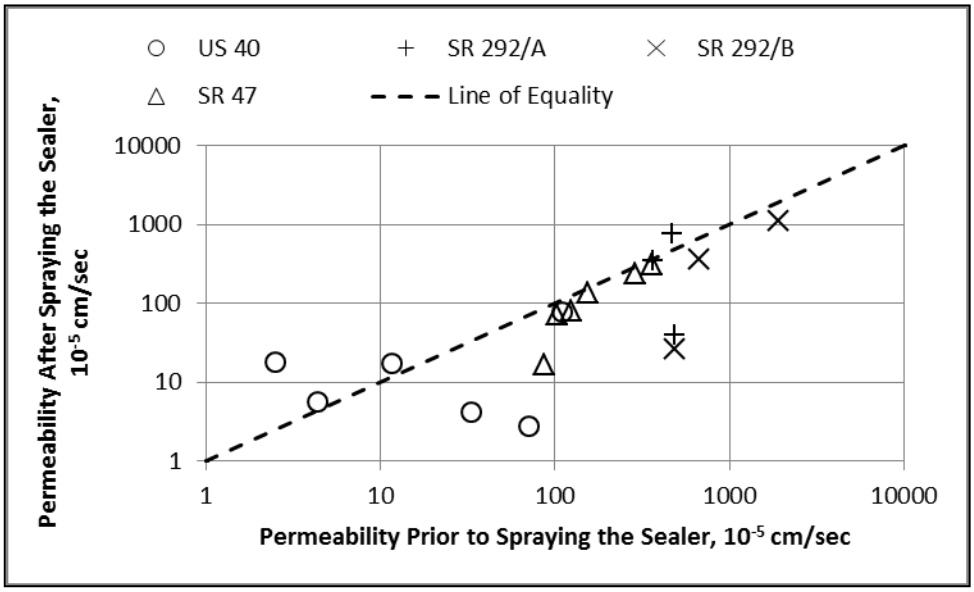


Figure 18. Permeability of HMA Wearing Surface of the Individual Test Sections – Prior to Compared to After Sealer Application

3.6 Friction or Skid Number Tests

ODOT performed all surface friction tests prior to and after sealer application at different time periods. Figure 19 shows the ODOT skid trailer used for this testing. The first set of friction tests were performed before sealer application, a second set of tests performed after the material had been placed at time 0 and at one day, a third set 7 days after treatment, and a fourth set 30 days after treatment. ODOT completed all friction testing using two tire types specified by ASTM: smooth and ribbed tires. The skid numbers (SNs) from the ribbed tire are summarized in this section, because most states use the ribbed tire for quantifying surface friction (Hall, et al., 2008).

Results from the friction testing prior to sealer application are included in table 11, while table 12 includes the friction test results for 0, 1, 7 and 30-days after sealer application for the ribbed tire. The treated sections prior to sealer application were not tested, so the SNs measured on the control sections were assumed for the other sections.

Figure 19. Friction or Skid Number Testing

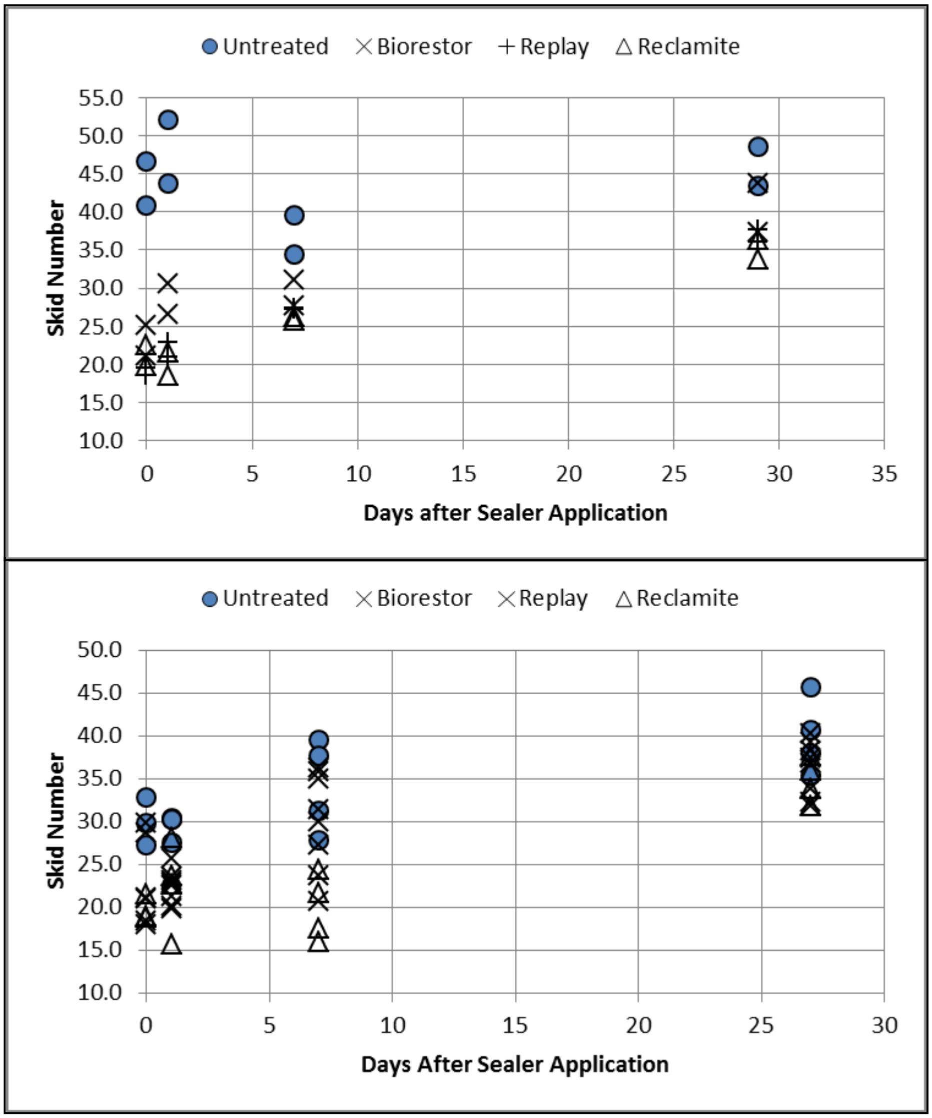
Table 11. Skid Numbers Measured Prior to Sealer Application; Ribbed Tire

Project	Lane	Condition	Type of Penetrating Sealer			
			Control	Biorestor	Replay	Reclamite
US-40	WB	Before	40.8	40.8	40.8	40.8
US-40	EB	Before	46.7	46.7	46.7	46.7
SR-292-A	WB	Before	32.8	32.8	32.8	32.8
SR-292-A	EB	Before	32.8	32.8	32.8	32.8
SR-292-B	NB	Before	27.3	27.3	27.3	27.3
SR-292-B	SB	Before	29.9	29.9	29.9	29.9
SR-47	WB	Before	38.6	38.6	38.6	38.6
SR-47	EB	Before	46.3	46.3	46.3	46.3

Figure 20 shows the average friction measured at different points in time for the different projects. As shown, all of the penetrating sealers significantly reduced the friction values or SNs in comparison to the control sections. Figure 21 also shows a comparison of the SNs of the sections immediately after sealer application and at 30-days after sealer application. As shown, the SNs did increase with time after sealer application for all three sealers, but even after 30 days, the SNs of the treated sections are still less than the control sections.

Table 12. Skid Numbers Measured after Sealer Application; Ribbed Tire

Project	Lane	Condition	Type of Penetrating Sealer			
			Control	Biorestor	Replay	Reclamite
0-Days After Sealer Application						
US-40	WB	After	40.8	21.1	18.6	22.6
US-40	EB	After	46.7	25.1	19.5	19.8
SR-292-A	WB	After	32.8	29.9	28.7	21.6
SR-292-A	EB	After	NA	NA	NA	NA
SR-292-B	NB	After	27.3	21.0	21.2	19.0
SR-292-B	SB	After	29.9	18.0	18.4	18.8
SR-47	WB	After	38.6	26.2	22.3	25.0
SR-47	EB	After	46.3	30.0	23.8	28.3
1-Day After Sealer Application						
US-40	WB	After	43.8	26.6	21.0	18.5
US-40	EB	After	52.0	30.6	22.8	21.5
SR-292-A	WB	After	27.6	22.9	19.9	22.8
SR-292-A	EB	After	30.2	25.7	23.5	15.7
SR-292-B	NB	After	30.3	22.5	23.2	28.2
SR-292-B	SB	After	30.4	20.1	21.3	23.7
SR-47	WB	After	NA	NA	NA	NA
SR-47	EB	After	NA	NA	NA	NA
7-Days After Sealer Application						
US-40	WB	After	39.6	31.0	27.4	25.8
US-40	EB	After	34.4	27.7	27.2	26.3
SR-292-A	WB	After	31.3	35.0	27.3	16.1
SR-292-A	EB	After	27.9	20.8	23.7	17.6
SR-292-B	NB	After	39.6	35.9	36.3	21.7
SR-292-B	SB	After	37.7	31.5	30.0	24.5
SR-47	WB	After	38.9	26.2	22.3	25.0
SR-47	EB	After	46.3	30.0	23.8	28.3
30-Days After Sealer Application						
US-40	WB	After	43.4	37.3	36	33.8
US-40	EB	After	48.5	43.8	37.6	36.4
SR-292-A	WB	After	38	36.8	33.9	33.8
SR-292-A	EB	After	35.4	31.8	32.3	31.9
SR-292-B	NB	After	45.7	40.2	38.3	36
SR-292-B	SB	After	40.7	39.3	37.5	37.6
SR-47	WB	After	NA	NA	NA	NA
SR-47	EB	After	NA	NA	NA	NA

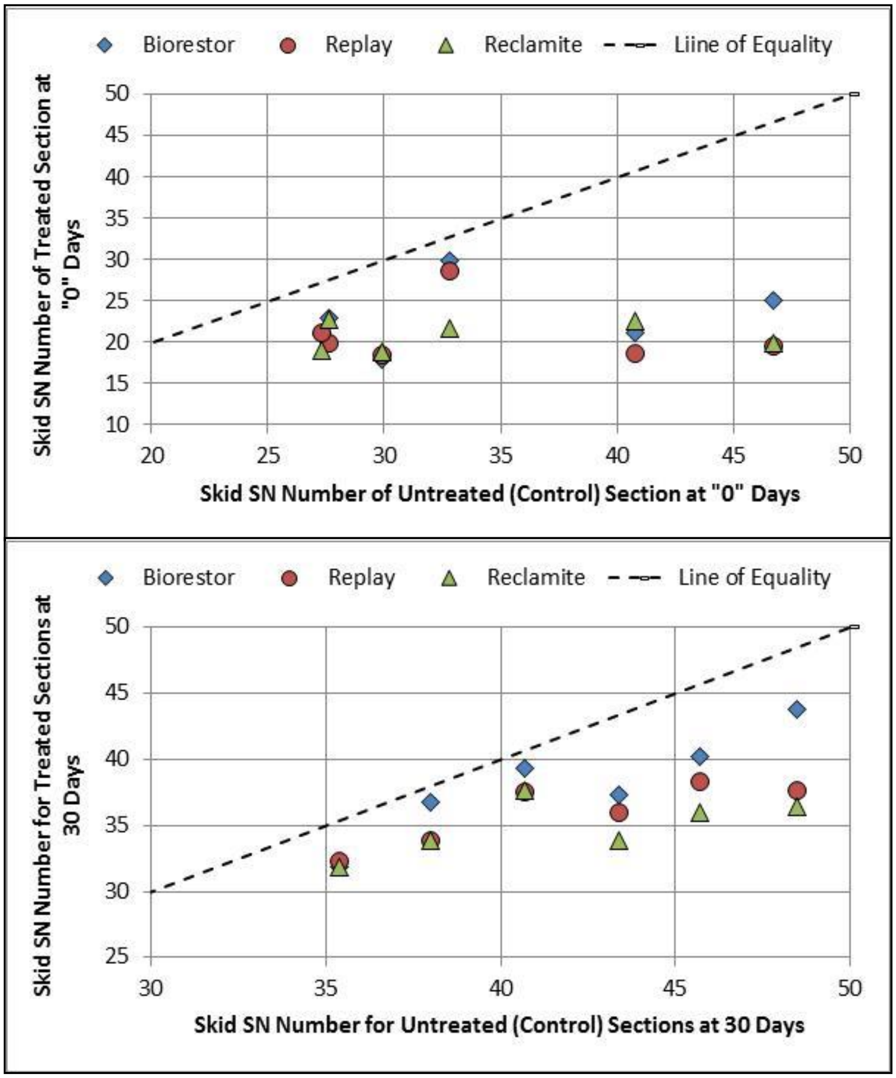


(a) US 40 Project.

(b) SR 292 Project; Locations A and B.

NOTE: The SNs measured for the SR 47, Sydney project are not included in figure 19, because they were only measured immediately and 7 days after sealer application.

Figure 20. Skid Numbers Measured at Different Ages for the Control and Treated Sections, Ribbed Tire



(a) Comparison of Skid Numbers between untreated and treated segments measured immediately after sealer placement.

(b) Comparison of Skid Numbers between untreated and treated segments measured 30-days after sealer placement.

Figure 21. Comparison of the Skid Numbers Measured at Different Time Periods between the Control and Treated Sections; Ribbed Tire

3.7 Summary

Table 13 lists the average surface properties measured prior to and after sealer application for all sections combined. On the average, the permeability and texture depth decreased, while the density slightly increased after spraying the sealers on the HMA wearing surface for most of the projects. The following lists observations made between the projects and test sections that may be pertinent to the performance of the control and treated test sections.

- The surface property found to be significantly different between the values measured prior to and after sealer application is SN (see figure 21). The SN significantly decreased after sealer application for all treated sections.

- The SR-47 project exhibited different surface characteristics in comparison to the other projects, which are noted below:
    - Figure 22 includes a comparison between the average texture depth and average permeability for all test sections combined. As shown and expected, the permeability increased with an increase in texture depth, except for the SR-47 project.
    - Figure 23 includes a comparison between HMA density and permeability. As shown and expected, the permeability increases for the lower HMA densities. The HMA wearing surface for the SR-47 project has higher permeability relative to the HMA density in comparison to the other projects.
    - Figure 24 includes a comparison between HMA air voids and permeability. As shown and expected, the permeability increased with the higher air voids. The HMA wearing surface for the SR-47 project has higher permeability relative to the HMA air voids in comparison to the other projects.
    - The SR-47 HMA mixture consistently exhibited lower texture depths, higher densities, and lower air voids in comparison to the other projects, while the permeability was higher within the same range of other mixture properties (see figures 22, 23, and 24). The reason for the higher permeability relative to the other in place mixture properties is unknown. The SR-47 HMA mixture, however, is coarser with lower asphalt content (see table 2) which can result in more interconnected air voids near the surface. More importantly, as noted in chapter 2, the sealers were sprayed on the HMA wearing surface along SR-47 much later than for the other three projects.

Table 13. Surface Properties Measured for the Different Projects Prior to and After Sealer Application; All Sections Combined

Project		Density, pcf	Air Voids, percent	Permeability, 10^{-5} cm./sec.	Texture Depth, mm
Prior to Sealer Application:					
US-40	EB Lane	143.8	6.54	135.5	0.272
	WB Lane	144.6	6.02	36.8	0.265
SR-292/A		143.3	6.95	379.4	0.329
SR-292/B		142.2	6.67	847.6	0.403
SR-47	WB Lane	145.9	6.46	214.9	0.167
	EB Lane	146.7	5.95	97.2	0.162
After Sealer Application:					
US-40	EB Lane	144.1	6.35	32.6	0.244
	WB Lane	---	---	8.9	0.204
SR-292/A		142.6	7.43	384.0	0.274
SR-292/B		142.6	6.40	497.5	0.294
SR-47	WB Lane	147.4	5.52	208.6	0.135
	EB Lane	147.9	5.16	74.9	0.163

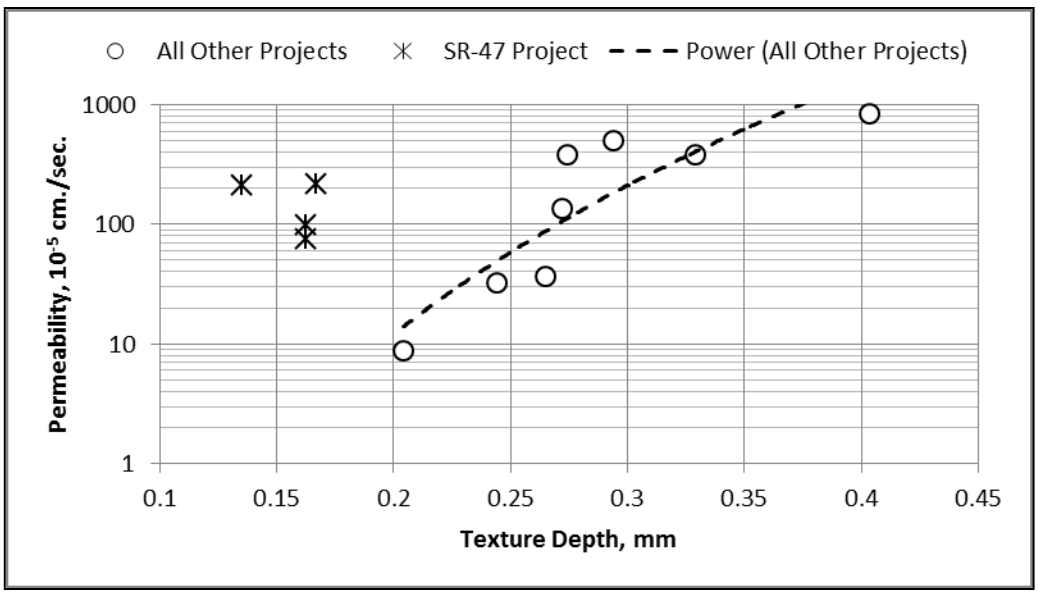


Figure 22. Average Texture Depth Compared to Average Permeability for all Test Sections Combined for each Project

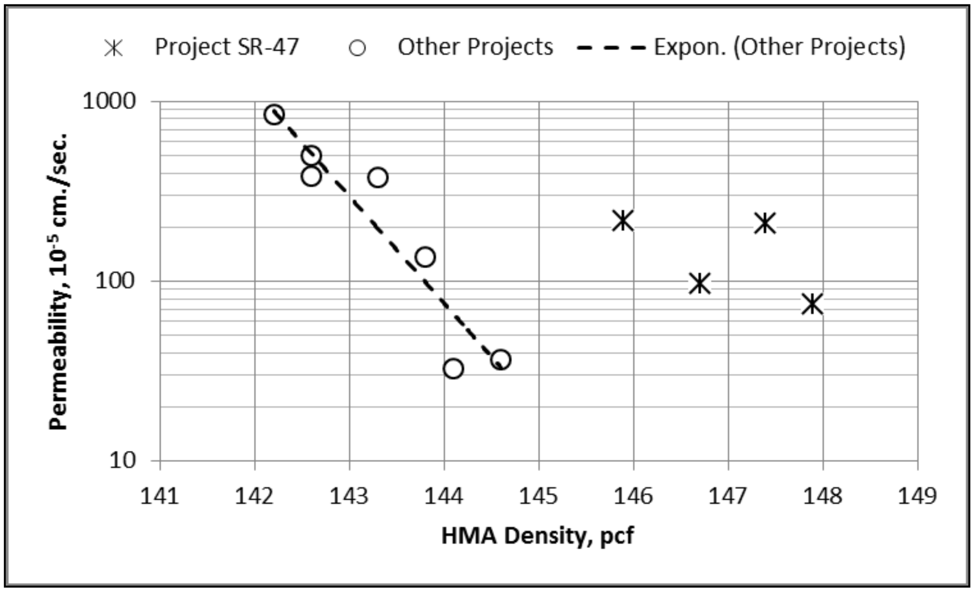


Figure 23. Average HMA Density compared to Average Permeability for all Test Sections Combined for each Project

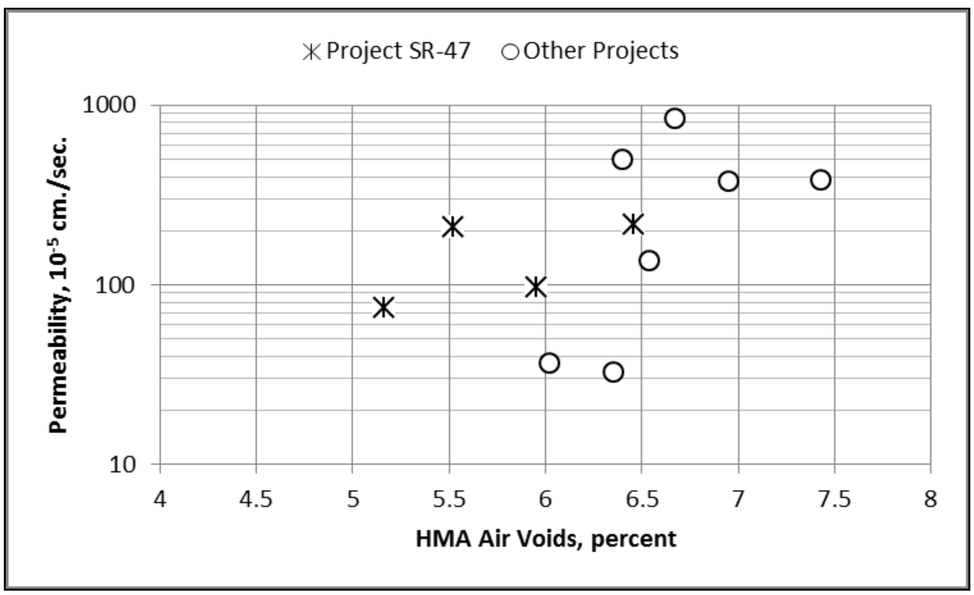


Figure 24. Average HMA Air Void Compared to Average Permeability for all Test Sections Combined for each Project

4. TEST SECTION PERFORMANCE

This chapter provides information and data from monitoring the tests sections over about 4 years. Three basic activities or surface property tests were completed as part of the monitoring process, which are listed below and discussed in the following sections of this chapter:

1. Distress surveys on an annual basis.
2. Sand patch tests on an every other year frequency.
3. Field permeability tests on an every other year frequency.

4.1 Distress/Condition Surveys

Distress or condition surveys were performed in accordance with the FHWA Distress Identification Manual, as mentioned in chapter 3. Distress surveys were also performed by ODOT personnel for determining the pavement condition rating (PCR) value. The ODOT annual surveys were conducted using their Pavement Condition Rating System Manual (ODOT, 2006). PCR values were calculated using both distress data sets in accordance with Ohio's Pavement Condition Rating System Manual. The following subsections provide a brief explanation of the distress types and magnitudes exhibited and recorded on each project.

4.1.1 US-40: Springfield, OH

The primary distress exhibited along all test sections of the US 40 project is transverse cracking, none of which have been sealed. With the exception of transverse cracking, all test sections are considered in very good condition. Figures 25 to 28 show examples of the condition of the surface for each test section in the eastbound lane in 2016, while figures 29 to 32 include examples of the surface condition in the westbound lane. Extensive lengths of transverse cracks with various severity levels were observed along all of the treated and control or untreated sections.

The transverse cracks are reflection cracks from the underlying transverse joints and mid-slab cracks of the JPCP. Some of these cracks are relatively wide and exhibit adjacent cracking to the transverse crack and/or crack deterioration (see figures 25 and 28). Reflection cracks started to occur even before sealer application. Figure 33 shows the growth of total and moderate severity transverse crack lengths in the two control sections (one in the eastbound and one in the westbound outer lane). As shown, there is considerable growth in the length of transverse cracks shortly after sealer application. The growth of the transverse crack length in the treated sections was similar to the control sections; no significant reduction in the length or severity of the transverse cracks in the treated sections. The FHWA/LTPP distress surveys are similar in distress extent and severity for the treated sections.

Figure 25. Project US-40, Springfield, Eastbound Lane: Photograph showing Typical Cracking Distress along Control Test Section, Summer of 2016

Figure 26. Project US-40. Springfield, Eastbound Lane: Photograph showing Typical Cracking Distress along Replay Test Section, Summer of 2016

Figure 27. Project US-40, Springfield, Eastbound Lane: Photograph showing Typical Cracking Distress along Reclamite Test Section, Summer of 2016

Figure 28. Project US-40, Springfield, Eastbound Lane: Photograph showing Typical Cracking Distress along Biorestor Test Section, Summer of 2016

Figure 29. Project US-40, Springfield, Westbound Lane: Photograph showing Typical Cracking Distress along Control Test Section, Summer of 2016

Figure 30. Project US-40, Springfield, Westbound Lane: Photograph showing Typical Cracking Distress along Replay Test Section, Summer of 2016

Figure 31. Project US-40, Springfield, Westbound Lane: Photograph showing Typical Cracking Distress along Reclamite Test Section, Summer of 2016

Figure 32. Project US-40, Springfield, Westbound Lane: Photograph showing Typical Cracking Distress along Biorestor Test Section, Summer of 2016

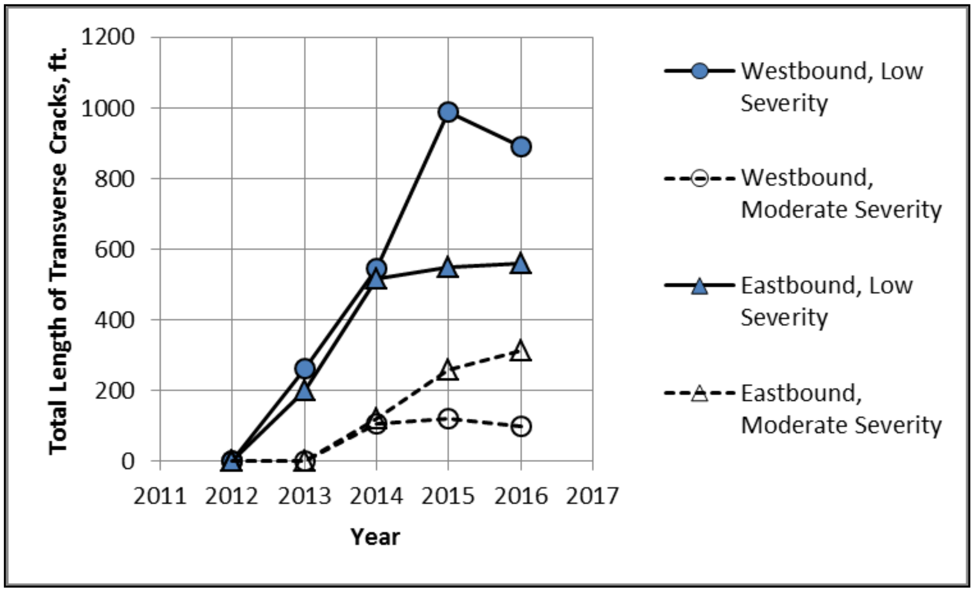


Figure 33. Project US-40, Springfield: Growth of Transverse Crack Lengths within Monitoring Period for Control Sections

In summary, transverse cracks (reflection cracks) are the predominant distress along all test sections. Longitudinal cracks along the longitudinal construction joints and localized, low severity raveling were also recorded. The following summarizes the differences between the ODOT and FHWA/LTPP distress surveys.

- Higher percentages of reflection cracks were recorded using the FHWA/LTPP procedure.
- Greater lengths of longitudinal cracks were recorded using the FHWA/LTPP procedure. Cracks along the longitudinal construction joints were included within the longitudinal cracking category.
- No pressure damage/upheaval (bumps) were identified or recorded using the FHWA/LTPP procedure.
- Only localized raveling of a low severity level were identified and recorded in some of the test sections using the FHWA/LTPP procedure.

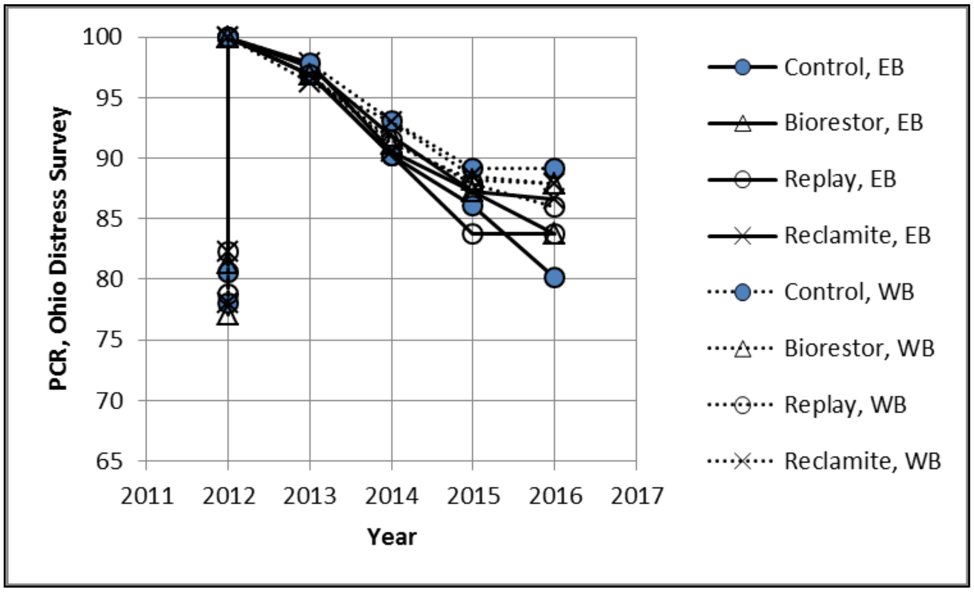
Table 14 lists the PCR values calculated from both distress surveys in accordance with the ODOT procedure, and lists the total extent of the predominant distresses identified and recorded from the FHWA/LTPP condition surveys. Figure 34.a shows the change in PCR values over time for all test sections along the project using the ODOT condition survey data. As shown, no consistent difference was found between the PCR values of the treated and control sections. PCR values were also calculated from the FHWA/LTPP distress surveys in accordance with the ODOT procedure and are shown in figure 34.b. No significant or consistent difference was observed between treated and control sections.

Table 14. Extent of the Predominant Distress Exhibited in 2016 and PCR Values Calculated for the US-40 Springfield Project

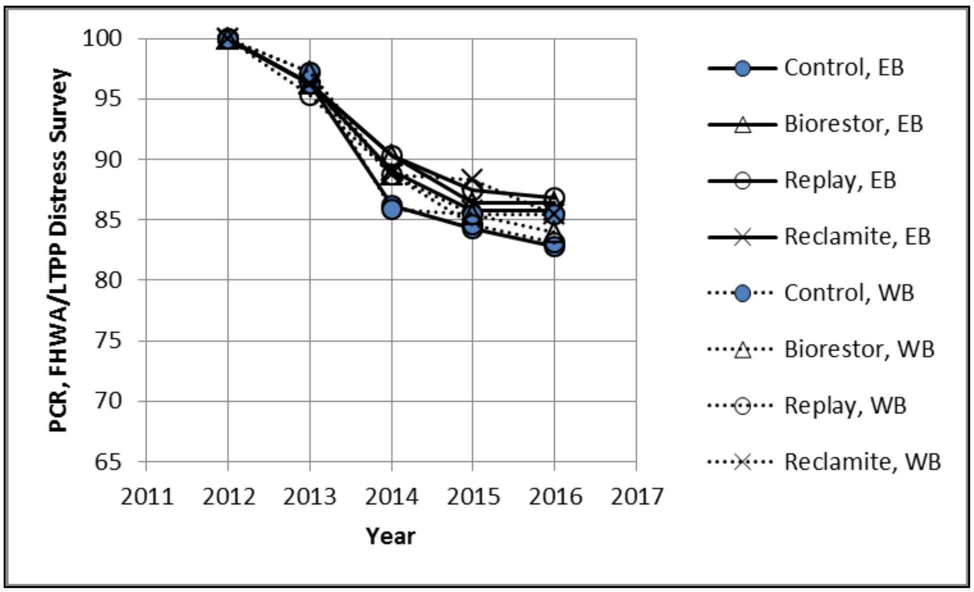
Test Section	Lane	Transverse Crack Length, FHWA/LTPP, ft.		PCR Values	
		Low	Moderate	FHWA/LTPP	Ohio DOT
Control	Westbound	891	97	85.4	89.2
	Eastbound	561	311	82.8	80.2
Biorestor	Westbound	989	144	83.9	87.9
	Eastbound	476	237	86.4	83.8
Replay	Westbound	706	130	83.1	86.0
	Eastbound	468	223	86.8	83.8
Reclamite	Westbound	680	93	85.4	87.9
	Eastbound	599	106	85.8	86.6

4.1.2 SR-292/A: Southeast of East Liberty, OH

Multiple lengths of transverse cracks and areas of longitudinal cracks were observed along all test sections. A few of the transverse and longitudinal cracks and/or construction joints have been sealed in localized areas (see figure 35). Figures 35 to 38 show examples of the condition of the surface for each test section. The transverse cracks are believed to be thermal or low temperature related cracks, while the longitudinal cracks are traffic related or fatigue cracks. Transverse cracks are low to moderate severity, while the longitudinal fatigue cracks are considered low severity.



a. PCR Values Derived from ODOT Distress Surveys



b. PCR Values Derived from FHWA/LTPP Distress Surveys

Figure 34. Project US-40, Springfield: Decrease in PCR Value through Monitoring Period

Figure 35. Project SR-292/A, East Liberty: Photograph showing Typical Cracking Distress along Control Test Section, Summer of 2016

Figure 36. Project SR-292/A, East Liberty: Photograph showing Typical Cracking Distress along Replay Test Section, Summer of 2016

Figure 37. Project SR-292/A, East Liberty: Photograph showing Typical Cracking Distress along Reclamite Test Section, Summer of 2016

Figure 38. Project SR-292/A: Photograph showing Typical Cracking Distress along Biorestor Test Section, Summer of 2016

Transverse and longitudinal cracks are the predominant distresses along all test sections. Figures 39 and 40 show the growth of the longitudinal and transverse cracks in the two control sections along this project, respectively. Transverse cracks were exhibited a couple of years after sealer application, while the longitudinal cracks started to occur during the fourth monitoring year. Longitudinal cracks along the longitudinal construction joints and localized low severity raveling in localized areas were recorded using the FHWA/LTPP distress surveys. The following summarizes differences between the FHWA/LTPP and ODOT distress surveys.

- ODOT performed their distress surveys using the composite pavement form. The FHWA/LTPP distress surveys were conducted assuming the existing structure was a flexible pavement. The ODOT pavement survey form was used for computing the PCR values using the data from the FHWA/LTPP distress surveys.
- No pressure damage/upheaval (bumps) was identified or recorded using the FHWA/LTPP procedure.
- Longitudinal cracks were exhibited in and/or adjacent to the wheel paths, so these cracks were recorded as fatigue cracks using the FHWA/LTPP procedure.
- ODOT defined the transverse and longitudinal cracks as block cracking, while these cracks were recorded separately in the FHWA/LTPP distress surveys.
- Localized raveling of a low severity was identified and recorded in some of the test sections using the FHWA/LTPP procedure.

Table 15 summarizes the PCR values calculated from the FHWA/LTPP and ODOT distress surveys and lists the extent of the predominant distresses identified and recorded from the FHWA/LTPP condition surveys. Figure 41.a shows the decrease in the PCR values derived from the ODOT distress surveys over the monitoring period, while figure 41.b shows the decrease in the PCR values derived from the FHWA/LTPP distress surveys. As shown, no consistent difference was found between the treated and control sections using both data sets.

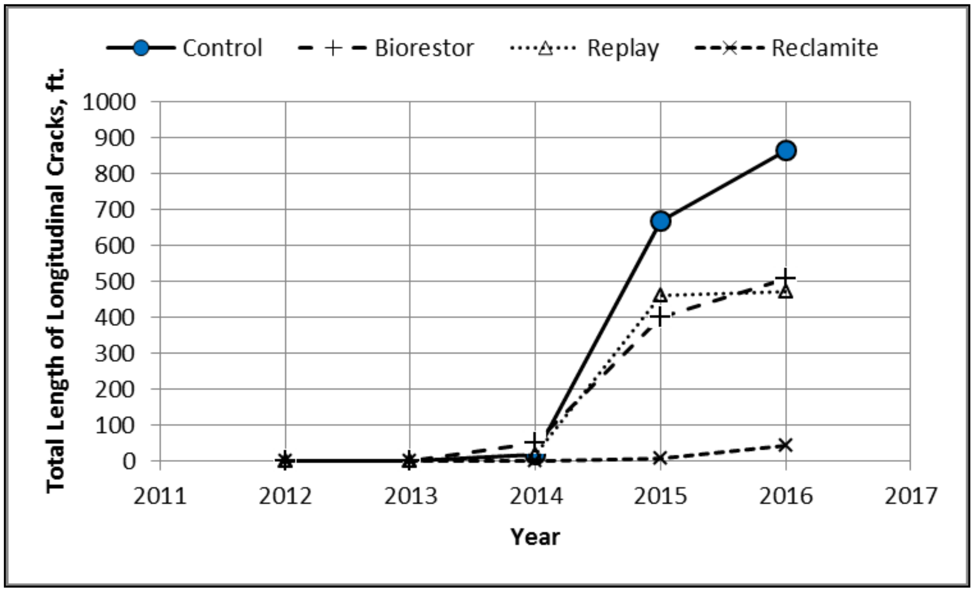


Figure 39. Project SR-292/A, East Liberty: Growth of Area of Total Length of Longitudinal Cracks within Monitoring Period for Control Section

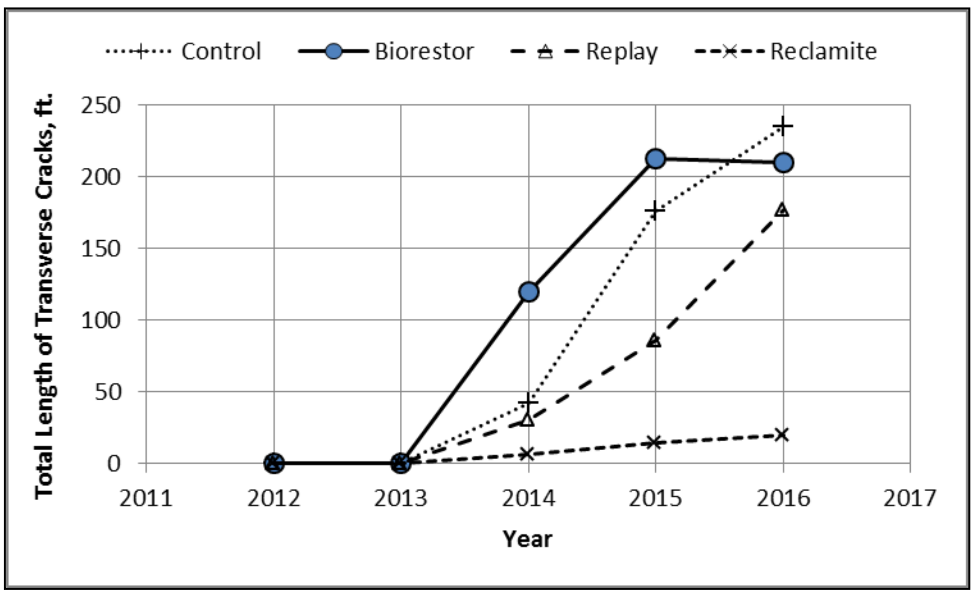


Figure 40. Project SR-292/A, East Liberty: Growth of Transverse Crack Length within Monitoring Period for Control Section

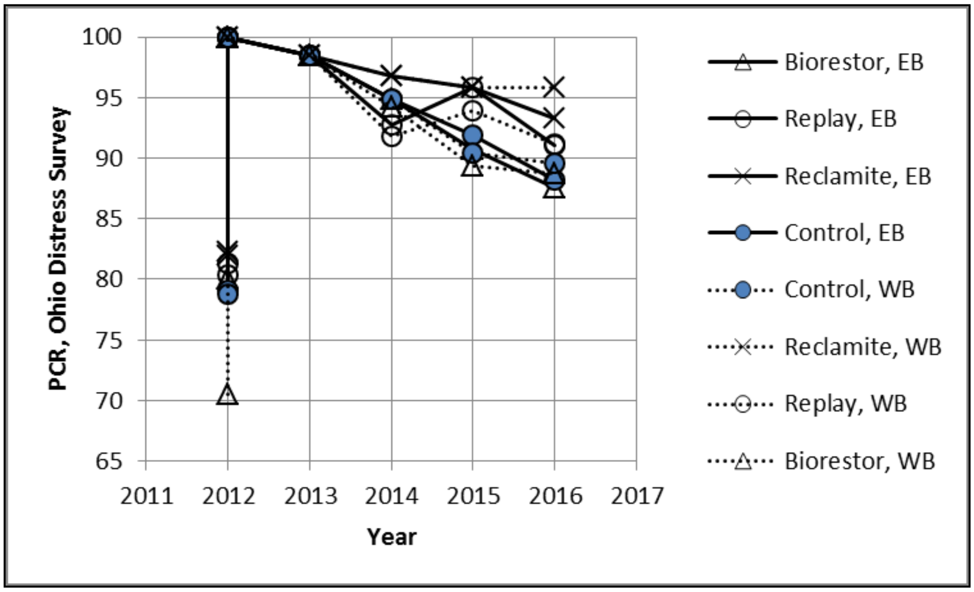
Table 15. Extent of the Predominant Distresses Exhibited in 2016 and PCR Values Calculated for the SR-292/A, East Liberty Project

Test Section	Lane	FHWA/LTPP Distresses		PCR Values	
		Transverse Cracks	Longitudinal Cracks	FHWA/LTPP	Ohio DOT
Control	Westbound	235	865	84.1	89.6
	Eastbound	209	1002	87.6	88.2
Biorestor	Westbound	210	506	89.9	88.8
	Eastbound	272	281	88.0	87.6
Replay	Westbound	177	471	89.9	91.2
	Eastbound	155	509	89.4	91.1
Reclamite	Westbound	20	44	89.9	95.8
	Eastbound	14	19	88.4	93.3

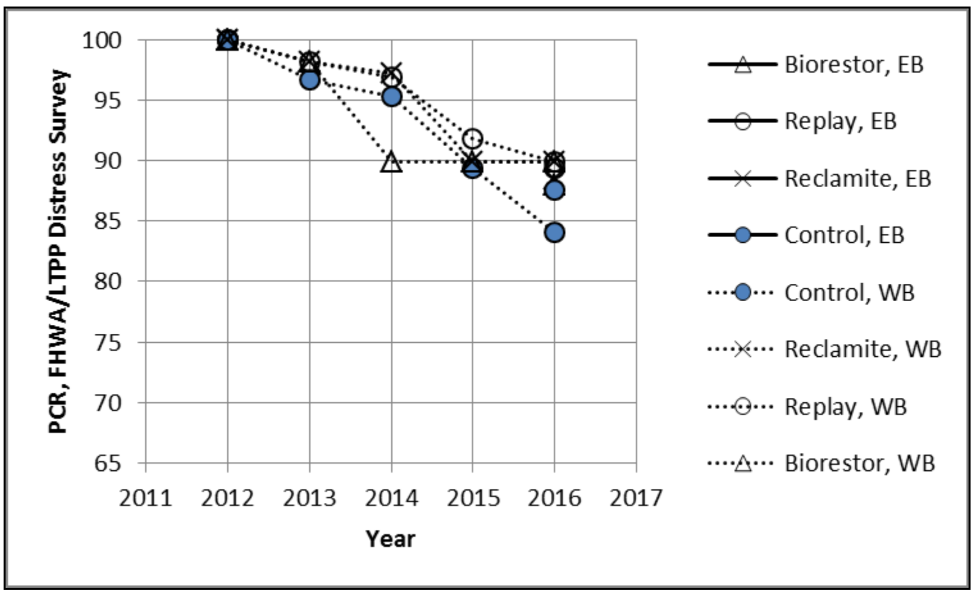
4.1.3 SR-292/B: Northwest of East Liberty, OH

Multiple lengths of transverse and longitudinal cracks and areas of fatigue cracking were observed along all test sections (treated and control). The fatigue and longitudinal cracks are the predominant distresses, and none of these cracks have been sealed. Figures 42 to 45 show examples of the surface condition for each test section.

The transverse cracks are believed to be a result of low temperatures, while the fatigue cracks are traffic related. Most of the transverse, longitudinal, and fatigue cracks are considered low severity. The longitudinal cracks are outside the wheel paths along or near the edge of pavement (probably caused by farm traffic riding along the pavement’s edge) and along the longitudinal construction joint.



a. PCR Values Derived from ODOT Distress Surveys



b. PCR Values Derived from FHWA/LTPP Distress Surveys

Figure 41. Project SR-292/A, East Liberty: Decrease in PCR Value through Monitoring Period

Figure 42. Project SR-292/B, East Liberty: Photograph showing Typical Cracking Distress along Control Test Section, Summer of 2016

Figure 43. Project SR-292/B, East Liberty: Photograph showing Typical Cracking Distress along Replay Test Section, Summer of 2016

Figure 44. Project SR-292/B, East Liberty: Photograph showing Typical Cracking Distress along Reclamite Test Section, Summer of 2016

Figure 45. Project SR-292/B, East Liberty: Photograph showing Typical Cracking Distress along Biorestor Test Section, Summer of 2016

The longitudinal and transverse cracks started to occur a few years after sealer application, while fatigue cracks were exhibited in the fourth monitoring year. Figures 46 and 47 show the growth of fatigue and longitudinal cracks along this project for the test sections in the northbound lane, respectively. In addition, minor lengths of longitudinal cracks along the longitudinal construction joints and localized low severity raveling were recorded using the FHWA/LTPP distress surveys. The following summarizes the differences between the FHWA/LTPP and ODOT distress surveys.

- ODOT defined the transverse and longitudinal cracks as block cracking, while these cracks were recorded separately in the FHWA/LTPP distress surveys.
- Some longitudinal cracks were exhibited in and/or adjacent to the wheel paths, so these cracks were recorded as fatigue cracks using the FHWA/LTPP procedure.
- Localized raveling of a low severity was identified and recorded in some of the test sections, but not all, using the FHWA/LTPP procedure.

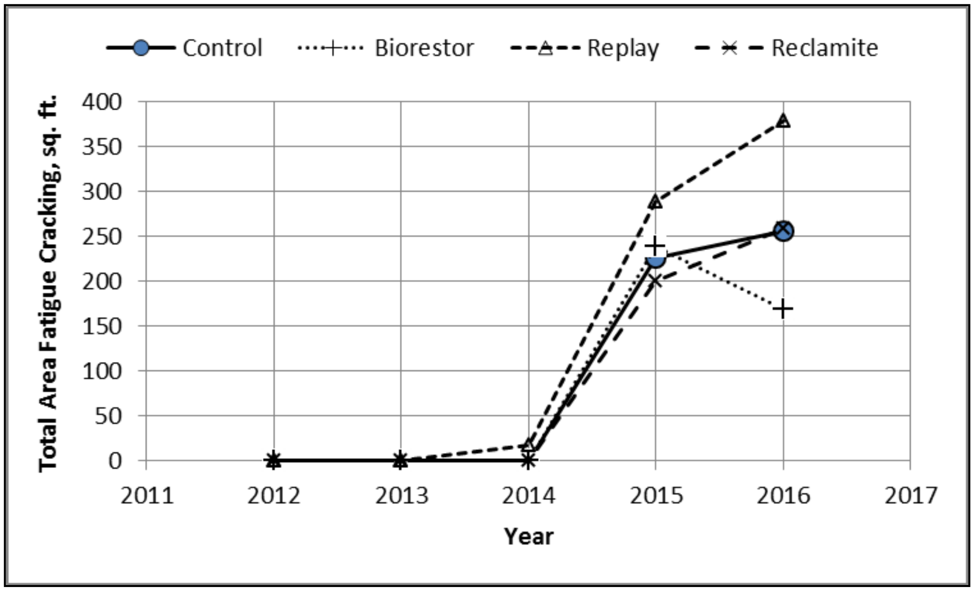


Figure 46. Project SR-292/B, East Liberty: Growth of Area of Fatigue Crack within Monitoring Period for Control Section

Table 16 summarizes the PCR values calculated from the FHWA/LTPP and ODOT distress surveys and lists the total extent of distresses identified and recorded from the FHWA/LTPP distress surveys. Figure 48 shows the decrease in the PCR value over the monitoring period for this project. As shown, there is no significant and consistent difference between the treated and control sections.

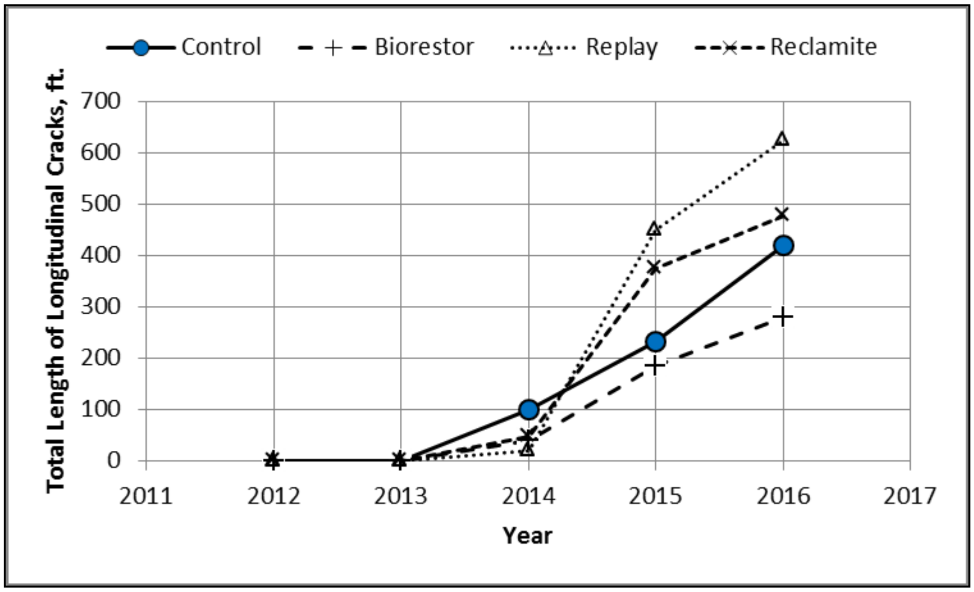
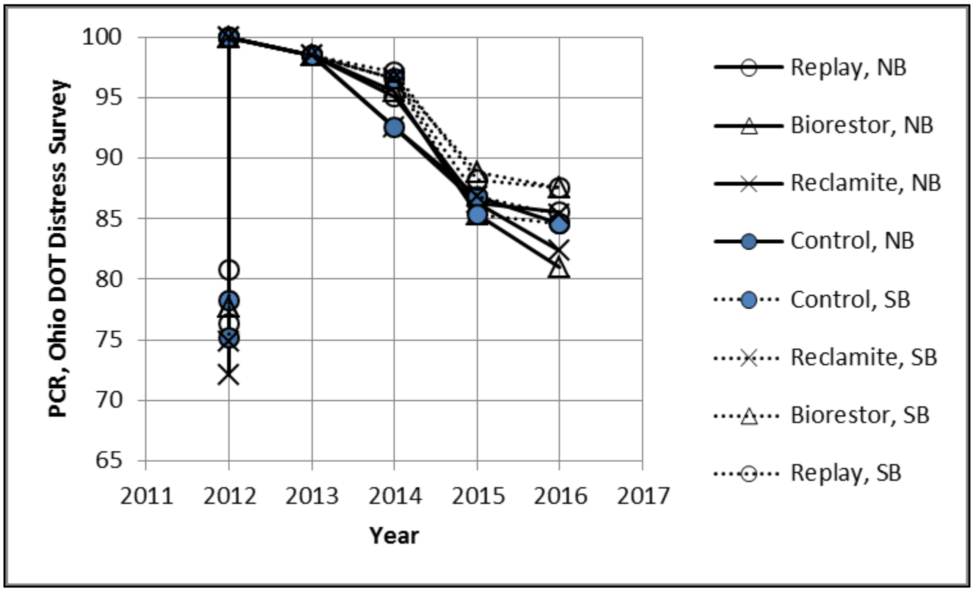


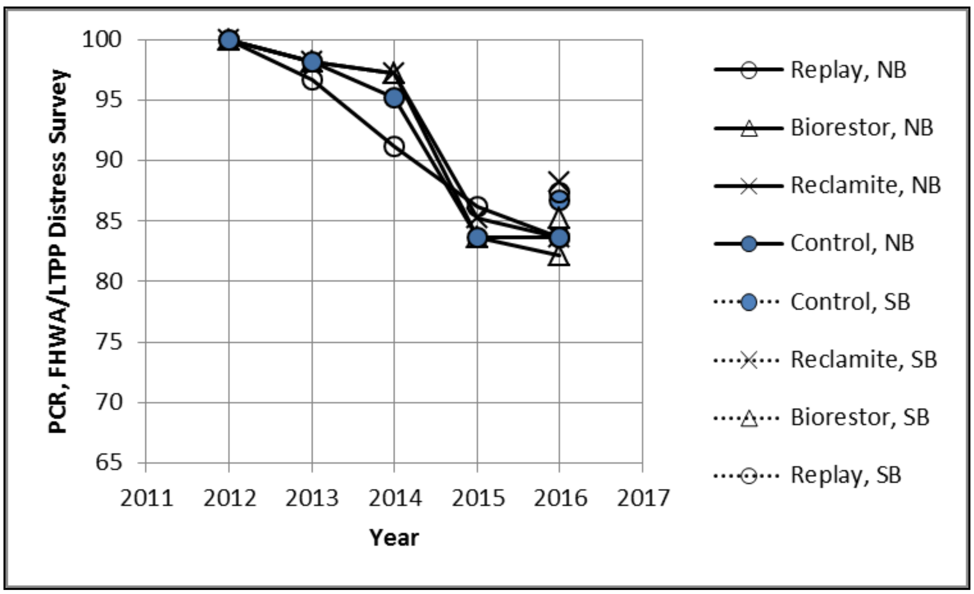
Figure 47. Project SR-292/B, East Liberty: Growth of Longitudinal Crack Length within Monitoring Period for Control Section

Table 16. Extent of the Predominant Distresses Exhibited in 2016 and PCR Values Calculated for the SR-292/B, East Liberty Project

Test Section	Lane	FHWA/LTPP Distresses		PCR Values	
		Longitudinal Cracks	Fatigue Cracks	FHWA/LTPP	Ohio DOT
Control	Northbound	421	256	83.7	84.7
	Southbound	378	0	86.7	84.7
Biorestor	Northbound	281	168	82.2	81.1
	Southbound	146	0	85.2	87.6
Replay	Northbound	625	379	83.7	85.6
	Southbound	43	0	87.4	87.6
Reclamite	Northbound	478	258	83.7	82.4
	Southbound	260	0	88.2	85.4



a. PCR Values Derived from ODOT Distress Surveys



b. PCR Values Derived from FHWA/LTPP Distress Surveys

Figure 48. Project SR-292/B, East Liberty: Decrease in PCR Value through Monitoring Period

4.1.4 US-47: Sidney, OH

Longitudinal cracking is the predominant distress observed along all test sections, only a few transverse cracks were observed in any one section. None of the cracks have been sealed. The performance of this project is considered excellent. Figures 49 to 52 show examples of the condition of the surface for each test section along the westbound lane, while figures 53 to 56 show the condition of the test sections along the eastbound lane. Most of the longitudinal cracks are outside the wheel path and/or located along the longitudinal construction joints, which are considered non-load related. The transverse cracks are believed to be low temperature related. All cracks are considered low severity.

The longitudinal cracks started to occur a year after sealer application. Figure 57 shows the growth of the longitudinal cracks in all test sections along this project.

Figure 49. Project SR-47, Sydney, Westbound Lane: Photograph showing Typical Cracking Distress along Control Test Section, Summer of 2016

Figure 50. Project SR-47, Sydney, Westbound Lane: Photograph showing Typical Cracking Distress along Replay Test Section, Summer of 2016

Figure 51. Project SR-47, Westbound Lane: Photograph showing Typical Cracking Distress along Reclamite Test Section, Summer of 2016

Figure 52. Project SR-47, Sydney, Westbound Lane: Photograph showing Typical Cracking Distress along Biorestor Test Section, Summer of 2016

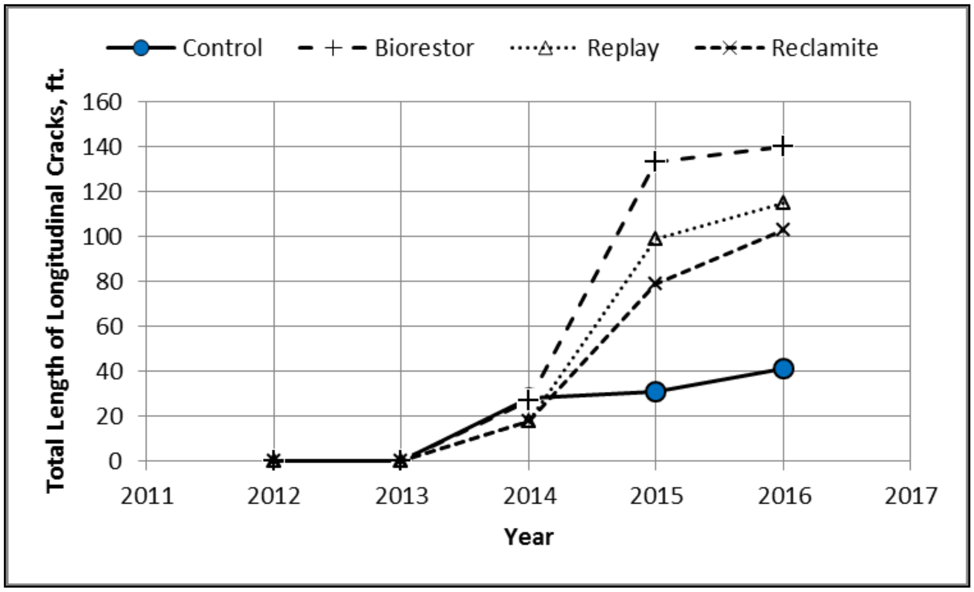
Figure 53. Project SR-47, Sydney, Eastbound Lane: Photograph showing Typical Cracking Distress along Control Test Section, Summer of 2016

Figure 54. Project SR-47, Sydney, Eastbound Lane: Photograph showing Typical Cracking Distress along Replay Test Section, Summer of 2016

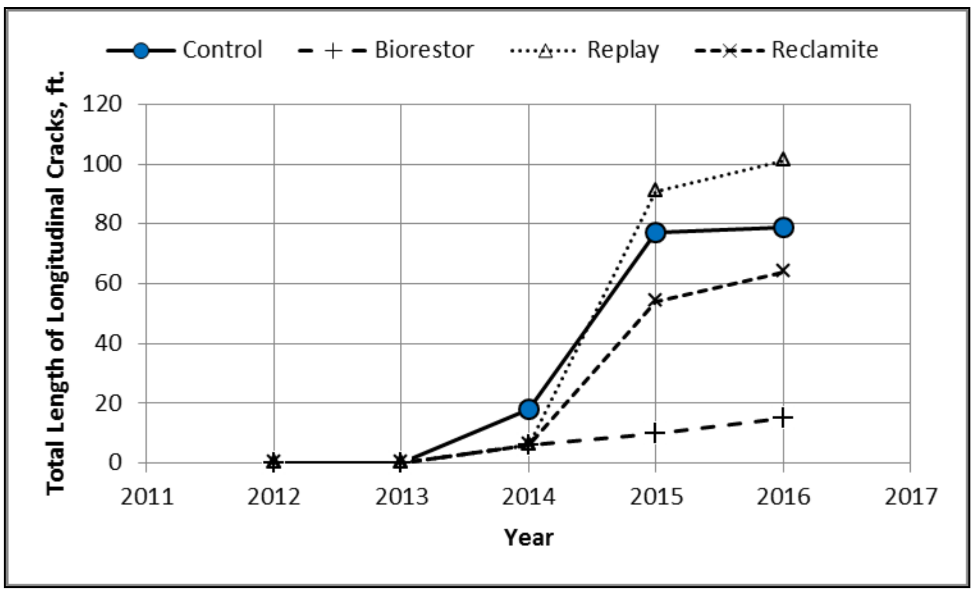
Figure 55. Project SR-47, Eastbound Lane: Photograph showing Typical Cracking Distress along Reclamite Test Section, Summer of 2016

Figure 56. Project SR-47, Sydney, Eastbound Lane: Photograph showing Typical Cracking Distress along Biorestor Test Section, Summer of 2016

Table 17 summarizes the PCR values calculated from the FHWA/LTPP and ODOT distress surveys and lists the total extent of the predominant distresses identified and recorded from the FHWA/LTPP distress surveys. Figure 58 shows the decrease in the PCR value within the monitoring period for all test sections. As shown, no consistent difference was found between the treated and control sections.



a. Eastbound Lane



b. Westbound Lane

Figure 57. Project SR-47, Sydney: Growth of Total Longitudinal Crack Length within Monitoring Period for Control Section

Table 17. Extent of the Predominant Distress Exhibited in 2016 and PCR Values Calculated for the US-47 Sidney Project

Test Section	Lane	Longitudinal Crack Length, FHWA/LTPP, ft.	PCR Values	
			FHWA/LTPP	Ohio DOT
Control	Westbound	41	88.5	NA
	Eastbound	79	86.7	NA
Biorestor	Westbound	140	88.2	NA
	Eastbound	15	94.2	NA
Replay	Westbound	115	90.2	NA
	Eastbound	101	89.2	NA
Reclamite	Westbound	103	90.2	NA
	Eastbound	64	94.2	NA

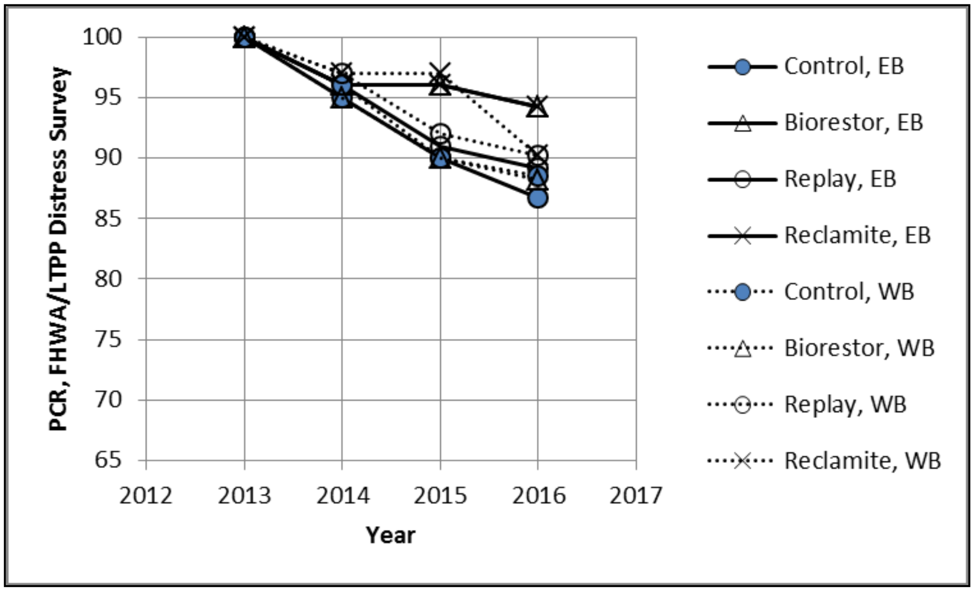


Figure 58. Project SR-47, Sydney: Decrease in PCR Value Derived from FHWA/LTPP Distress Survey through Monitoring Period

4.2 Sand Patch Tests

Sand patch tests were performed every other monitoring year. Table 18 lists the average texture depths calculated from the sand patch test, while figures 59 to 62 provide a comparison between the treated and control sections for each project. All wearing surfaces are considered to have a macro-texture (0.5 to 50 mm) at construction and throughout the monitoring period. As shown, the texture depth starts to increase after the second or third monitoring year, which has been observed on other projects.

Table 18. Average Texture Depth in 2016, All Projects; mm

Project	Lane	Test Section			
		Control	Biorestor	Replay	Reclamite
US 40	Westbound	0.675	0.642	0.651	0.699
	Eastbound	0.690	0.814	0.685	0.766
SR 292/A	Westbound	1.173	0.975	0.938	0.721
	Eastbound	1.115	1.099	0.919	0.670
SR 292/B	Northbound	0.967	0.953	1.076	0.659
	Southbound	1.119	0.922	0.961	0.713
SR 47	Westbound	0.786	0.758	0.664	0.666
	Eastbound	1.027	0.842	0.756	0.670

The test results show no significant and consistent difference between the treated and control sections for the US 40 project. Conversely, the Reclamite test sections exhibit a smaller texture depth for the SR 292 projects in comparison to the control and other treated sections. The SR 47 project exhibits the greatest increase in texture depth over the monitoring period, which was unexpected because the HMA overlay exhibited the higher density and lower air void level with PG76-22 asphalt. In general, the treated sections exhibited a smaller texture depth over time, in comparison to the control sections with the exception of the US 40 project.

4.3 Permeability Tests

Field water permeability tests were performed every other monitoring year. Table 10 in chapter 3 listed the average permeability measured prior to and after sealer application, while Table 19 lists the average permeability in 2016. Figures 63 to 66 provide a comparison between the treated and control sections over time for each project. Permeability less than 100 x10^{-5} cm./sec. is generally considered low for HMA wearing surfaces. An important observation from this data is the amount of variability between the test sections over time, which is large. As reported in chapter 3, the average COV for permeability within a test section is over 50 percent. Thus, it is difficult to define any consistent difference or trend in the data between the treated and control surfaces, as well as between the treated surfaces themselves.

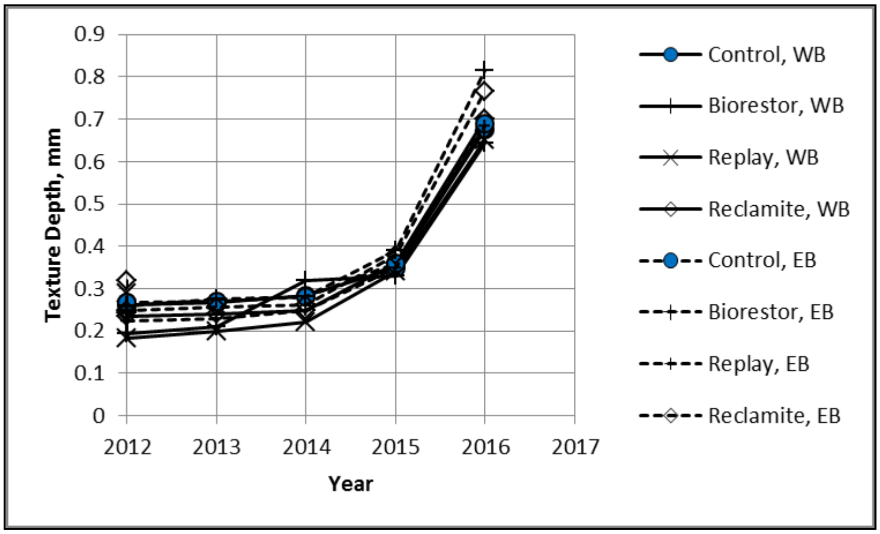


Figure 59. Comparison of the Texture Depths Calculated for the Treated and Control Sections along the US 40 Project

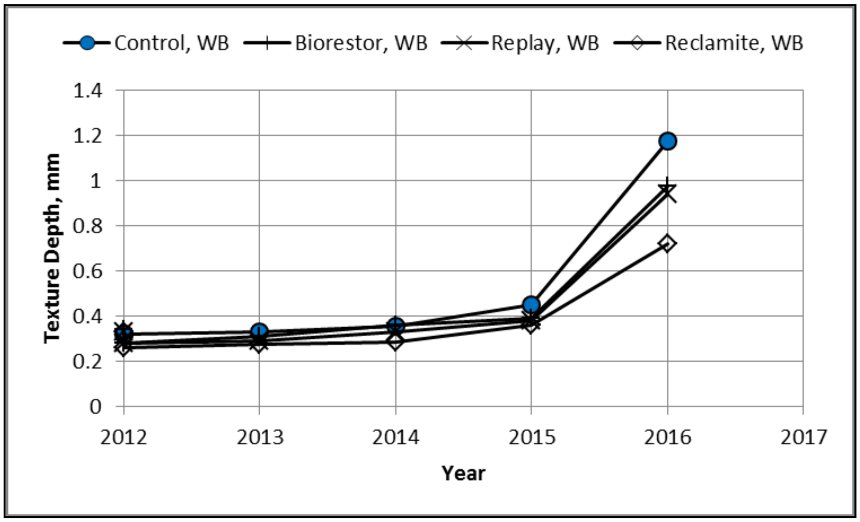


Figure 60. Comparison of the Texture Depths Calculated for the Treated and Control Sections along the SR 292, Location A Project

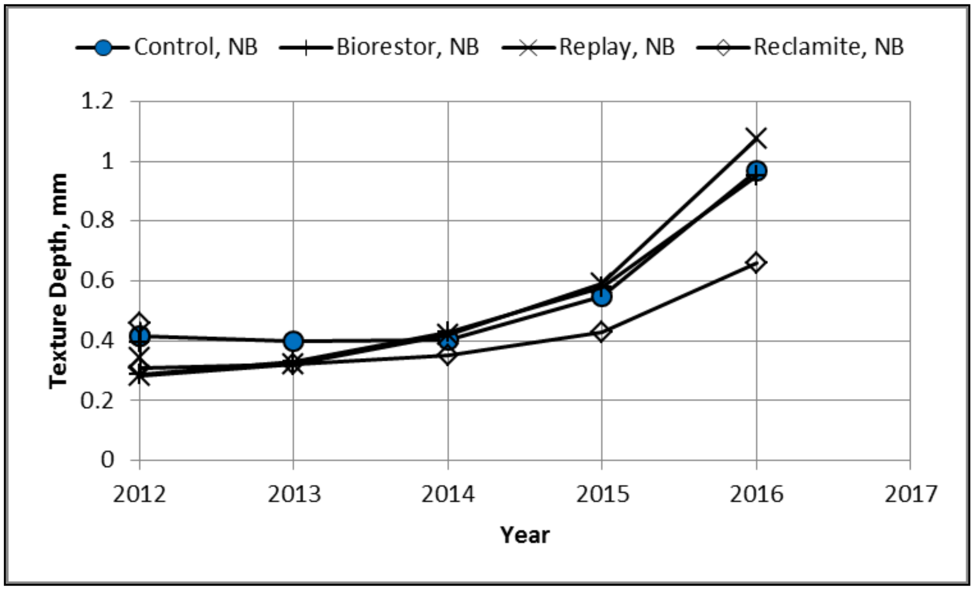


Figure 61. Comparison of the Texture Depths Calculated for the Treated and Control Sections along the SR 292, Location B Project

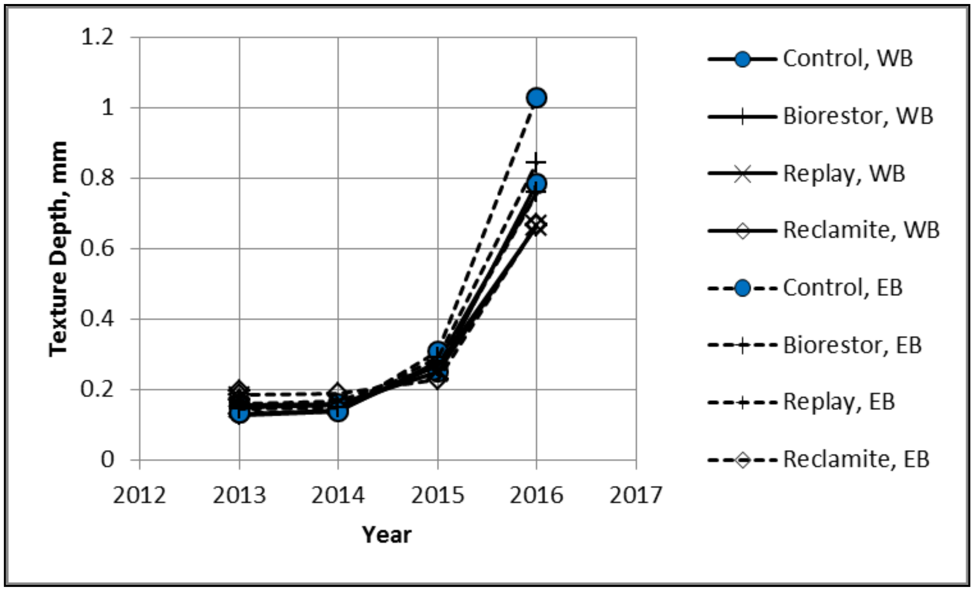


Figure 62. Comparison of the Texture Depths Calculated for the Treated and Control Sections along the SR 47 Project

Table 19. Average Permeability in 2016, All Projects; 10^{-5} cm/sec

Project	Lane	Test Section			
		Control	Biorestor	Replay	Reclamite
US 40	Westbound	16.7	21.3	20.5	25.7
	Eastbound	9.50	3.17	10.0	4.5
SR 292/A	Westbound	16.8	13.0	22.3	16.7
	Eastbound	18.0	58.7	37.3	15.8
SR 292/B	Northbound	13.3	6.67	20.0	35.7
	Southbound	11.0	12.3	21.7	18.3
SR 47	Westbound	10.7	9.67	19.0	42.0
	Eastbound	7.33	12.7	11.3	19.0

Figure 63 show the permeability measured along the US 40 project increased and decreased over the monitoring period, while the SR 292 and SR 47 projects clearly exhibit a decrease in permeability (refer to figures 64 to 66). The permeability measured along the SR 47 project slightly increased between 2014 and 2016. In general, the permeability decreased with time as the HMA surface densifies with traffic and the surface pores become filled with fines, until raveling and the loss of fines begins to occur. It is important to note that the average permeability for all test sections (treated and control) was less than 100×10^{-5} cm./sec. in 2016 (see figures 63 to 66). In summary, all test sections (treated and control) exhibited a much greater reduction in permeability over time, than from spraying the sealers on the wearing surface.

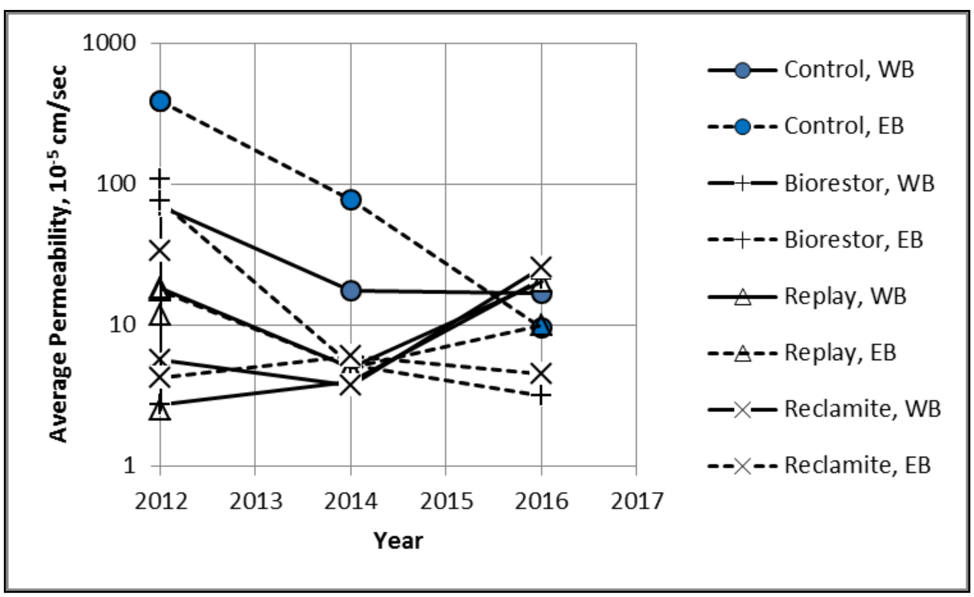


Figure 63. Comparison of the Average Permeability for the Treated and Control Sections along the US 40 Project

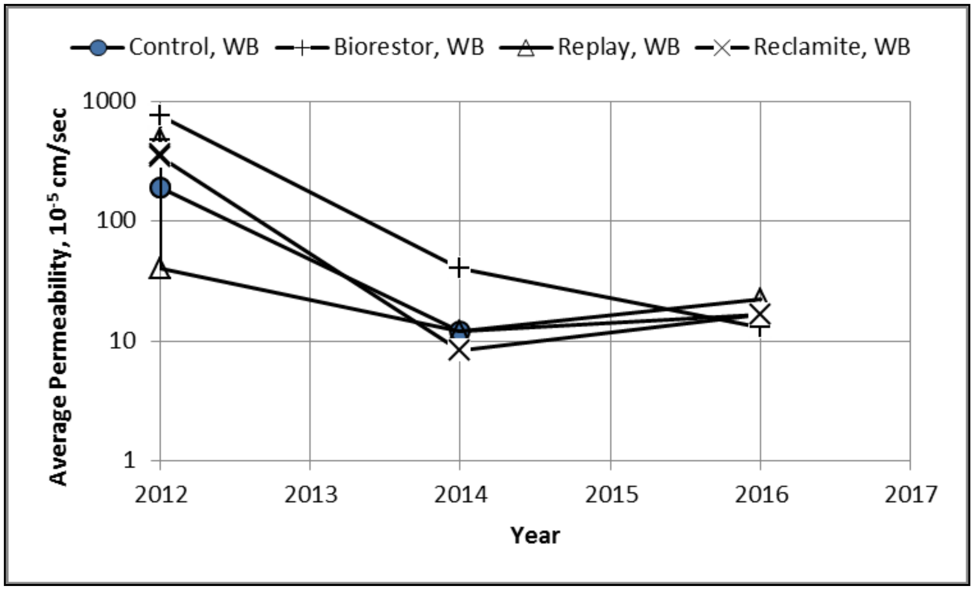


Figure 64. Comparison of the Average Permeability for the Treated and Control Sections along the SR 292, Location A Project

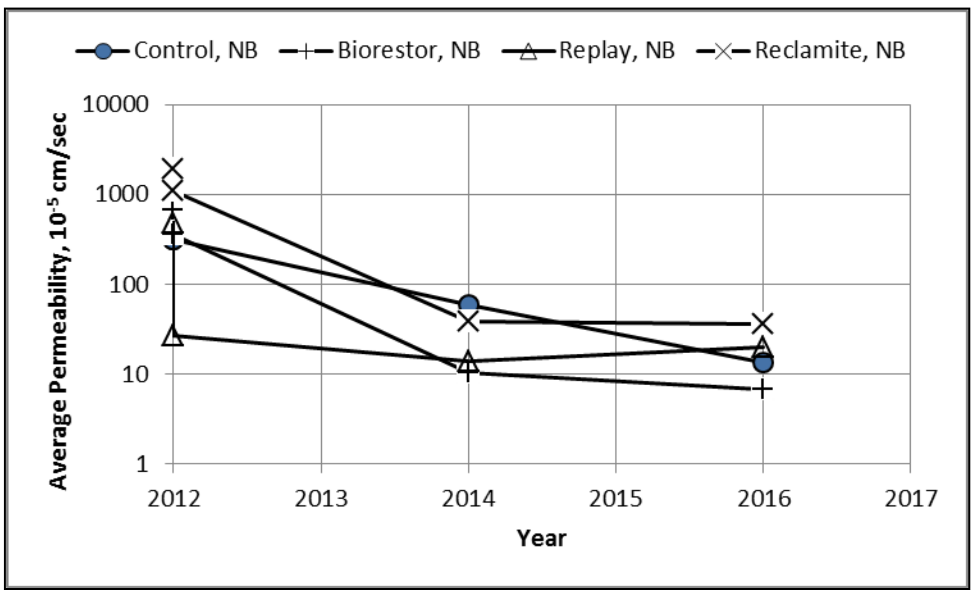


Figure 65. Comparison of the Average Permeability for the Treated and Control Sections along the SR 292, Location B Project

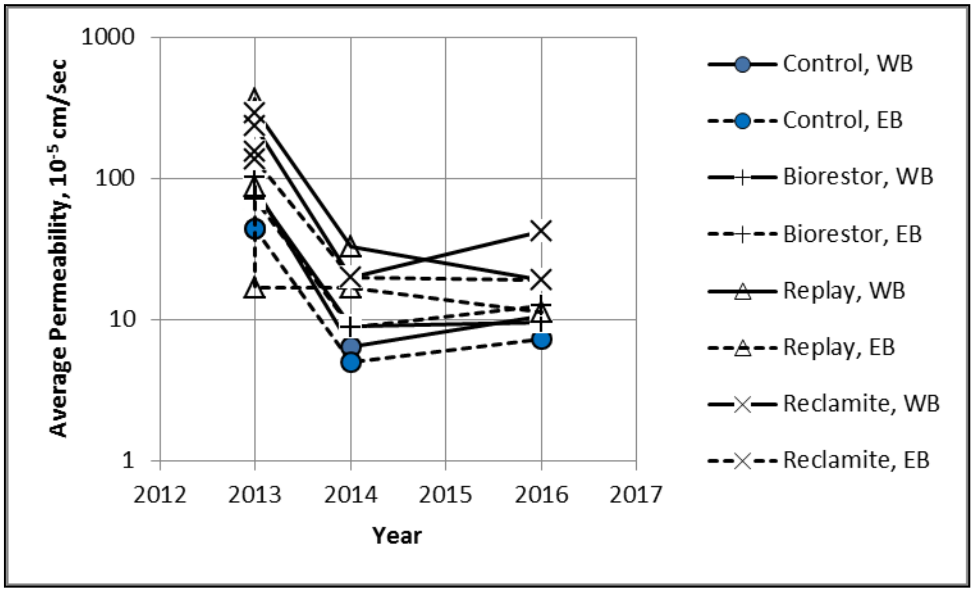


Figure 66. Comparison of the Average Permeability for the Treated and Control Sections along the SR 47 Project

5. ANALYSIS AND COMPARISON OF TEST RESULTS

This chapter provides an evaluation and comparison of test results between the control and treated sections along each project, as well as a comparison between surface properties. The evaluation was grouped into two comparisons: a comparison between the surface properties, and a comparison between the control and treated sections.

5.1 Comparison between Surface Properties—All Sections

As noted in chapter 2, three properties were measured during pre and post-sealer application: water permeability, density, and surface texture. This section reviews the relationship between each property in terms of future performance or how those properties could influence the distresses exhibited between each test section and project.

5.1.1 Permeability versus Density

Figure 67 includes a comparison between the permeability and density for all projects and test sections. No correlation was found between permeability and density for these sections, but the higher densities did exhibit lower permeability.

Figure 67 was divided into four quadrants to ensure no one penetrating sealer or the control sections were all located within one of the quadrants. Quadrant I represents the permeability and densities that are most susceptible to raveling, loss of fines and/or damage, while Quadrant IV represents the values most resistant to raveling and loss of fines. As shown, all treated and untreated surfaces are not confined to any one quadrant.

5.1.2 Mat Texture versus Permeability

Figure 68 includes a comparison between the permeability and texture depth for all projects and test sections. No correlation was found between these two surface properties, but the greater texture depths did exhibit higher permeability. A couple of the sections with the lower permeability and higher densities contained crushed aggregate at the surface which could explain the greater texture depths (refer to table 5).

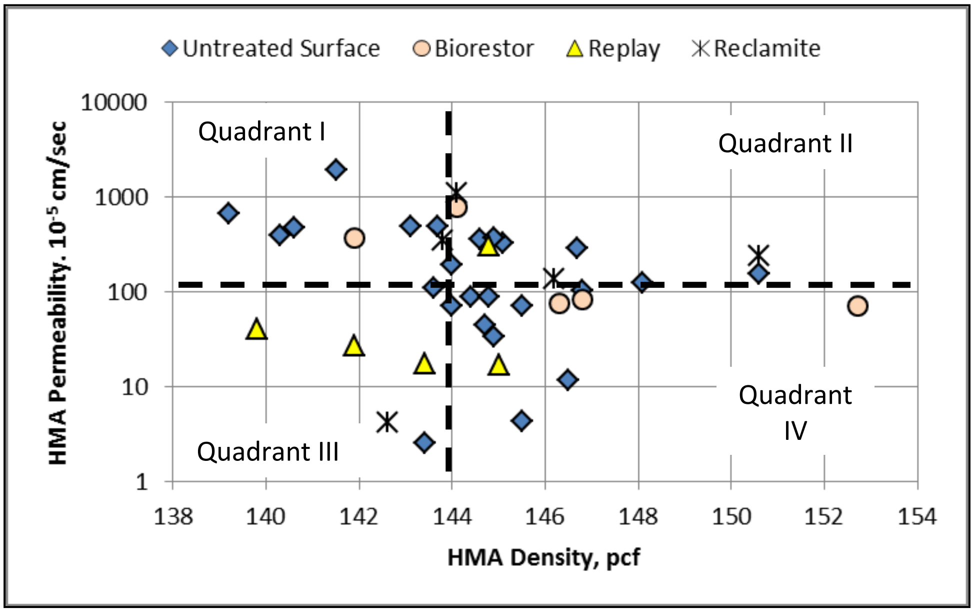


Figure 67. Comparison between Field Permeability and Mat Density

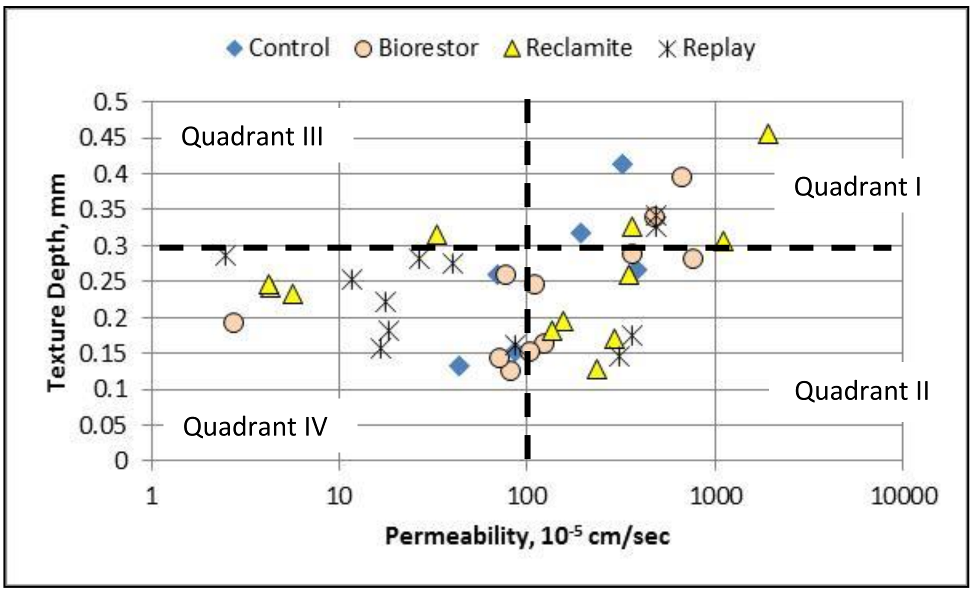


Figure 68. Comparison between Field Permeability and Mat Texture Depth

Figure 68 was divided into four quadrants to ensure no one penetrating sealer or the control sections were all located within one of the quadrants. Quadrant I represents the permeability and texture depths most susceptible to raveling and loss of fines, while Quadrant IV represents the values most resistant to raveling and loss of fines.

The field permeability individual values appear to be independent of both density and texture depth. More importantly, none of the control and treated sections have an inferior property combination consistently between the different projects. Thus, the original properties of the HMA overlay should have no effect on the outcome of the performance observations related to benefiting one of the treated sections over the other treated or control sections. In other words, no confounding factor was identified that could bias the results from the performance observations.

5.2 Comparison between Control and Treated Surfaces – All Sections

The average test results and predominant distresses measured for each test section, as well as the average PCR values for all projects in 2016 were tabulated in chapter 4. The following paragraphs describe the measurements and outcomes from the distress surveys between the test sections and projects.

5.2.1 HMA Density

Figure 69 includes a comparison of the HMA mat density between the control and treated test sections for all projects. As shown, no significant difference exists between the control and treated test sections, as well as between the treated test sections of a specific project.

5.2.2 Permeability

Figure 70 includes a comparison of the HMA permeability between the control and treated test sections for all projects. As shown, the treated sections have a lower permeability relative to the control section for all but one of the Biorestor test sections. The difference, however, would be considered statistically insignificant except for one of the projects—US-40 segment in Springfield, OH. Thus, the water-based field permeability test suggests a small improvement or benefit for the treated surfaces.

5.2.3 Texture Depth

Figure 71 includes a comparison of the texture depth of the HMA mat between the control and treated test sections for all projects. As shown, the treated sections have lower texture depths relative to the control sections and the difference is increasing over time. A lower texture depth suggests less loss of surface fines. Thus, the sand patch test suggests an improvement or benefit for the treated surfaces.

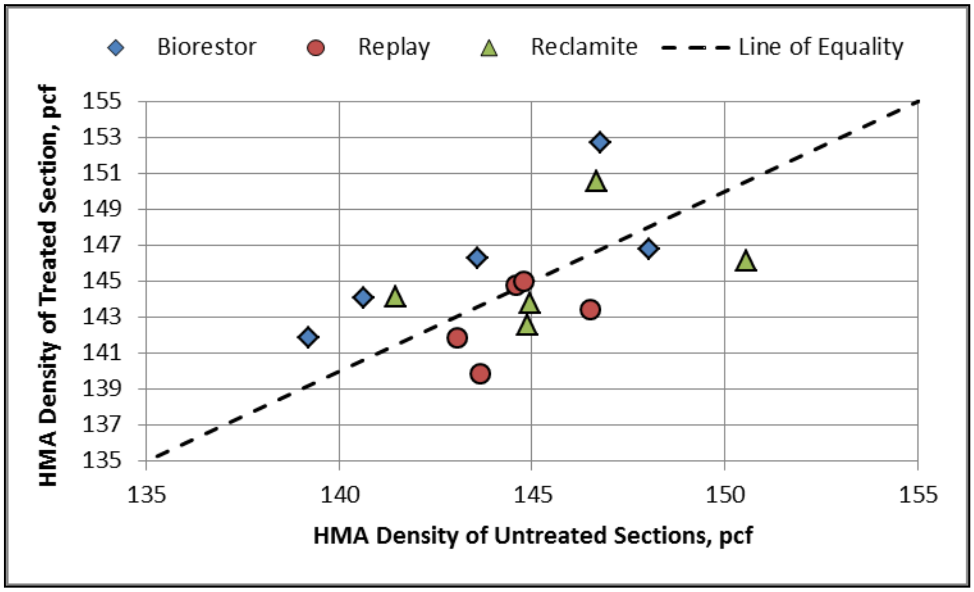


Figure 69. Comparison of HMA Mat Density between Control and Treated Test Sections

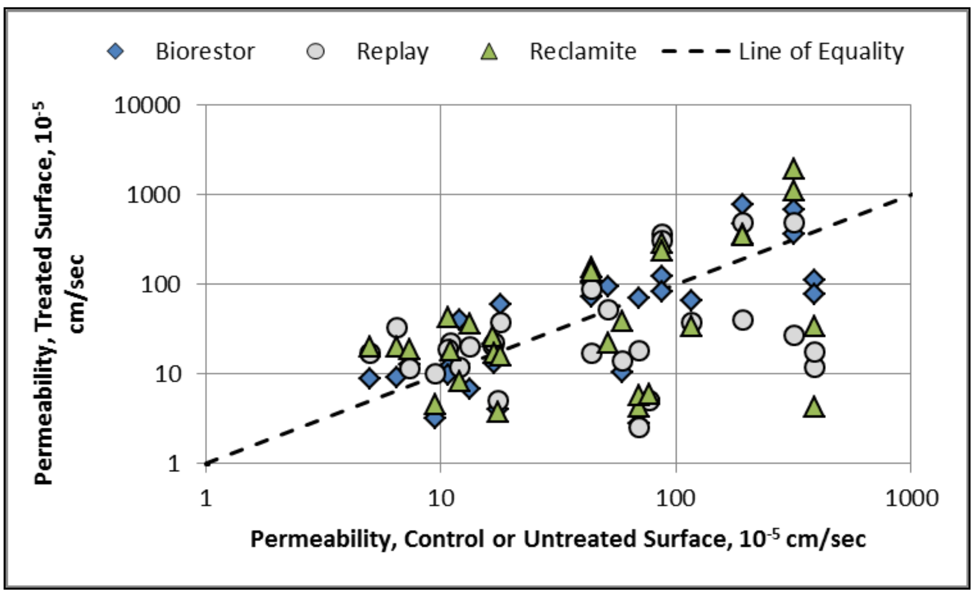


Figure 70. Comparison of HMA Mat Permeability between Control and Treated Test Sections

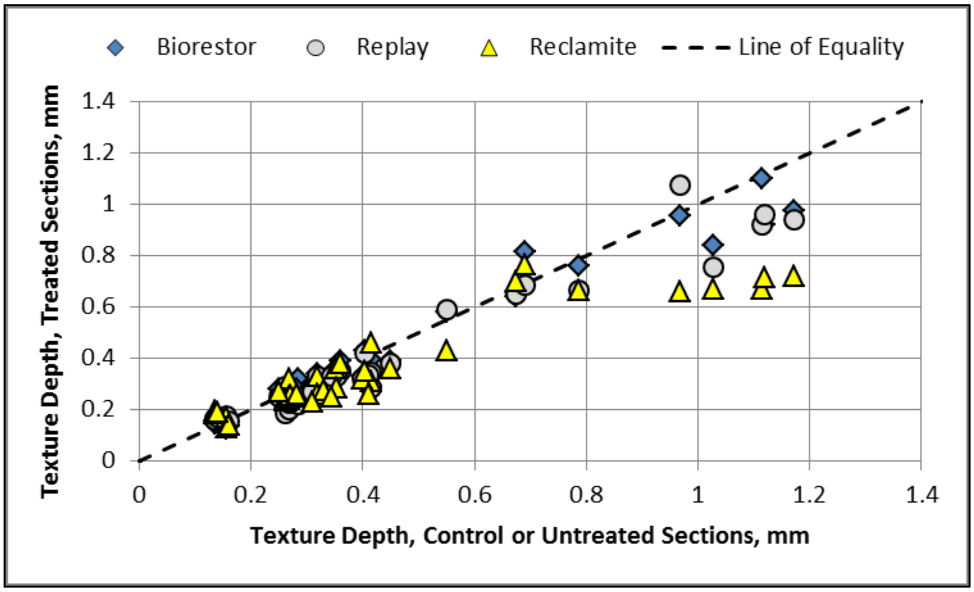


Figure 71. Comparison of HMA Surface Texture Depth between Control and Treated Test Sections

5.2.4 Skid Resistance

A comparison of the skid numbers measured immediately after sealer placement and 30 days after placement was included in figure 20. The treated sections were found to have a statistically lower SN relative to the control section, which would be considered a disadvantage of the treated surfaces. Comparing the SN values at the same test date, however, maybe inappropriate if the SN values are changing over time for the control surfaces.

Figure 72 shows the change in SN measured over time for the control sections. The SN values measured on the control surfaces remained relatively constant for the US 40 and SR 47 projects, while the SN values increased over the 30-day testing period for the two SR 292 projects. Table 12 in chapter 3 shows the SN values measured 30-days after applying the sealers are higher than 30 and are greater than the values measured on the control surfaces prior to sealer application for the SR 292 projects, except for the SR 47 project. SN values were only measured on the treated surfaces of the SR 47 project immediately and 7 days after applying the sealers.

The loss of SN was found to be related to the residual application rate of the sealers, but the loss was project dependent. Figure 73 shows the loss of SN measured immediately after application as a percentage of the SN measured on the control section. As shown, the greater the application rate the greater the loss of SN.

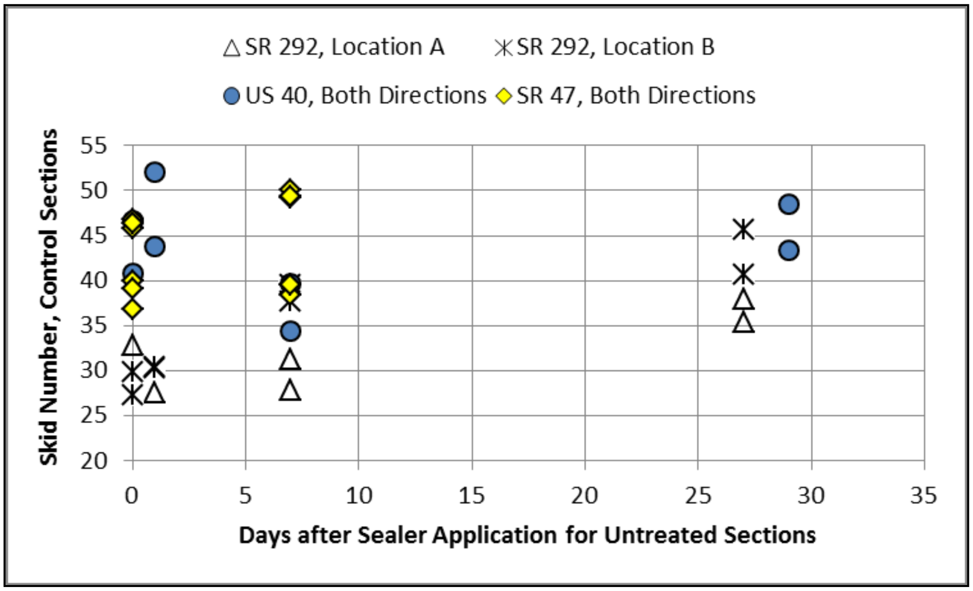


Figure 72. Skid Numbers Measured over the 30-Day Test Period; Ribbed Tire

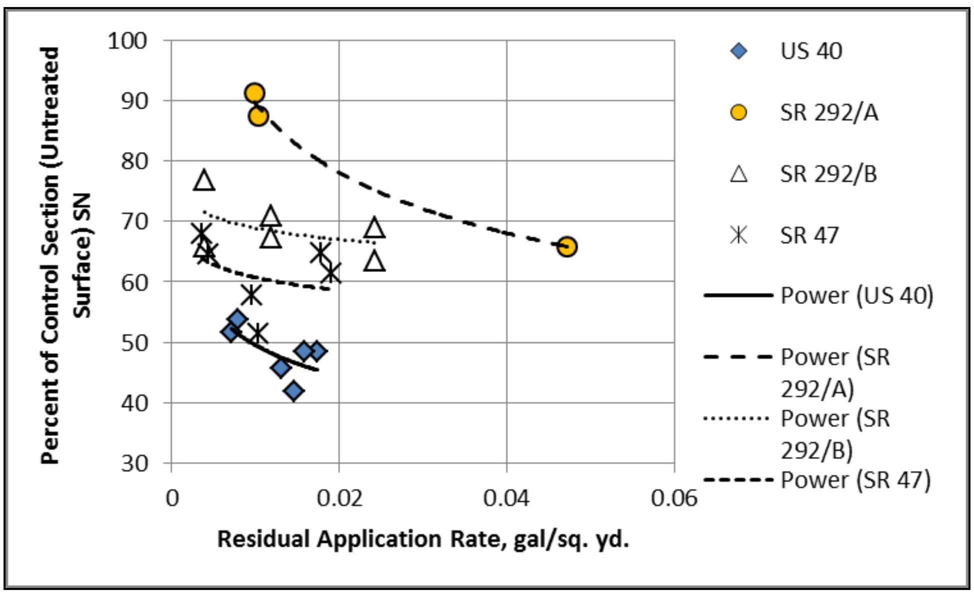


Figure 73. Skid Numbers Measured Immediately after Applying the Sealers; Ribbed Tire

To put the SNs measured along the treated and control sections into perspective, the following provides information on threshold values that are used to determine if the surface has adequate friction.

- Rizenberg et al. (1972) reported the accident rate started to increase when the SN dropped below 40.
- Henry (2000) and NCHRP (2009) report many agencies consider the wearing surface to exhibit adequate friction when the SN is above 37 to 40.
- Hall et al. (2000) summarized interviews with various agencies and report the threshold value for surfaces with adequate friction is above 25 for all agencies and above 32 for above half of those agencies interviewed.

Thus, an SN of 35 was used to evaluate the treated to control surfaces relative to friction. Table 12 in chapter summarized the SNs for each test section at different points in time. About 50 percent of the control sections exhibited SNs below 35 after construction, while 100 percent of the treated surfaces were below 35 immediately after sealer application. After 30-days, however, all of the control sections and 75 percent of the treated sections were above an SN of 35. All but one treated section with SNs below 35 were from the SR-292/A project.

5.2.5 Surface Distress

A comparison was completed between the treated and control sections for the predominant surface distresses measured on the different projects. The predominant distresses included: transverse cracks, fatigue cracks, longitudinal cracks, and raveling. Raveling was not identified as a predominant distress on any one project, but was included in the comparison because it is a materials related distress that the penetrating sealers are supposed to reduce.

PCR values were also included in the comparison because ODOT uses the PCR value to determine if a maintenance or rehabilitation activity should be applied to the pavement surface. The calculated PCR values are discussed and summarized in the next subsection of this chapter. The following bullets summarize the comparisons.

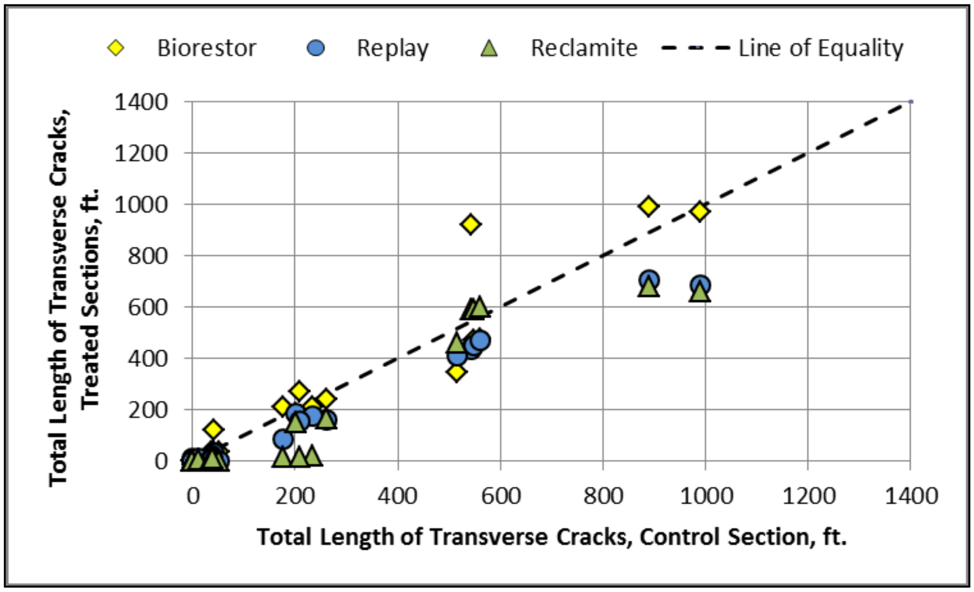
- Transverse cracks: Figure 74 includes a comparison of the lengths of total and moderate transverse cracks between the control and treated sections for all projects. As shown, the treated sections have a slightly lower amount or lengths of transverse cracks in comparison to the control sections.

- Fatigue cracks: Figure 75 includes a comparison of the total area of fatigue cracking between the control and treated sections. As shown, there is no difference between treated and control sections, as expected. Fatigue cracking is more related to the truck traffic and structural response of the pavement structure.
- Longitudinal cracks: Figure 76 includes a comparison of the total length of longitudinal cracking between the control and treated sections. There is a significant amount of scatter in the data, so it was concluded there is no difference between treated and control sections. Longitudinal cracking is more related to the truck traffic being applied near the edge of the pavement and structural response of the pavement structure.
- Raveling: Figure 77 includes a comparison of the total area of raveling between the control and treated sections. Although there is a significant amount of scatter in the data, it was observed that the treated sections consistently exhibited less raveling than the control sections. However, most of the test sections exhibited localized raveling, except for the SR 292 location B project. Most of the raveling occurred within the wheel path area, but was confined to selected areas within the test sections.

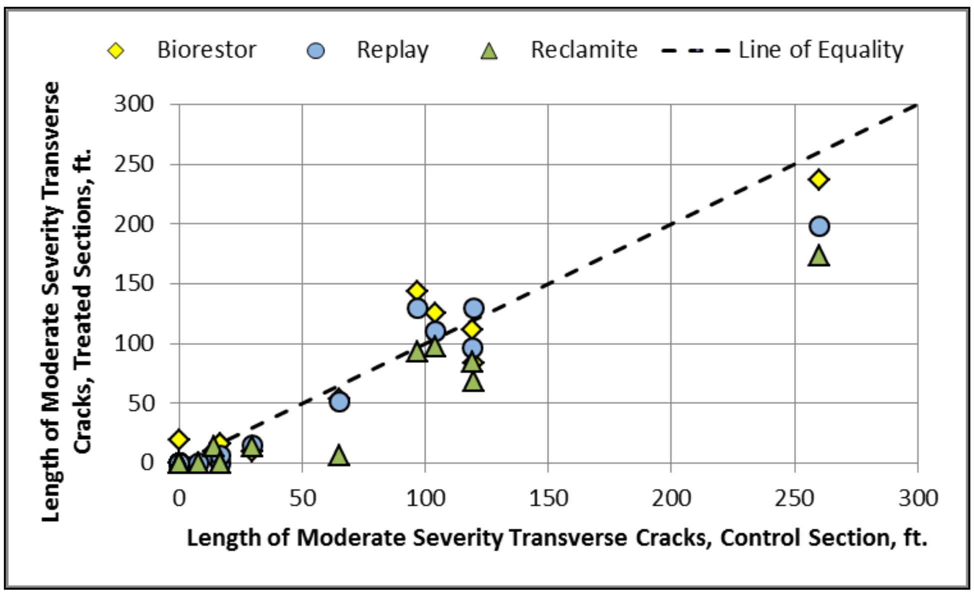
5.2.6 PCR Values

As noted in chapter 2, distresses were recorded using two procedures: the FHWA/LTPP distress identification system and the ODOT Pavement Condition Rating System. PCR values were calculated based on the distresses from both condition surveys using the ODOT procedure. Figure 78 compares the PCR values from both procedures. As shown, use of the FHWA/LTPP distress surveys resulted in slightly lower PCR values. The reason for the lower values was related to the extent and severity of the distress recorded using the FHWA/LTPP procedure.

Figures 79 and 80 provide a comparison in the calculated PCR values between the control and treated sections using the ODOT and FHWA/LTPP distress surveys, respectively. As shown, there is no consistent or significant difference between the PCR values calculated for the control and treated sections from the ODOT distress surveys. Conversely, a small consistent difference was observed using the FHWA/LTPP distress surveys; the treated sections consistently exhibited a slightly higher PCR value (see figure 80).



a. All Severities of Transverse Cracks



b. Moderate Severity of Transverse Cracks

Figure 74. Comparison of Total Transverse Crack Lengths between Control and Treated Test Sections

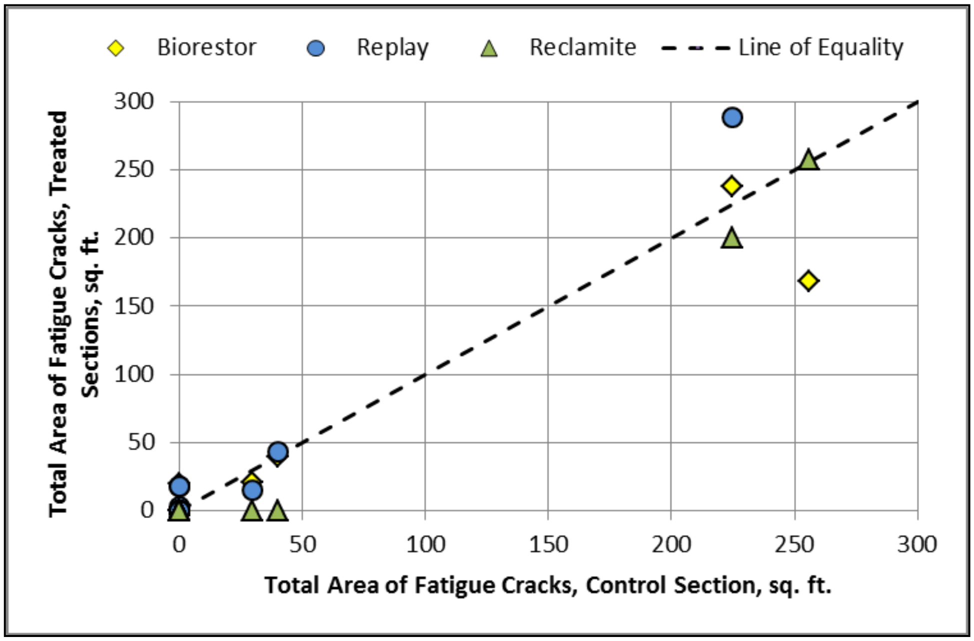


Figure 75. Comparison of Total Areas of Fatigue Cracking between Control and Treated Test Sections

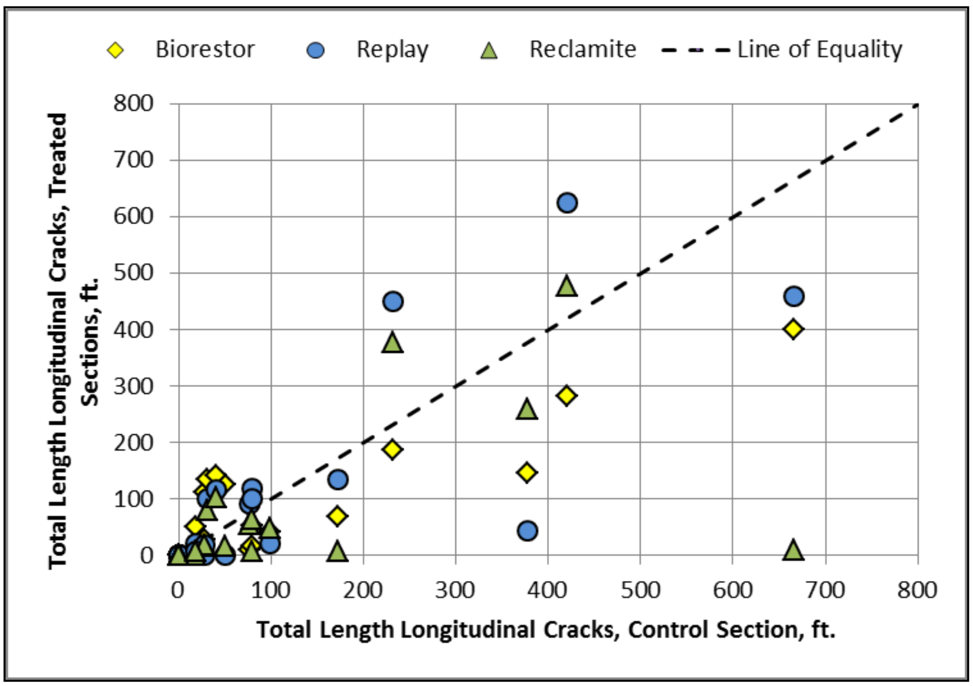


Figure 76. Comparison of Total Longitudinal Crack Length between Control and Treated Test Sections

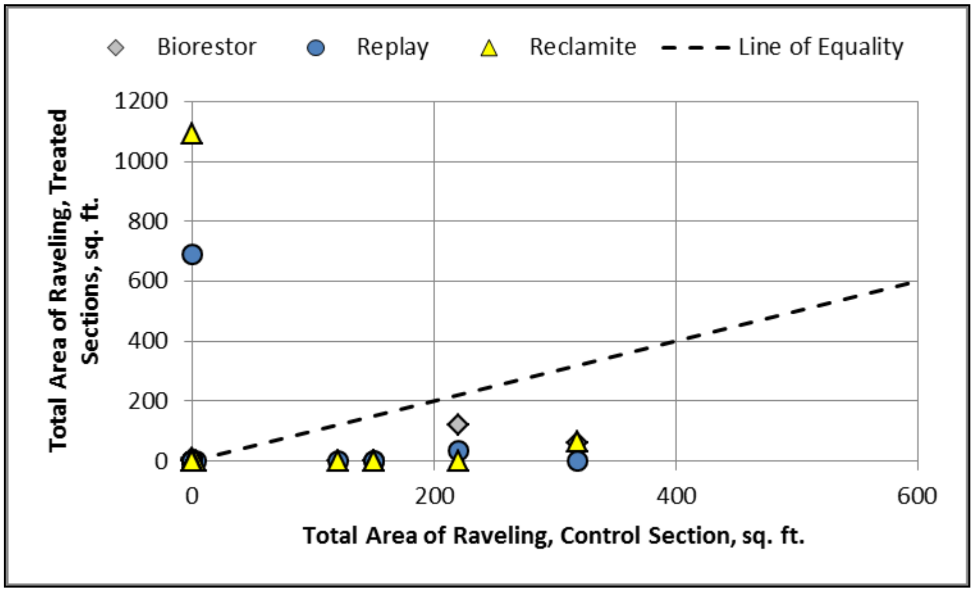


Figure 77. Comparison of Raveling between Control and Treated Test Sections

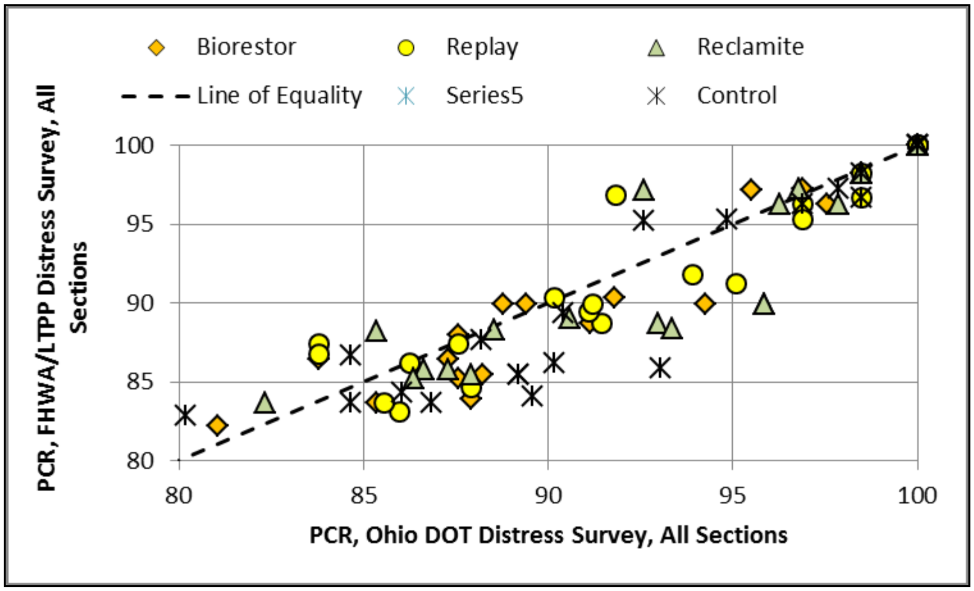


Figure 78. Comparison of PCR Values Calculated from the ODOT and FHWA/LTPP Distress Surveys for all Sections and Projects

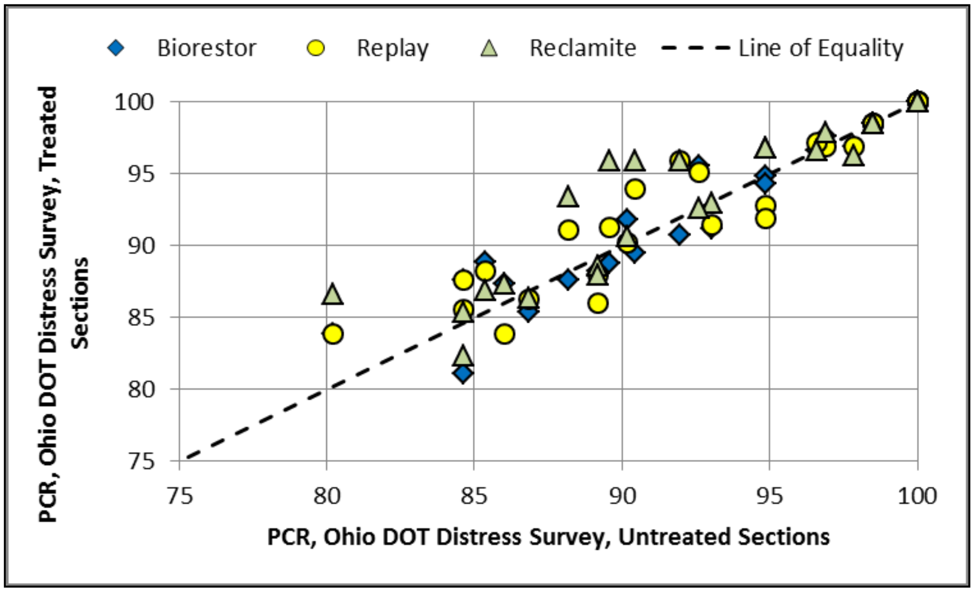


Figure 79. Comparison of PCR Values between Control and Treated Test Sections using the ODOT Distress Surveys

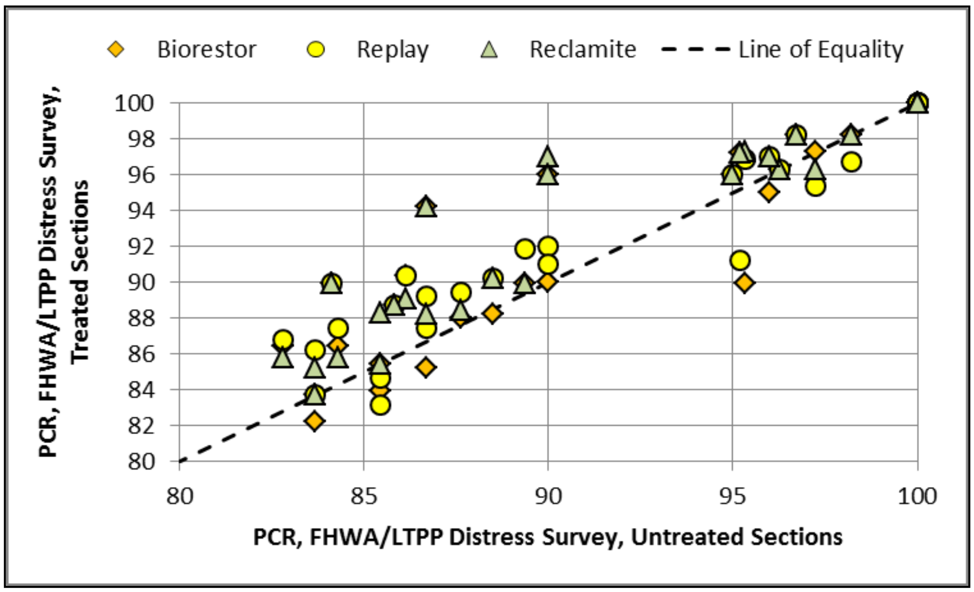


Figure 80. Comparison of PCR Values between Control and Treated Test Sections using the FHWA/LTPP Distress Surveys

Table 20 summarizes the average residual error or bias and standard error between the control and treated sections for all projects. On the average, the treated sections had a slightly higher PCR value than the control sections and the difference was higher using the FHWA/LTPP distress surveys in comparison to ODOT distress surveys. The treated sections with Reclamite exhibited the greater difference from the control sections, followed by the Replay and Biorestor treated sections. Figure 81 shows the average bias in PCR values between the treated and control sections in comparison to the average sealer application rate. As shown, the higher the sealer application rate, the greater the difference or bias in PCR values between the treated and control sections.

Table 20. Bias (Average Residual Error) between the Control and Treated Sections

Parameter	Sealer	ODOT Distress Surveys	FHWA/LTPP Distress Surveys
Bias or Average Residual Error; difference between PCR value of Treated and Control Surface	Biorestor	0.081	1.093
	Replay	0.432	1.212
	Reclamite	1.230	2.158
Standard Error between Treated and Control Surfaces	Biorestor	1.776	2.835
	Replay	2.138	2.227
	Reclamite	2.457	2.282

NOTE: A positive bias implies the treated surface has a higher PCR value than the control surface, on the average.

The standard errors, however, are high in comparison to the bias value. To determine whether the differences between the control and treated sections are statistically significant, a paired t-test was used. Table 21 summarizes the results from the paired t-test using all the PCR data and the last two distress surveys for the ODOT and FHWA/LTPP procedures. In summary, the small difference or bias between the control and treated sections is considered statistically insignificant for the Biorestor sections but statistically significant for the Reclamite sections using the FHWA/LTPP distress surveys, while all penetrating sealers are considered statistically insignificant relative to the control sections based on the ODOT distress surveys. More importantly, the difference is too small to delay any maintenance or rehabilitation activity based on the PCR intervals used by ODOT for all sealers.

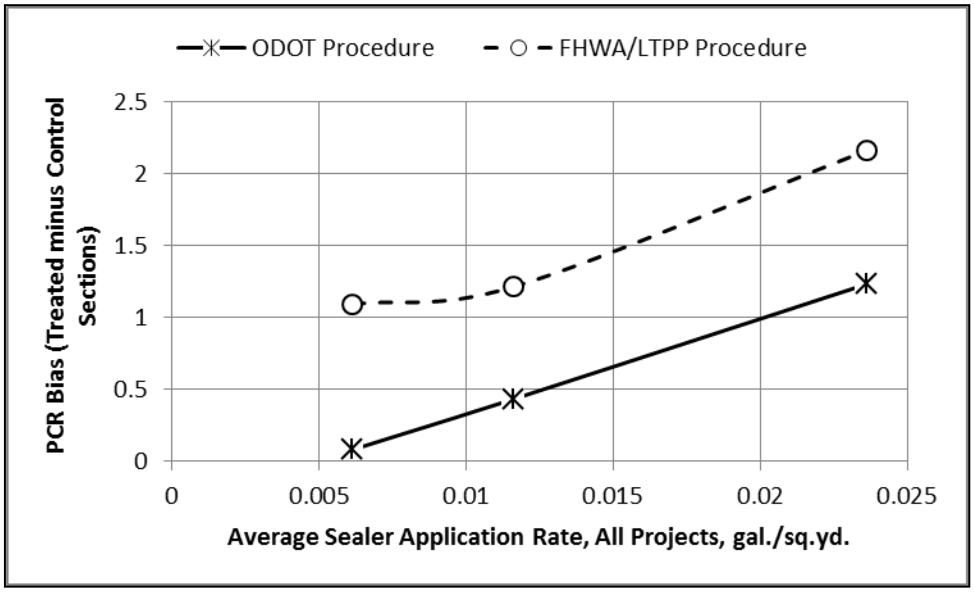


Figure 81. Average Bias or Difference in PCR Values between the Treated and Control Sections as Related to the Average Sealer Application Rate

Table 21. Results from the Paired t-Test for Determining the Significance of the Difference in PCR Values between the Control and Treated Sections

Procedure	**PCR Values**	**Parameter**	**Sealer**		
			Biorestor	Replay	Reclamite
ODOT	All Surveys	Number of Deltas	30	30	30
		t-value	0.25	1.11	2.74
		t-critical (@=0.01)*	2.756	2.756	2.756
		Result	Indifferent	Indifferent	Different
	Last Two Surveys	Number of Deltas	12	12	12
		t-value	0.033	1.74	2.39
		t-critical (@=0.01)	3.106	3.106	3.106
		Result	Indifferent	Indifferent	Indifferent
FHWA/LTPP	All Surveys	Number of Deltas	24	24	24
		t-value	1.89	2.66	4.63
		t-critical (@=0.01)	2.807	2.807	2.807
		Result	Indifferent	Indifferent	Different
	Last Two Surveys	Number of Deltas	14	14	14
		t-value	1.87	3.25	4.02
		t-critical (@=0.01)	3.012	3.012	3.012
		Result	Indifferent	Different	Different
** The level of significance for defining t-critical in the above table is 0.01. In addition, the shaded cells are those that are statistically different between the treated and control sections.*					

Although the differences in the PCR values between the control and treated sections is considered small within the monitoring period, it is expected the difference may become larger over time. To estimate the difference in PCR values over a longer period of time, the authors used a mathematical relationship to predict the decrease in PCR values with time, which is provided in equation 1 (Von Quintus, et al., 2004). Figure 82 shows the comparison between the measured distress-derived and predicted PCR using equation 1 for all of the control sections.

$$PCR = 100\left(1 - e^{-a\left(\frac{t}{t_{design}}\right)^{b}}\right) \quad (1)$$

Where:

t = Age after construction, years.

t_{design} = Design period; assumed to be 10 years for rehabilitation or HMA overlays of existing pavements – composite or flexible.

a, b = Regression coefficients; typical values derived from other studies and used on this study are: a = -0.4 and b = 0.90.

Equation 1 was used to predict the PCR values over time given an average 2 point PCR difference at 4 years for the Reclamite material (see table 20). The predicted PCR for the control surface in comparison to the treated surface is shown in figure 83. The extended service life for the treated sections is no more than one year for the bias of the Reclamite treated sections at a PCR terminal value of 75. A PCR of 75 was used to establish the difference in age between the treated and control sections, because that is the value used by ODOT between a pavement condition rating of good and fair (ODOT, 2006).

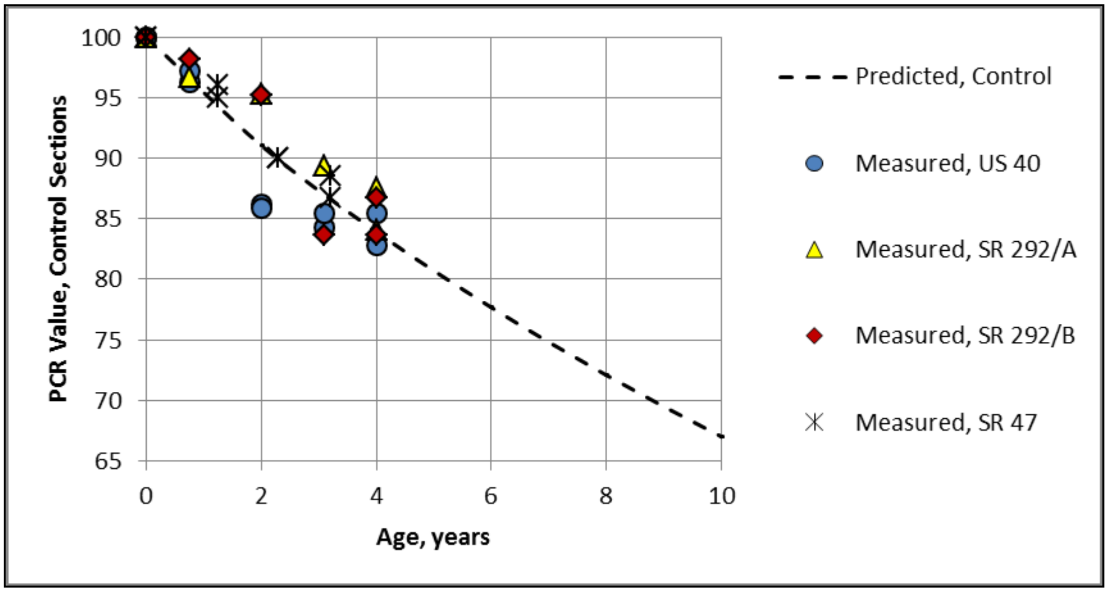


Figure 82. Predicted PCR Value Compared to the Measured PCR Values using the FHWA/LTPP Distress Surveys for the Control Sections

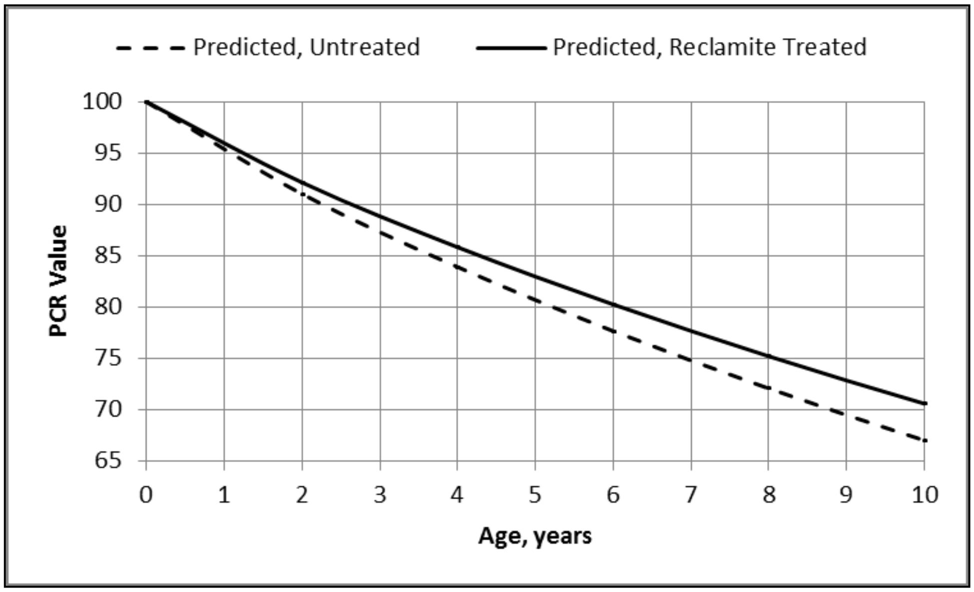


Figure 83. Predicted PCR Value between the Reclamite and Control Surfaces (Based on a 2-Point PCR Difference, or Bias)

5.2.7 Visual Observations of Pavement Surface

Although the distress data and PCR values do not show a significant difference in performance between any of the treated and control sections, one of the penetrating sealers did show visual differences over time, which is described below.

- Figure 84 includes a photograph taken shortly after rain at the beginning of the Reclamite test section along the SR-292/B project. As shown, the treated surface is drier than the adjacent untreated transition area between sections. The location of where the sealer was applied is clearly visible.
- Figure 85 includes a photograph taken at the transition of the Reclamite section of the SR-47 project. The location of where the sealer was placed is still visible in 2016 in terms of a darker surface appearance. The boundary designating the beginning and end of the Reclamite test sections was visible for all projects even in 2016.
- Figure 86 includes a photograph that shows a crack in the transition area (untreated surface) to the Reclamite section of the SR-292/B project. The crack is visible in the area that is untreated, but is not visible on the treated surface.

Thus, there is a difference but that difference is small using the distress data and PCR values. Some reasons why a larger difference was not identified between the treated and control sections are listed below:

- The PCR values used in the comparison are based on a large interval for the weighting factors for calculating the PCR values – even under a controlled field experiment.
- None of these projects exhibited extensive segregation or excessive air voids during placement of the HMA; only localized areas with segregation were exhibited on a few of the projects.
- The HMA longitudinal and transverse joints are in good condition – suggesting good construction techniques used by the contractors.
- Most of the distresses are a result of other factors not related to the materials (i.e.; reflection cracks, low temperature cracks, fatigue cracks, etc.). Only localized areas of raveling were recorded using the FHWA/LTPP distress survey procedure, and ODOT recorded a minor severity and minor extent of surface fine loss on just about all sections.
- A limited monitoring period; 4 years of a typical 10 year rehabilitation design period.

Figure 84. Surface of Reclamite Test Section of the SR 292/B Project Shortly after Rain in Comparison to the Untreated Surface (Control Section)

Figure 85. Transition between the Untreated and Reclamite Section Showing the Difference in Color of the Surface for the SR 47 Project; Photograph taken in 2016

5.3 Effectiveness of Surface Sealers

As summarized in the previous section of this chapter, the bias in the PCR value between the treated and control surfaces is small relative to the standard error (see table 20). These small differences in the average PCR value will not extend a pavement's service life beyond a year using the data collected from the four year monitoring period (see figure 83). The following summarizes the observations made for each of the projects in extending the service life between the treated and control sections.

- US 40, Springfield Project: Reflection cracking and the deterioration of the reflected cracks will control the service life of this roadway segment. The different sealers had an insignificant impact for improving the surface condition and service life of this project. Thus, the penetrating sealers will be ineffective for improving the performance and extending the service life of this project and other rehabilitation projects susceptible to extensive reflection cracking (HMA overlays of JPCP or jointed reinforced concrete pavement [JRCP]).

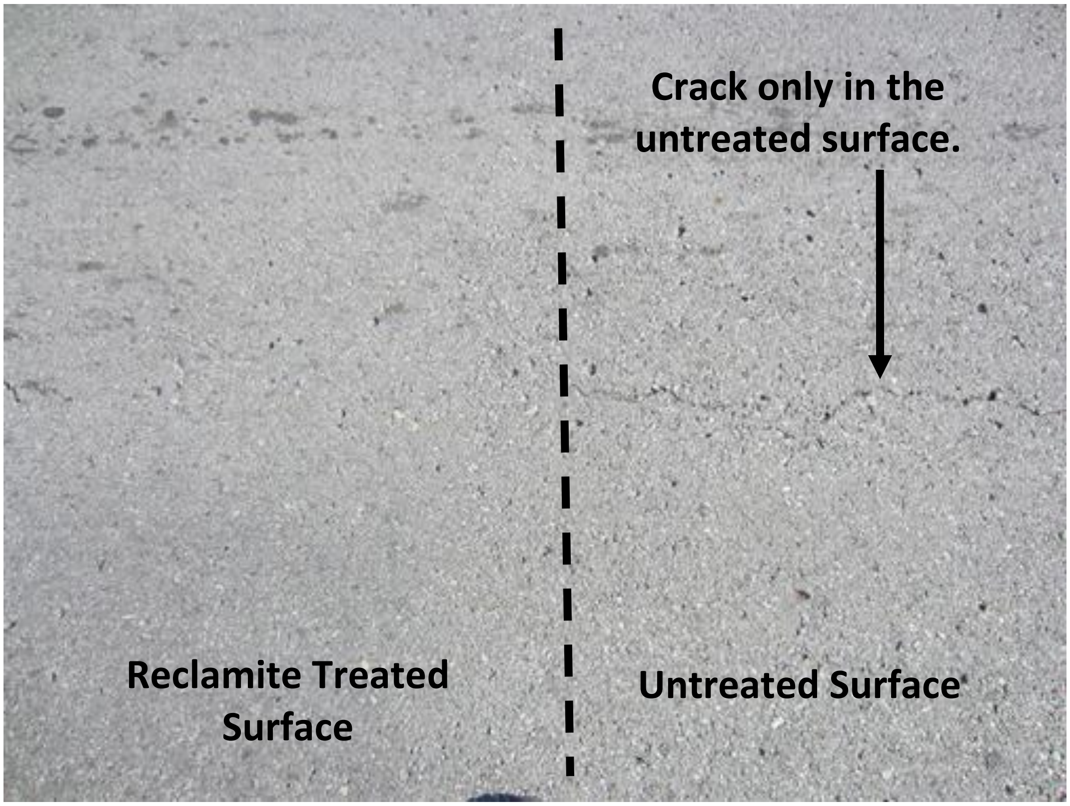


Figure 86. Crack Visiable in the Untreated Surface and not Visible in the Reclamite Treated Surface of SR 47 Project

- SR 292, Location A, East Liberty Project: The Reclamite treated section exhibited a lot less cracking than the control and other treated sections (refer to figures 39 and 40). The difference in the length of transverse cracks between the Reclamite and control sections, however, is within the same extent interval for calculating the PCR value.
- SR 292, Location B, East Liberty Project: The treated sections exhibited less raveling than the control section, but the difference was within the same extent interval for calculating the PCR values. Thus, in terms of the PCR value the difference would be considered insignificant.
- SR 47, Sydney Project: As stated in chapter 2, applying the penetrating sealers to the pavement surface along this project was delayed due to other issues, so this segment of pavement was monitored for 3 years, rather than 4 years. The amount of distress exhibited along the sections is minimal and all sections are considered in very good condition based on the calculated PCR values. As such, the different sealers had an

insignificant impact for improving the surface condition and service life of this project. Thus, the penetrating sealers are considered ineffective for improving the performance and extending the service life of this project.

A life cycle cost (LCC) analysis was used to determine the added cost for applying the penetrating sealer so the equivalent annual pavement cost (EAPC) is below the equivalent annual pavement cost without a penetrating sealer. A 0.5 and 1-year life extension was used to determine the cost increment. For this example, an asphalt concrete overlay with repairs rehabilitation strategy was used for a two-lane mile project. The average unit cost of $18 per square yard was assumed from bid tabs provided by ODOT.

Figure 87 shows the EAPC for the example with and without a treated surface for a 0.5 year and 1-year life extension (see table 20 and figure 83). As shown, penetrating sealers are cost effective as long as the application cost is less than about $15,000 for a 0.5-year life extension and about $30,000 for a 1-year life extension. The cost to apply the penetrating sealer should include the material and application costs, traffic control costs, and skid resistance testing costs.

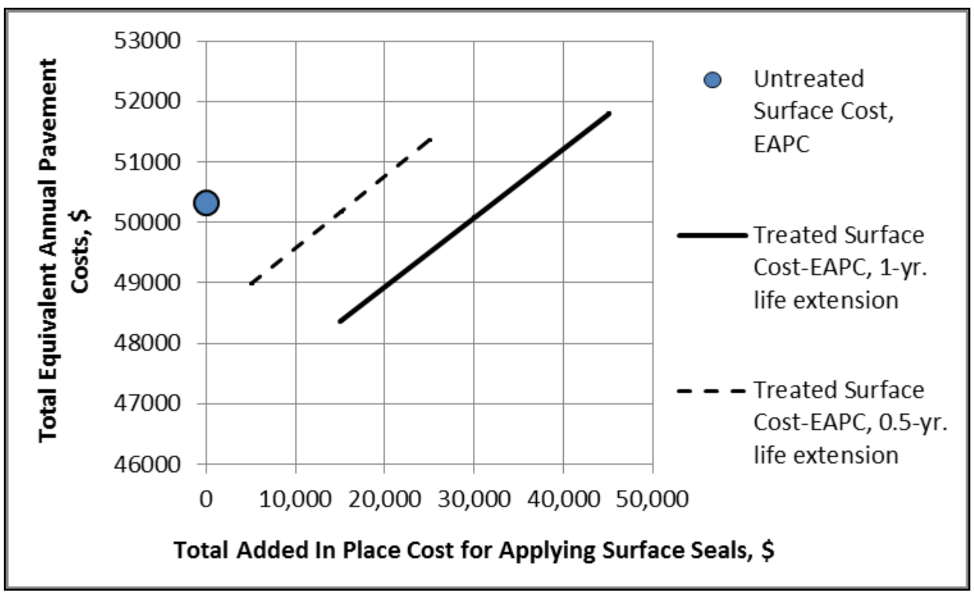


Figure 87. Total Equivalent Annual Pavement Costs Calculated for Different Conditions between Treated and Untreated Surfaces

6. SUMMARY OF OBSERVATIONS, FINDINGS, AND RECOMMENDATIONS

This chapter provides a summary of observations and findings from evaluating and comparing the performance of the HMA overlay with the individual sealers (treated surfaces) to the control sections related to extending the service life or delaying various maintenance or rehabilitation activities that ODOT uses as part of their day to day business practice.

6.1 Observations

The following are general observations made at the beginning of the monitoring period; prior to and immediately after sealer application.

1. Table 4 summarized some of the surface conditions or defects that might result in a difference in performance over time. Overall, a few construction defects or anomalies were observed prior to applying the sealers but none are believed to be significant. None of the HMA overlays exhibited extensive segregation; only a few test sections were found to have limited segregation. The construction joints also appear to be in very good condition, suggesting the contractors used good construction practices in placing the HMA overlay on all projects. In summary, it is believed the contractors used good construction practice in placing the HMA mixtures along each project.
2. No significant difference was identified between the control and treated sections prior to sealer application in terms of in place HMA mat density, permeability, and texture depth. In addition, no significant difference or confounding factor was identified between the treated and control sections prior to and after sealer application.
    a. As a reminder from chapter 2, the SR-47 project included PG76-22 asphalt while the other projects included PG70-22. The HMA wearing surface placed along the SR-47 project included a coarser aggregate gradation and lower asphalt content (see table 2).
    b. In addition, the penetrating sealers were sprayed on the HMA wearing surface of the SR-47 project a lot later than for the other three project locations.
3. The SN values measured on the treated surfaces immediately after applying the sealers significantly decreased in comparison to the SN values measured along the control surfaces. Thirty days after sealer application, the SN values measured on the treated

surfaces are statistically lower than the control sections. The SN values measured 30-days after sealer application increased to a value higher than 30, based on the use of ribbed tires.

4. The loss of skid resistance (or SN value) immediately after applying the sealers is believed to be related to the residual application rate of the sealers, but that trend was project dependent (see figure 73).

The following are observations made from the test data and distress surveys during the monitoring period.

5. The texture depth increased over the monitoring period for all test sections, and the texture depth for the treated surfaces was less than for the control surfaces (see figure 12). Lower texture depths suggest a lower loss of fines for the treated sections.
6. A statistically insignificant decrease in permeability was exhibited after spraying the sealers on the HMA wearing surface, because the field test is highly variable. The average permeability significantly decreased over the monitoring period for both the treated and control sections (see figure 70). In 2016, the average permeability was less than 100 $x10^{-5}$ cm./sec. for all test sections – treated and control.
7. Slightly less distress was exhibited on the treated surfaces in comparison to the control surfaces.
    a. Less raveling was exhibited on the treated sections (see figure 77). However, the extent of raveling was localized for most of the projects. The SR 292, Location B project exhibited the higher areas of raveling on some of the test sections, but not all sections.
    b. There was no difference in the rut depths between the treated and control surfaces for all projects. The rut depths were considered a low severity on all test sections of all projects, not exceeding 0.25 inches.
    c. Slightly less transverse cracking was exhibited on the treated sections (figure 74).
    d. Slightly less longitudinal cracking was exhibited on the treated sections (figure 76).
8. Bias in PCR values between the treated and control sections:

a. The PCR calculated from the distress surveys performed in accordance with the ODOT procedure was statistically insignificant between the treated and control test sections. Although slightly less distress was exhibited on the treated surfaces, the lesser amount did not change the extent category based on ODOT's procedure for calculating PCR. In addition, the severity category between the treated and control surfaces was the same, on the average.

b. The PCR calculated from the distress surveys performed in accordance with the FHWA/LTPP procedure was statistically significant between the treated and control sections for the Reclamite sections with the higher residual application rates but statistically insignificant for the Biorestor sections with the lower residual application rates.

6.2 Findings

The following are important findings from the study.

1. The permeability significantly decreased over the monitoring period for both the treated and control sections (see figures 63 to 66), while only a slight to insignificant decrease was observed after spraying the sealers on the wearing surface (see figure 18). The sealers had no significant effect on permeability – time had a significantly greater impact. In 2016, all permeability values were less than 100 x^{-5}cm./sec. (see table 19).
2. As noted in observation #5, texture depth significantly increased over time for all test sections (see figures 59 to 62). Immediately after sealer application, the wearing surface for the SR-292/B project had the greater texture depth and the SR-47 surface had the lower texture depth (see table 6). In 2016, however, the US-40 project exhibited the lower texture depth, while the SR-292/A project exhibited the higher texture depth for the control sections (see table 18). Figure 88 shows the average percentage change in texture depth between the treated and control sections for different points in time for all projects. As shown, the Reclamite surfaces with the higher residual application rates exhibit the greatest reduction in texture depth compared to the control section in 2016. The greatest reduction or difference from the control sections simply means the least change in texture depth over time.

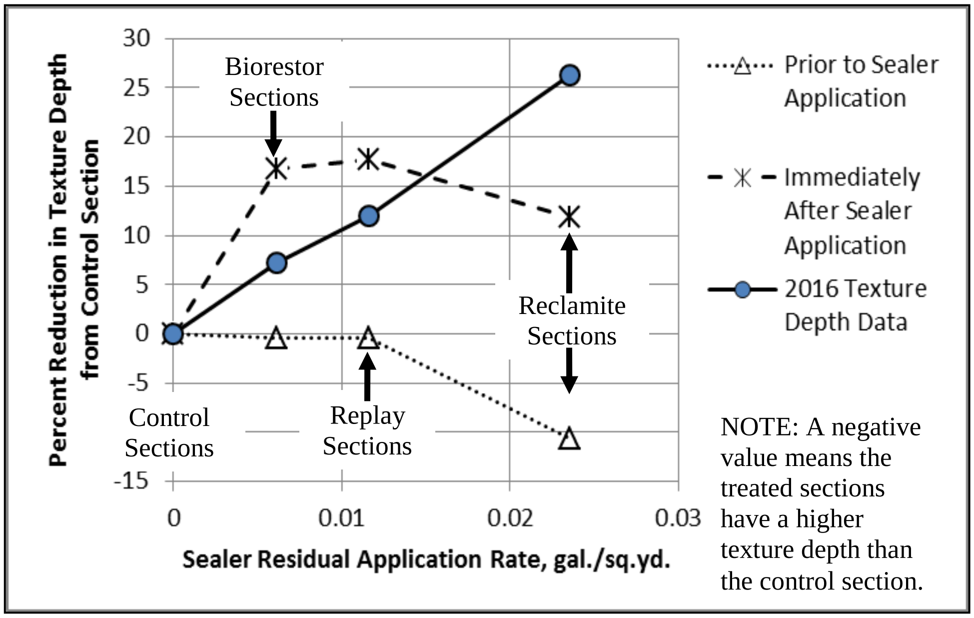


Figure 88. Percentage Reduction (Difference) in Texture Depth between the Treated and Control Surfaces Prior To, Immediately After, and in 2016

3. The skid resistance testing found a significant decrease in the SN for the treated surfaces; 33 percent of the treated surfaces tested immediately after sealer application were below an SN of 20 using a ribbed tire, while 100 percent of the treated surfaces were below 35. After 30-days, however, the SN for 75 percent of the treated sections was above 35. An SN of 35 is the approximate threshold value used by many agencies for defining a friction deficient surface (Hall et al., 2008). The following summarizes the SN values measured at different points in time relative to this threshold value (see table 11):
    a. Prior to sealer application: the SN was greater than 35 for all of the treated and control sections using the ribbed tire for the US-40 and SR-47 projects, while all of the test sections for the SR-292/A and SR-292/B were below 35.
    b. Immediately after sealer application: all of the treated surfaces for all projects exhibited an SN significantly less than 35.
    c. 7 days after sealer application: about 62 percent of the control sections exhibited an SN greater than 35, and only one of the treated surfaces (Biorestor of the SR-292/B project) was greater than 35.

   d. 30 days after sealer application: all of the control sections exhibited an SN greater than 35, while 17 percent of the Biorestor, 33 percent of the Replay, and 50 percent of the Reclamite sections exhibited an SN less than 35.

4. The PCR values calculated from the distresses measured in accordance with the ODOT and FHWA/LTPP procedure were different. Use of the FHWA/LTPP distress data resulted in a slightly lower PCR values in comparison to the PCR value calculated from the ODOT distress surveys (see figure 78).
5. The PCR values between the treated and control sections were found to be statistically indifferent based on the ODOT distress surveys, but the Reclamite penetrating sealer did show visual differences at the end of the monitoring period. Surface cracks observed in the untreated adjacent area were not observed at the boundary to the Reclamite treated surface (see figure 85). In addition, the boundaries of the Reclamite test sections were still visible 4 years after application (see figure 84) and the surface dried quicker than the untreated surface (see figure 83).
6. As noted above under observation #8, the PCR values calculated from the FHWA/LTPP distress survey data were statistically different between the treated and control surfaces. The PCR bias between the control and treated sections after 4 years, on the average however, was found to be 1.1 years for the Biorestor, 1.2 years for the Replay, and 2.2 years for the Reclamite sections relative to the untreated sections (see table 20). These differences were found to be related to the application rates. Using a regression equation to predict the PCR over time with the bias defined at 4 years resulted in the following extended service life, on the average.
   a. A 2-point PCR difference will result in a 1-year increase in service life at a PCR value of 75.
   b. A 1-point PCR difference will result in a 0.5-year increase in service life at a PCR value of 75.
7. A life cycle cost procedure was used to determine the costs for which the EAPC would be equal between the control and treated surfaces using the increased service life listed above which is based on the average PCR bias. On the average, applying the penetrating sealer is cost-effective if the added cost for a 2-lane mile roadway is less than about $15,000 for a 1-year increase in service life and less than about $30,000 for a 2-year

increase in service life (see figure 87). The added cost needs to include all costs related to applying the sealer to the pavement surface: material and application costs, traffic control costs, and skid resistance testing costs, as a minimum.

8. The skid resistance or SN values and bias in PCR values were found to be related to the residual application rate: the higher the residual application rate, the lower the SN value, but the greater bias between the PCR of the control and treated sections. The following summarizes the percentage of sections with an SN below 35 relative to the average residual application rate, which suggests a trend between the application rate and SN recovering or increasing over time relative to the threshold value of 35, as well as for the PCR bias:

Test Section	Control	Biorestor	Replay	Reclamite
Average Residual Application Rate, gal./sq.yd.	0.0	0.0061	0.0116	0.0236
Percent of Sections below an SN of 35	0.0	17	33	50
Average Bias between PCR of Treated and Control Sections	0.0	1.1	1.2	2.2

As shown, limiting the application rate based on skid resistance reduces the bias between the PCR of treated and control sections using the FHWA/LTPP distress survey procedure.

6.3 Conclusions and Recommendations

The objective of this study was to provide an answer to ODOT's question noted in the Introduction: Are surface treatments or penetrating sealers cost-effective? The answer to that question based on 4 years on monitoring data is: no using the ODOT distress surveys, but yes for the FHWA/LTPP distress surveys. It is assumed that ODOT will continue to use their distress survey procedure to quantify the surface condition of flexible and composite pavements. Thus, the authors conclude the use of penetrating sealers on newly placed HMA will not extend the service life of the HMA wearing surface. It is recommended, however, that ODOT continue to monitor the test sections to ensure the accuracy of the predicted time to reach a critical PCR value for the treated and control sections. The following lists the recommendations for continued monitoring of the test sections along all projects:

- Monitor the test sections on an every other year basis. Two additional monitoring periods should be sufficient to confirm the predicted change in PCR values within a typical rehabilitation design period.

- Continue to use the ODOT and FHWA/LTPP distress survey procedures.
- Calculate the PCR using the ODOT procedure to determine if the difference in PCR between the treated and control sections is observed in the latter years of each project and if the bias in PCR continues to be related to the average sealer residual rate.
- Continue to use the sand patch test on an every other year basis and calculate the texture depth to determine if the percent reduction in texture depth from the control section continues to be related to the average sealer residual application rate.
- Discontinue use of the field permeability test because of its variability. There is an insignificant difference between the treated and control sections compared to the differences measured over time for all test sections.

As summarized under Findings, applying penetrating sealers is cost-effective when using the bias established from the FHWA/LTPP distress surveys if: the added cost for a 2-lane mile roadway is less than about $15,000 for a 1-year increase in service life (residual application rate greater than 0.012 gal./sq.yd.); or less than about $30,000 for a 2-year increase in service life (residual application rate greater than 0.0235 gal./sq.yd). This finding is tempered by the reduction is skid resistance after applying the sealers. As such, penetrating sealers are not recommended for roadways where skid resistance is a design consideration. The following are recommendations for ODOT to consider, if penetrating sealers are used:

- The residual application rate should be measured.
- Skid resistance testing should be completed after each project where the penetrating sealers are used to ensure adequate friction is present. It is recommended that ODOT establish an SN threshold value for use on future projects.
- The incremental project costs for the penetrating sealer needs to include the material and application process, measuring the residual sealer rate, traffic control, and skid resistance testing.

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