DEPARTMENT OF TRANSPORTATION

Nontraditional Fog Seals for Asphalt Pavement: Performance on Shoulder Sections in Minnesota

Eddie N. Johnson, Principal Investigator
Minnesota Department of Transportation
Office of Materials and Road Research

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The pavement engineering community has recently been introduced to a number of nontraditional products intended for uses as surface sealers for bituminous pavements. Many new products use agricultural-based components and little is known regarding their effect on bituminous pavement performance.

Several nontraditional and “bio-based” fog sealants were applied to bituminous shoulder sections less than two years old. A field evaluation was performed over a three-year period, and included documenting installation, application rates, equipment types, locations, and sampling of the product. Annual field reviews were performed, including tests of pavement marking reflectivity, friction, cracking, appearance, and permeability.

Application rates varied from 0.015 to 0.10 gallons per square yard according to the product used. It was found that during the evaluation period, the applications provided various levels of waterproofing, and some test sections experienced less thermal cracking than the control. Nontraditional product applications did not adversely affect the long-term visibility of pavement markings or the overall pavement performance. Laboratory testing of pavement cores showed similar high- and low-temperature performance relative to the control.

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NONTRADITIONAL FOG SEALS FOR ASPHALT PAVEMENT: PERFORMANCE ON SHOULDER SECTIONS IN MINNESOTA

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TABLE OF CONTENTS

CHAPTER 1: Introduction 1

1.1 Background 1

1.2 Research Objectives 2

CHAPTER 2: Related Literature 3

2.1 Equipment 3

2.2 Binder Modification 3

2.3 Performance Evaluations 5

CHAPTER 3: Minnesota Test Sections 8

3.1 Materials 8

3.2 Installation 9

CHAPTER 4: Material Evaluations 21

4.1 FTIR Scan Results 21

4.2 Laboratory Binder Testing 24

CHAPTER 5: Test Section Performance 28

5.1 Field Testing 28

5.2 Field Reviews 44

5.3 Inspection Summary Following Routine Fog Sealing Over Project Test Sections 54

CHAPTER 6: Survey of Nontraditional Fog Sealing 57

6.1 Responses 57

CHAPTER 7: Conclusion 65

7.1 Summary 65

7.2 Recommendations 67

REFERENCES 69

APPENDIX A Screening Review, Bid Price for Bituminous Fog Seal, Photos of Nontraditional Fog Material Samples

APPENDIX B Survey Letter

LIST OF FIGURES

Figure 3.1 Typical section from SAP 086-675-018 plan. 9

Figure 3.3 Layout of fog treatments applied during 2014. 10

Figure 3.4 Installation of CSS-1h on Wright CSAH 75 shoulder. 11

Figure 3.5 Installation of RePlay™ on Wright CSAH 75 shoulder. 12

Figure 3.6 Test setup for monitoring retroreflectivity and application rate; RePlay™. 12

Figure 3.7 Close-up of residue on transverse striping. 13

Figure 3.8 Close-up of residue on longitudinal striping. 13

Figure 3.9 Installation of Biorestor® on Wright CSAH 75 shoulder. 14

Figure 3.10 Close-up of transverse striping. 14

Figure 3.11 Close-up of longitudinal striping. 15

Figure 3.12 Installation of Jointbond® on Wright CSAH 75 shoulder. 15

Figure 3.13 Test setup for monitoring retroreflectivity and application rate; Jointbond®. 16

Figure 3.14 Close-up of residue on striping at Location B. 17

Figure 3.15 Cell 33 Transition at MnROAD (google earth). 17

Figure 4.1 Residue from the three proprietary sealant products. 21

Figure 4.2 FTIR of a cured asphalt emulsion. 22

Figure 4.3 FTIR of Jointbond®. 22

Figure 4.4 FTIR of RePlay™. 23

Figure 4.5 FTIR of Biorestor®. 23

Figure 4.6 Core preparation diagram. 24

Figure 4.7 DSR results with single operator standard deviation. 26

Figure 4.8 BBR results with single operator standard deviation. 27

Figure 5.1 Retroreflectivity before/after RePlay™ application. 29

Figure 5.2 Retroreflectivity before/after Biorestor®015 application. 30

Figure 5.3 Retroreflectivity before/after Biorestor®020 application. 30

Figure 5.4 Retroreflectivity before/after Jointbond® application. 31

Figure 5.5 Retroreflectivity performance with RePlay™. 32

Figure 5.6 Retroreflectivity performance with Biorestor®. 32

Figure 5.7 Retroreflectivity performance with Jointbond®. 33

Figure 5.8 DFT test output for a plant mixed asphalt surface. 34

Figure 5.9 DFT Data from CSAH 75: Control section. 35

Figure 5.10 DFT Data from CSAH 75: HMA with various fog treatments. 36

Figure 5.11 CTM standard deviations for treatment location and octant, Year Two (left) and Year Three (right). 38

Figure 5.12 Mean Profile Depth by Treatment. 38

Figure 5.13 Plot of In-Place Air Voids versus Permeability for 12.5mm coarse mix (25). 39

Figure 5.14 Field permeability of Fog sections: Year One. 40

Figure 5.15 Field permeability of Fog sections: Year Two. 42

Figure 5.16 Ponded water soaking into surface texture (left, right). 43

Figure 5.17 Transverse Cracking Histories. 47

Figure 5.18 Differential Cracking Rates Relative to EB Control. 48

Figure 5.19 Year One wet-condition photos clockwise from upper left: WB Control, Jointbond®, Biorestor® 0.015, CSS-1h, RePlay™, and Biorestor® 0.020. 49

Figure 5.20 Year Two wet-condition photos clockwise from upper left: WB Control, Jointbond®, Biorestor® 0.015, CSS-1h, RePlay™, and Biorestor® 0.020. 51

Figure 5.21 Year Two dry-condition photos clockwise from upper left: WB Control, Jointbond®, Biorestor® 0.015, CSS-1h, RePlay™, and Biorestor® 0.020. 52

Figure 5.22 Year Three dry-condition photos clockwise from upper left: WB Control, Jointbond®, Biorestor® 0.015, CSS-1h, RePlay™, and Biorestor® 0.020. 54

Figure 5.23 Year Four following routine fog seal, condition photos clockwise from upper left: WB Control, Jointbond®, Biorestor® 0.015, CSS-1h, RePlay™, and Biorestor® 0.020. 56

Figure 6.1 Use of nonstandard fog seal material among Minnesota Cities and Counties. 58

Figure 6.2 Nonstandard products used by MN cities and counties. 58

Figure 6.3 Miles of treatment by type. 59

Figure 6.4 Performance measures. 60

Figure 6.5 Regular maintenance vs. test section. 60

Figure 6.6 Material acceptance method. 62

Figure 6.7 Respondent opinion on other agencies trying similar treatments. 63

Figure 6.8 Respondents able to provide more information. 63

LIST OF TABLES

Table 3.1 Sealant-treated Pavement Markings Installed at MnROAD 18

Table 3.3 Description of Fog Seal Materials 18

Table 3.4 Treatment Rates as Measured With Two Methods 20

Table 3.5 Cost per Treated Test Section 20

Table 4.1 Binder Test Results; Minnesota Year Three 25

Table 5.1 Permanent Pavement Markings (MnDOT 2582, published 2014) 28

Table 5.2 Friction Results on New Fog Treatments (ASTM E274 and E1911) 35

Table 5.3 Mean Profile Depth 37

Table 5.4 Field Permeability Values: Year Two 41

Table 5.5 Permeability Reductions: Year Two 41

Table 5.6 Field Observations: Infiltration and Runoff 43

Table 5.7 Basic Sealant Functionality on CSAH 75 Test Sections: Years 2 and 3 44

Table 5.8 Distress Surveys of Test Sections 46

Table 5.9 Relative Cracking Performance in Year Three 46

Table 6.1 Product Age and Performance 61

Table 6.2 Composite Performance Summary 62

LIST OF ABBREVIATIONS

AHTD	Arkansas State Highway and Transportation Department
ASTM	ASTM International, formerly American Society for Testing and Materials
BBR	Bending Beam Rheometer
CSAH	County State Aid Highway
DFT	Dynamic Friction Tester
DSR	Dynamic Shear Rheometer
FHWA	Federal Highway Administration
FTIR	Fourier Transform Infrared Spectroscopy
gsy	Gallons per square yard
HMA	Hot Mix Asphalt
LRRB	(Minnesota) Local Road Research Board
LTPP	Long Term Pavement Performance (FHWA program)
MnDOT	Minnesota Department of Transportation
mph	miles per hour
NMAS	Nominal Maximum Aggregate Size
ODOT	Ohio Department of Transportation
PennDOT	Pennsylvania Department of Transportation
PG	(Asphalt Binder) Performance Grade
SARA	Saturate, Aromatic, Resin, and Asphaltene
SSU	Saybolt Universal Second (kinematic viscosity)
TDOT	Tennessee Department of Transportation
TRIG	Transportation Research and Innovation Group

EXECUTIVE SUMMARY

In recent years, the pavement engineering community has been introduced to a number of nontraditional products intended for uses as surface sealers for streets, highways, shoulders, and recreation trails. Many new products use agricultural-based components and little is known regarding their effect on bituminous pavement performance.

Several nontraditional and "bio" based fog sealants were applied to bituminous shoulder sections less than two years old. Field evaluation over a three-year period included documenting the installation, application rates, equipment types, locations, and sampling of the product. Annual field reviews were performed, including tests of pavement marking reflectivity, friction, cracking, appearance, and permeability.

Application rates varied from 0.015 to 0.10 gallons per square yard according to the product used. It was found that the applications did not adversely affect overall pavement performance. At the end of the study, no problems were encountered on any test section after they were covered with a routine maintenance fog seal of emulsified asphalt.

All applications provided a reduction of pavement permeability, and two nontraditional products developed less cracking relative to untreated sections. However, the nontraditional products in the study did not improve the low- or high-temperature properties of the asphalt binder. All of the products caused reductions in pavement friction and pavement marking retroreflectivity. The recovery period for friction was much shorter for nontraditional fog seal treatments when compared to an emulsified asphalt fog seal. Recovery of retroreflectivity occurred under traffic.

A survey found that local agencies had tried a number of nontraditional products and observed effective performance between two to six years.

CHAPTER 1: INTRODUCTION

This report is a result of research sponsored by the Minnesota Local Road Research Board (LRRB) and the Minnesota Department of Transportation (MnDOT) Transportation Research and Innovation Group (TRIG) for a project named LRRB project number 974, Field Investigation of Bio-Based Asphalt Sealers.

This final report follows a series of interim and special reports that were sent to the project technical panel. Prior report topics included:

- Site and product selection
- Field installation and baseline properties
- Field performance (Year One, Year Two, Year Three)
- Survey of Minnesota cities and counties

1.1 BACKGROUND

Asphalt-based fog seal surface treatments have been successfully used for many years as a preventive maintenance tool for bituminous pavements. In recent years the pavement engineering community has become increasingly aware of a number of products that have been introduced as alternative surface sealers for streets, highways, shoulders, and recreation trails. Many new products use agricultural-based components and little is known regarding their effect on bituminous pavement performance.

In the traditional sense, fog seal materials for bituminous streets and highways include a type of emulsified asphalt as the main ingredient. Sources define fogs seals as: "… an application of asphalt emulsion sprayed onto a pavement surface with or without a sand cover" (1), and "… a light application to an existing surface of a slow setting asphalt emulsion diluted with water" (2). It is commonly known that asphalt material is a byproduct generated from the crude oil refining process. Furthermore, modern generic fog seal standards focus on materials where asphalt is the main ingredient.

For the purpose of this report, nontraditional, nonstandard fog seal materials will be broadly represented. They will be said to contain main ingredients that have:

- a primary active material component not derived from petroleum, or
- primary active materials with relative proportions of maltene (resins, aromatic oil, and saturate oil) or similar compounds found in asphalt, but relatively low proportion of asphaltenes, or
- material having a special formulation.

It was proposed that "bio"-sealers should be studied in concurrent laboratory and field research projects to document their performance and effect on bituminous pavements. This report contains details about the field research, for details on the laboratory research refer to Ghosh et al. and Ghosh (3, 8).

1.2 RESEARCH OBJECTIVES

Bituminous shoulder sections less than two years old would be used for field test sections. The proposal included the purchase of products in addition to the research. Field evaluation would include documenting the installation, application rates, equipment types, locations, and sampling of the product. Annual field reviews and photos would be used, along with tests for effects on pavement marking reflectivity, friction, cracking, appearance, and permeability. The project final report would include both performance and cost results.

In addition to untreated control sections, the field study included a traditional emulsified asphalt fog seal (CSS-1h), two agricultural-based "bio-sealers" (RePlay™ and Biorestor®), and a longitudinal joint stabilizer (Jointbond®).

Environmental and other testing: Environmental testing was of interest to the project sponsors but was beyond the scope of this work plan. The researchers received an initial environmental screening of the nontraditional fog products. Samples and cores were obtained for future or concurrent laboratory work conducted outside the scope of this research. Applications over pavement markings were evaluated for the effect on retroreflectivity.

CHAPTER 2: RELATED LITERATURE

Academic research has been performed on the subject of asphalt binder modifiers, but to date there has been relatively little academic research to evaluate the use of spray applied fog seal treatments in the field. Much of the useful and available literature includes reports that have been published by public transportation agencies or manufacturer-sponsored testing conducted by independent laboratories. Transportation agency reports generally focus on benefits relative to particular roadway performance characteristics that are chosen by the reporting agency, and manufacturer-sponsored literature may include white papers or independent laboratory test reports. All of these literature types are presented here in the spirit of sharing information.

2.1 EQUIPMENT

Pavement sealing has long focused on the use of bituminous-type materials. Many that are familiar with bituminous materials realize the importance of achieving conditions that are appropriate for pumping and applying the material. However, factors like pumping characteristics, working temperatures, and application rates may change with material type, and so will influence the design and selection of distribution equipment. For example, a state of the art asphalt distributor may become useless in a situation where agricultural-type equipment is better suited to the material.

Although there are many components to spray-applied distribution vehicles, several resources are offered for readers that would like to familiarize themselves with spray nozzles.

- The Tee-Jet Company produced a reference titled “The User’s Guide to Spray Nozzles” (4). This document discusses nozzle fundamentals, type, selection, maintenance, and calibration.
- The University of Kentucky’s College of Agriculture produced a document titled Sprayer Nozzles: Selection and Calibration (5). This six-page document covered the topics of nozzle type, spray pattern, and calibration.

2.2 BINDER MODIFICATION

2.2.1 University of Illinois Binder Modification study

In 1980 Carpenter and Wolosick authored a report on a University of Illinois experiment that studied the effect of introducing a binder modifier into an asphalt mixture (6). Two types HMA laboratory specimens were produced using the identical mixture components and proportions. In the first case a rejuvenator dose was added to a mixture that contained RAP salvaged from a milling project. This created a partially rejuvenated recycled material. In the second case the salvaged binder was extracted from the RAP and fully reacted with the rejuvenator dose, then recombined with the RAP aggregate to make a fully rejuvenated material. Specimens of both types were tested at various times to observe mixture performance as the rejuvenator diffused into the recycled binder.

It was observed that tests of the rejuvenated mixture showed little variation of resilient modulus, creep compliance, or rutting potential over time using the VESYS procedure. The recycled mixture results showed resilient modulus decreasing over time after high initial results, little variation in creep compliance, and softening followed by hardening over time using the VESYS procedure. The authors concluded that the time between mixing and testing is critical for materials that contain modifying agents. Mixture test results will be influenced by a rejuvenator's reaction rates for different types of virgin and recycled binder.

2.2.2 U.S. Army Rejuvenator Study

In 2003 Schoenberger (7) authored a U.S. Army Corps of Engineers research report about the field and laboratory testing of rejuvenator and seal coat material for bituminous pavement. The product test matrix for rejuvenators included eight coal-tar based and three petroleum-based materials. Likewise, the seal coat matrix included two coal-tar based, two petroleum-based, and one acrylic copolymer material. The laboratory evaluation focused on measuring (reduction of) stiffness using penetration, viscosity, ductility, and dynamic shear rheometer (DSR) tests. Field evaluations focused on surface texture and friction, and tests methods included sand patch, British Pendulum, Grip Tester, and Saab Friction Tester.

Report findings: (1) rejuvenators lowered friction in the short term, (2) materials containing coal-tar provided resistance to the effects of fuel spills, (3) phase angle from the DSR test was recommended over using G*, (4) seal coat products evaluated provided satisfactory skid resistance, and (5) skid resistance of treatments topped with aggregate will depend on the amount and type of aggregate.

2.2.3 University of Minnesota Study

Minnesota LRRB bio-sealer research was described in a thesis authored by Ghosh in 2017 (8). The work focused on material performance for cold climates. DSR and BBR tests evaluated laboratory-treated and untreated binders. Thin beams of treated and control mixtures were produced from pavement cores then tested using the BBR.

A significant softening effect was observed in the laboratory-prepared specimens when oil-based sealants treated the control binder. The oil-based sealants increased rutting and fatigue potential of the binder and improved the low-temperature cracking resistance. Different trends were observed for specimens produced from pavement cores. The report further states that "Fourier transform infrared spectroscopy (FTIR) analysis showed that the sealant products could not be detected in mixture samples collected from the surface of the treated section. Semi-empirical Hirsch model was able to predict asphalt mixture creep stiffness from binder stiffness. The results of a distress survey of the test sections correlated well with the laboratory findings."

The author proposed using a modified BBR binder strength test method to better select crack-resistant asphalt binders. Three-point BBR tests should be performed on mixtures at a constant loading rate at low temperature.

2.3 PERFORMANCE EVALUATIONS

2.3.1 Pennsylvania DOT Field Evaluation

In 2009 the Pennsylvania Department of Transportation (PennDOT) reported on an evaluation of RePlay™ installed on a "12.5 mm Superpave containing a PG 76-22 binder" (9). Traffic levels were 16,526 ADT on the control and treated sections. Aggregate skid resistance was reported to be level E, which is satisfactory for an ADT greater than 20,000 (10). The project objective was for PennDOT to measure the benefits of RePlay™ by employing skid tests, field observations and laboratory permeability testing.

Product was installed in the traffic lane at a rate of 0.015 gallons per square yard. Installation observation noted a darkening of the pavement surface and the joint (crack) sealant exhibited some softening. The project found there was no change in the permeability of the pavement due to the treatment after one year, and no visible difference could be found when comparing the treated to the untreated pavement. Skid tests revealed a temporary decrease in pavement friction. Pavement marking retroreflectivity was not measured, but reductions of pavement marking reflectivity were reported from a concurrent project installed on a county highway.

2.3.2 Bituminous Longitudinal Joint Evaluations for Tennessee DOT

In 2010 Huang and Shu reported on an evaluation of a variety of products intended to improve longitudinal construction joints in bituminous pavement (11) for the Tennessee Department of Transportation (TDOT). Treatments were organized by categories such as joint adhesives, joint sealers (Jointbond® and RePlay™), and infrared heating. Laboratory tests were performed on field cores from several project locations. Testing included air voids, permeability, indirect tensile strength, water absorption, and X-ray CT. The application rates for the joint sealers were 0.08 gsy (Jointbond®) and 0.03 gsy (RePlay™). The report noted that the joint sealer category performed well during the water absorption evaluations.

2.3.3 University of Arkansas Longitudinal Joint Study

The Arkansas State Highway and Transportation Department (AHTD) supported a report authored by Williams (12) in 2011. This research included the study of methods that could characterize both joint quality and performance. The ultimate objective was to recommend techniques to improve the quality of longitudinal joints, identify methods to quantify joint quality, and draft longitudinal joint quality specifications for use by AHTD. The research included evaluations of spray-applied materials including Jointbond® and Tack Coat. The Jointbond® was applied 3-ft wide to the longitudinal joint at a rate of 0.11 gallons per square yard. The report stated that the Jointbond® appeared to increase density and decrease permeability.

2.3.4 Dynamic Friction Tests of Biorestor® at Hurlburt Field

The Biorestor® webpage shows the result of friction tests performed in 2014 using Dynamic Friction Tester (DFT) equipment (ASTM E1911). In this one-page document DFT test results were obtained at 60 miles per hour on control and treated test strips (13). Correspondence with Freisthler indicates that the Army Corps of Engineers performed the friction testing (14). The DFT (µ at 60 mph) results for each test strip were plotted against the age of the treatment. In this experiment the treatments were Biorestor® applied at 0.015 and 0.020 gallons per square yard and age of the treatment ranged from approximately 0 to 120 hours after treatment. In the plot the maximum value of µ60 coefficient of dynamic friction was approximately 0.61 for the control strip. The greatest friction reduction was measured approximately 50 hours after treatment on the 0.015 gsy test strip (µ60 approximately 0.51). DFT values were found to increase after 50 hours. Graphical results showed the 0.020 gsy treatment performed slightly better than the 0.015 gsy treatment.

2.3.5 Testing for Pavement Technology, Inc.

During September 2016 Pavement Technology, Inc. (PTI) requested to extract a pair of treated and untreated cores from each of the CSAH 75 test sections from Wright County, Minnesota. The company planned a round of binder extraction, Dynamic Shear Rheometer, and Penetration testing. A report was later shared by PTI and their independent laboratory, Asphalt Paving and Recycling Technologies, Inc. of Shafter CA. Treatment rates are found elsewhere in this report.

The laboratory report (15) stated that comparisons were done on material taken from the top 3/8” of core. With the exception of the CSS-1h section, the report showed the treatments increasing the phase angle, and lowering binder viscosity and stiffness with respect to the untreated pavement.

Some reviewers of the report noted the fact that the CSS-1h fog seal emulsion was most likely manufactured using a stiffer base asphalt than was used for binder in the CSAH 75 asphalt mix may have caused difficulty in drawing conclusions from the DSR results. Minnesota proposed another round of tests using binder extracted from core slices taken from approximately mid-depth.

2.3.6 Testing for BioSpan Technologies, Inc.

In 2017 Thiele Geotech of Omaha Nebraska and PRI Asphalt Technologies, Inc. of Tampa Florida released a report on the analysis of a 2-in. bituminous overlay treated with RePlay™ on 168th Street in Douglas County, Nebraska.

The laboratory report (16) stated the bituminous pavement was constructed in 2016 with a mixture containing 25 percent RAP and using PG 64-34 asphalt binder. After three months the road was treated with RePlay™. The laboratory report did not contain information about the RePlay™ application rate.

Six cores were taken from both treated and untreated control sections after the treatment age reached one year. Cores were trimmed so that only thin slices of the overlay were tested using Texas Overlay

Test, Dynamic Shear Rheometer, SARA Components (ASTM D4124), and Carbonyl Index from FTIR. Slices were obtained from the first (top), second, and third 3/8-in. of the cores.

Dynamic Shear results from the Thiele report indicated relatively stronger effect from the treatment in the top 3/8-in. of the overlay core. The effect was somewhat less in the middle 3/8-in. of the core, and negligible at the core bottom.

2.3.7 Ohio DOT Evaluation

In 2017 Von Quintus and Raghunathan authored a report after studying the potential pavement life extension and cost effectiveness benefits of using asphalt sealers (17). A field research portion of the study evaluated the performance of RePlay™, Reclamite, Biorestor®, and Control sections over a four-year period. Evaluation methods included monitoring application rates, performing condition surveys, and performing sand patch, mat density, field permeability, and friction tests. Test sections were located on four different highways. The in-place mixtures used PG76-22 asphalt binder in one case, and PG70-22 for the rest. Although application rates varied, the average rates were approximately: Control 0.000 gsy, Biorestor® 0.006 gsy, RePlay™ 0.012 gsy, and Reclamite 0.024 gsy.

Field permeability results were highly variable, but sections that produced relatively lower initial values showed no permeability reduction benefit, and sections with relatively higher initial values showed a slight permeability reduction benefit. The report stated that "…all sections (treated and control) exhibited a much greater reduction in permeability over time, than from spraying the sealers on the wearing surface."

Sand patch test results showed a trend of decreased surface texture after sealer application. Skid trailer friction evaluations showed an immediate post-application reduction occurred. A partial friction recovery was measured over a 30 day period.

Distress ratings showed that treated sections developed slightly less cracking and raveling distress than the controls. The observations were recorded using the ODOT and FHWA/LTPP methods, to produced data that was converted to PCR ratings for analysis. Comparison of PCR from the two systems found no statistical difference for any treatment using ODOT, while the FHWA/LTPP method yielded statistical differences for treatments with higher application rates.

In the final analysis the use of penetrating sealers was recommended for roads where the respective added costs for one and two years of additional service life are less than $15,000 and $30,000. Use of penetrating sealers was not recommended on roads where friction is an issue.

CHAPTER 3: MINNESOTA TEST SECTIONS

3.1 MATERIALS

Fog seal test strips were constructed on 8-ft shoulder sections. The road and shoulders were paved full width in 2013 using a MnDOT SPWEB340C mix design (18) where:

SP refers to superpave gyratory mixture design

WE refers to Wear Course design

B refers to aggregate gradation with 12.5 mm (0.5 in.) NMAS and 19.0 mm (0.75 in.) maximum. Minnesota specifies that gradation B lift thickness will be no less than 1.5 in.

3 refers to design traffic level of 1 – 3 million ESAL's

40 refers to design percent air void of 4.0

C refers to asphalt performance grade PG58-34

3.1.1 Control Section

The control sections were untreated SPWEB340C asphalt pavement.

3.1.2 CSS-1h

CSS-1h nomenclature describes a slow set cationic emulsion with relatively low viscosity that is made using relatively hard base asphalt. In Minnesota the product is normally diluted 1:1 for fog sealing applications and used at full strength for chip sealing.

3.1.3 RePlay™

RePlay™ is a polymer-bearing, proprietary fog treatment product for bituminous pavement. The product is described as a preservation agent derived from agricultural oils.

3.1.4 Biorestor®

Biorestor® is a proprietary fog treatment product for bituminous pavement. Although the manufacturer lists several products bearing the Biorestor® name, the Asphalt Rejuvenator is described as a bio-based maltene.

3.1.5 Jointbond®

Jointbond® is a proprietary product that is designed for stabilizing the area surrounding longitudinal construction joints. The product is described as a polymerized maltene emulsion.

3.2 INSTALLATION

Test sections were located on portions of Wright County CSAH 75, north of Monticello, MN. The highway was paved in 2013, and fog sealing installation occurred on 8-ft shoulder sections in 2014. The paving project plan showed the traffic level at the time of construction was 3,737 AADT along 94 percent of the project, including the areas with fog seal test sections. Traffic on the remaining portions of the highway was 4,800 AADT. The following typical section (Figure 3.1) is copied from the CSAH 75 project plan from 2013, State Aid Project 086-675-018.

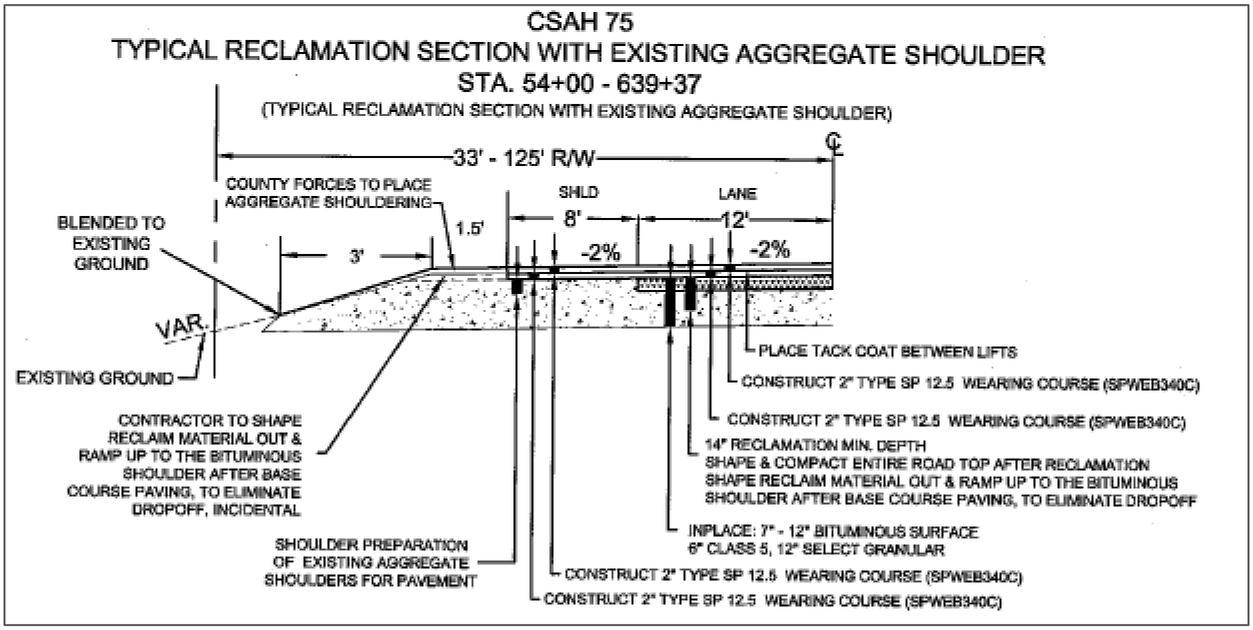

Figure 3.1 Typical section from SAP 086-675-018 plan.

With respect to Figure 3.2, the CSS-1h section was placed on the westbound shoulder of CSAH 75 between an intersection with a local road and the entrance to an aggregate pit. The section treated with RePlay™ was placed on the eastbound shoulder in the same general area. Two sections treated with Biorestor® were placed on the eastbound shoulder just east of an intersection with a county road. The section treated with Jointbond® was placed on the eastbound shoulder beginning at the intersection with a local road. Untreated control sections were located in the east and westbound shoulders.

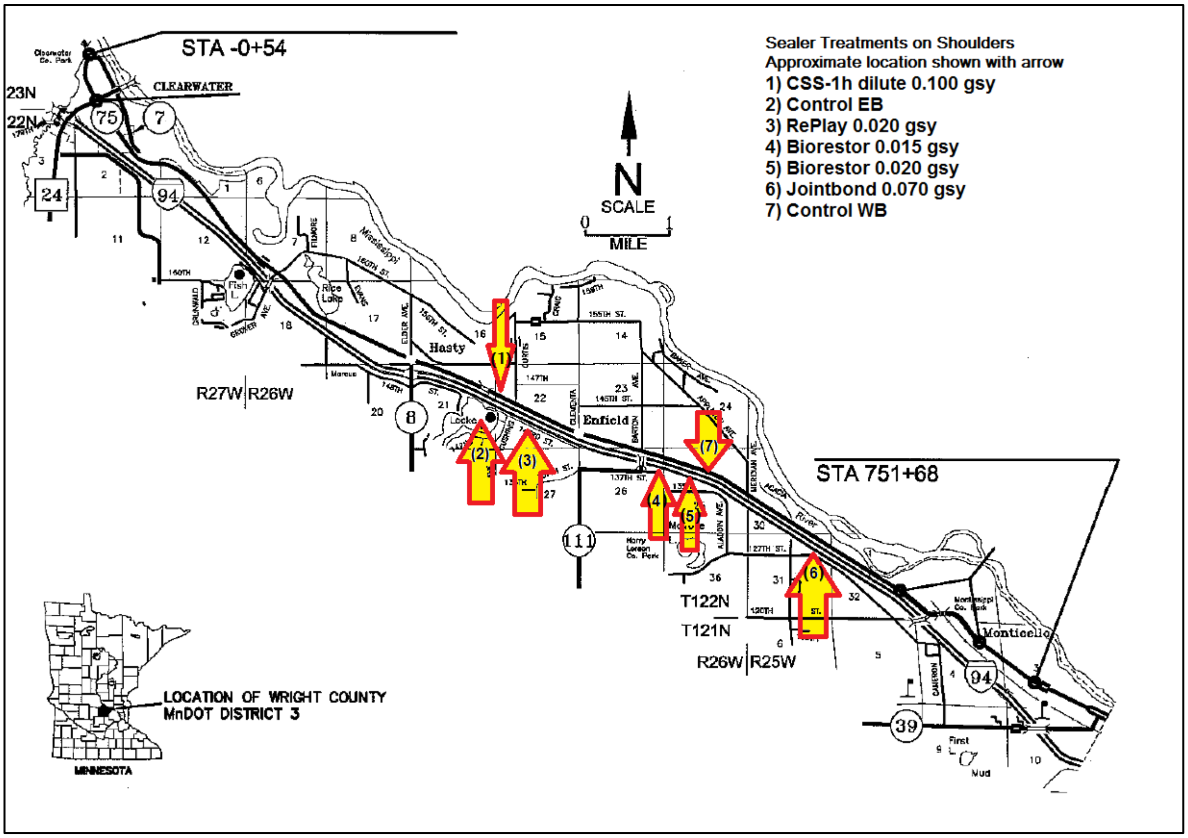

Figure 3.2 Layout of fog treatments applied during 2014.

3.2.1 Observations

3.2.1.1 Control Section

A 500-ft control section (EB Control) was selected in the south-facing shoulder of an east-west alignment (Number 2 in Figure 3.2). The test section was located across from the CSS-1h installation, received no shade, and had no cross traffic.

A 1,320-ft control section (WB Control) was selected in the north-facing shoulder of an east-west alignment (Number 7 in Figure 3.2). The test section was located across from the Biorestor® 0.020 (gsy) installation. This control section was later expanded to 2,640 feet during the Year-1 distress survey, and the expanded portion was located across from the Biorestor® 0.015 (gsy) installation. The section received partial shade, and had cross traffic from two residences.

3.2.1.2 CSS-1h Installation

The test section was installed on the north-facing shoulder of an east-west alignment (Number 1 in Figure 3.2). The test section received no shade, and had cross traffic from a single driveway. CSS-1h is a slow set cationic emulsion with relatively low viscosity that is made using relatively hard base asphalt. The CSS-1h was diluted 1:1 with water for the purpose of fog sealing, and 77.8 gallons were applied at a

7-ft width along 1,000 consecutive feet of bituminous shoulder. Application was performed by a contractor. An asphalt distributor applied the CSS-1h material at a rate of 0.1 gallons per square yard (Figure 3.3) in the westbound shoulder. Weather was dry and clear, with a light breeze.

There were no applications to the existing fog line. No pre-application sweeping was performed. Measurement of application rate was not necessary since the contractor was also performing chip seal work for MnDOT on two nearby projects, and MnDOT inspectors were monitoring the distributor performance.

Figure 3.3 Installation of CSS-1h on Wright CSAH 75 shoulder.

3.2.1.3 RePlay™ Installation

The test section was installed on the south-facing shoulder of an east-west alignment (Number 3 in Figure 3.2). The test section received no shade, and had no cross traffic. RePlay™ is a polymer-bearing, proprietary fog treatment product for bituminous pavement. The product has a reported SSU viscosity of 5 to 20 seconds at 25 °C, and at the time of application it was apparent that flow characteristics were similar to water at room temperature. 35.4 gallons of RePlay™ were applied at 6-ft width along 2680 consecutive feet of bituminous shoulder. Application was performed by the vendor.

The installer in this case had a set of vehicles and equipment dedicated to fog treatment. The crew arrived with two types of delivery vehicles, a small cart-mounted distributor system and also a truck-mounted distributor. Only the truck-mounted equipment was used. Spray bars were fitted with nozzles suitable for applying product in the range of 60 gallons per acre. Spray bars were height-adjustable, and were set at 14-in above the pavement. The distributor truck had a main bar with 8 evenly-spaced nozzles and two side bars with three nozzles each; giving the total treatment width of approximate 14 ft. The distributor cart was similar except the main bar contained 5 nozzles. According to the crew, vehicle speed was normally in the range of 5 to 10 mph during application.

The truck-mounted system was used to apply RePlay™ material at a rate of 0.020 gallons per square yard (Figure 3.4) in the eastbound shoulder. A pre-application sweep was performed with a mechanical broom. There were no applications to the existing fog line. Weather was dry and clear, with a light breeze.

Figure 3.4 Installation of RePlay™ on Wright CSAH 75 shoulder.

A measurement of the application rate was performed by securing 2-ft by 2-ft geotextile pads to the pavement surface. Two pads were used, and were separated by an interval of approximately one-third the treatment length.

Before-After measurements of retroreflectivity were taken on segments of permanent white marking tape. During installation, the tapes were placed in the vicinity the geotextile pads. Figure 3.5 shows the setup after pads had been removed.

Figure 3.5 Test setup for monitoring retroreflectivity and application rate; RePlay™.

Figure 3.6 and Figure 3.7 show the appearance of the tape after application. Note that some residue was visible on the tape.

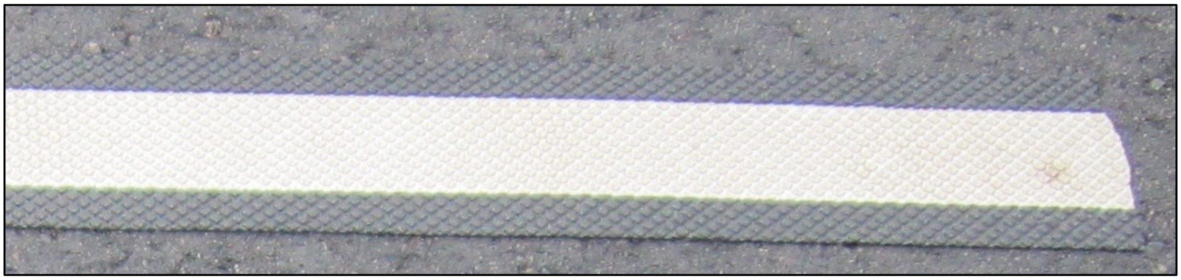

Figure 3.6 Close-up of residue on transverse striping.

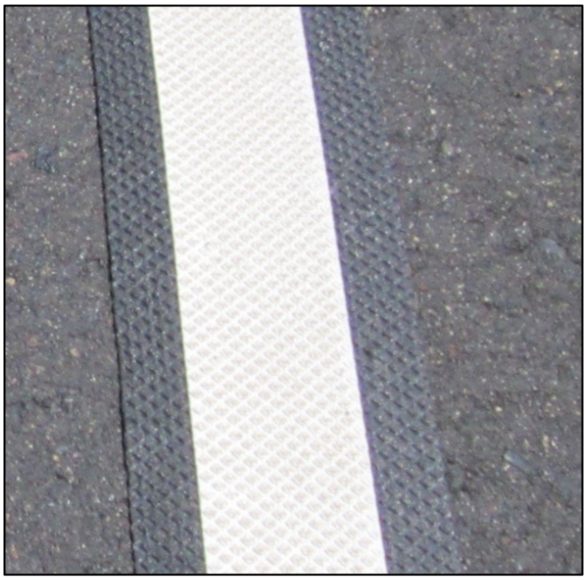

Figure 3.7 Close-up of residue on longitudinal striping.

3.2.1.4 Biorestor® Installation

The test sections were installed on the south-facing shoulder of an east-west alignment (Numbers 4 and 5 in Figure 3.2). The test sections received partial shade along the first 1,500 feet, and had cross traffic from two unmarked, unpaved trail approaches. Biorestor® is a proprietary fog treatment product for bituminous pavement. At the time of application it was apparent that flow characteristics were similar to water at room temperature. 37.78 gallons of Biorestor® was applied as a fog treatment of bituminous pavement along a 7-ft width along 2664 consecutive feet of bituminous shoulder. The application was performed by the vendor.

The vendor in this case used truck-mounted distributor equipment. The equipment was not dedicated solely to use with this fog product. Spray bars were fitted with AIC TeeJet #1108 nozzles suitable for applying product in the range of 0.745 gallons per minute at 35 psi. Spray bars were height-adjustable, and were set at a 14-in. The distributor truck had a main bar with 7 evenly-spaced nozzles and two side bars with 3 nozzles each; giving the total treatment width of approximate 13 ft. The vendor supplied information that application speeds were in the range of 450 ft per minute (5 mph).

A distributor truck applied the Biorestor® material at a rate of 0.015 gallons per square yard (Figure 3.8) to 1,338 feet of the eastbound shoulder. A rate of 0.020 gallons per square yard was applied to the following 1,326 feet. A pre-application sweep was performed using a mechanical broom. There were no applications to the existing fog line. Weather was dry and clear, with a light breeze.

Figure 3.8 Installation of Biorestor® on Wright CSAH 75 shoulder.

A measurement of the application rate was performed by securing 2-ft by 2-ft pads to the pavement surface. Two pads were used per treatment rate, and were separated by an interval of approximately one-third the treatment length.

Before-After measurements of retroreflectivity were taken on segments of permanent white marking tape. During installation the tapes were placed in the vicinity of the nonwoven geotextile pads. Figure 3.9 and Figure 3.10 show the appearance after fog application.

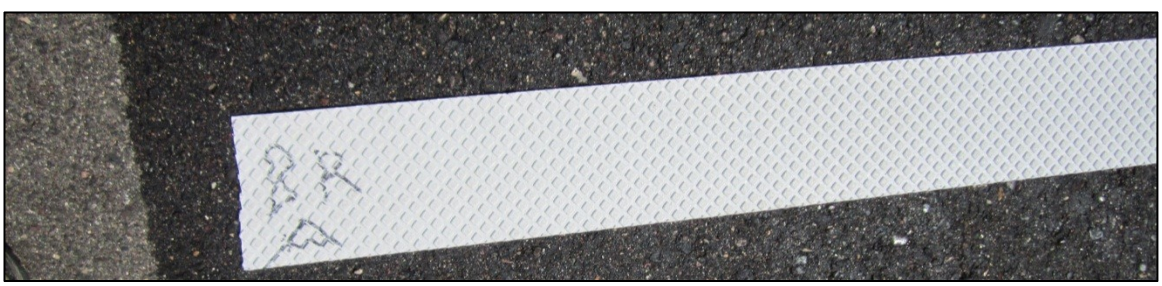

Figure 3.9 Close-up of transverse striping.

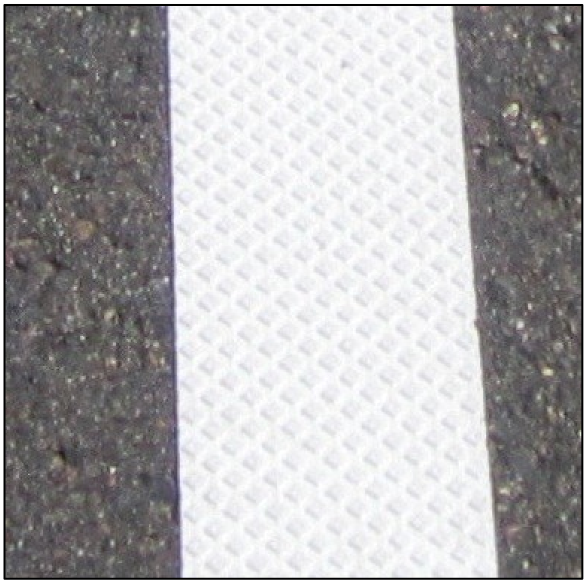

Figure 3.10 Close-up of longitudinal striping.

3.2.1.5 Jointbond® Installation

The test section was installed on the north-facing shoulder of an east-west alignment (Number 6 in Figure 3.2). The test section received no shade, and had no cross traffic. Jointbond® is a proprietary product that is designed for stabilizing the area surrounding longitudinal construction joints. 180 gallons of Jointbond® was applied as a fog seal of bituminous pavement to a 7-ft width along 3,000 consecutive feet of bituminous shoulder. Application performed by the manufacturer.

A dedicated distributor truck applied the Jointbond® material at a target rate of 0.08 gallons per square yard (Figure 3.11) to the eastbound shoulder. A pre-application sweep was not performed. There were no applications to the existing fog line.

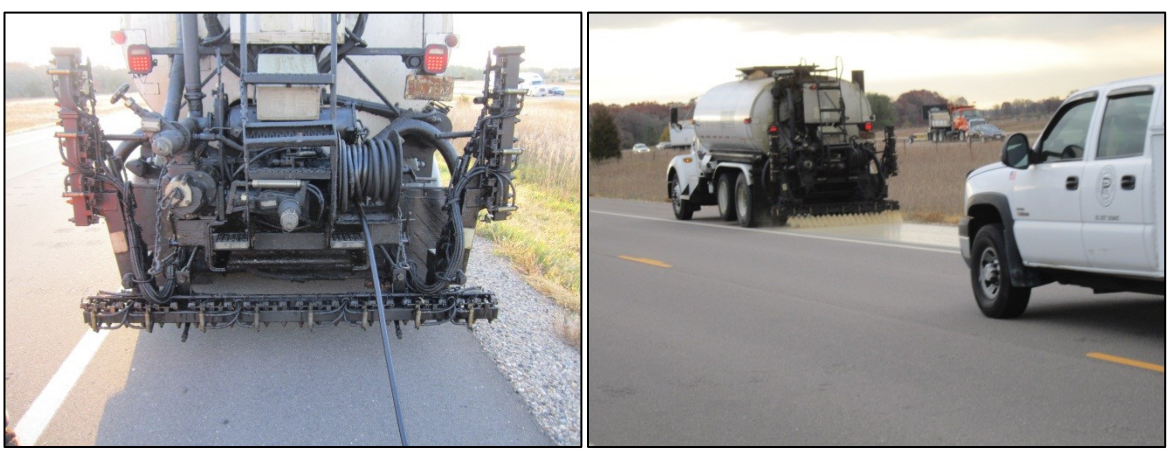

Figure 3.11 Installation of Jointbond® on Wright CSAH 75 shoulder.

The distributor truck was equipped with a main spray bar having 23 evenly-spaced nozzles and two side bars with 9 nozzles each; giving a total possible treatment width of approximate 14 ft. The product was applied through the main spray bar at a bar height of approximately 1 ft. The application crew had a separate sanding truck on hand if slipperiness was an issue, but once the product dried the crew decided sanding was not necessary.

A measurement of the application rate was performed by securing 2-ft by 2-ft pads to the pavement surface. Two pads were used, and were separated by an interval of approximately one-third the treatment length. Before-After measurements of retroreflectivity were taken on segments of permanent white marking tape. During installation the tapes were placed in the vicinity of the nonwoven geotextile pads.

Figure 3.12 and Figure 3.13 show the appearance after the fog application.

Figure 3.12 Test setup for monitoring retroreflectivity and application rate; Jointbond®.

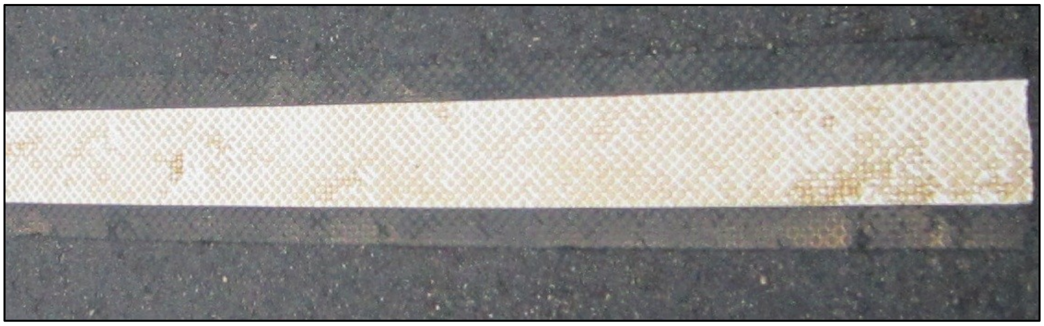

Figure 3.13 Close-up of residue on striping at Location B.

3.2.2 Retroreflectivity Experiment

Because of the observation of visible product residue on the traffic tapes, a secondary experiment was set up at the MnROAD Low Volume Road to find out if service under traffic would affect the residue, and whether the retroreflectivity would also improve.

A number of traffic marking tapes were treated with fog seal products used during construction of the sections on CSAH 75. The traffic marking tapes were subsequently removed from CSAH 75 and reinstalled on parts of MnROAD Low Volume Road (LVR) Cell 33 (Figure 3.14, Table 3.1). The advantage of the Low Volume Road was the controlled application of traffic. MnROAD LVR traffic was limited to regular repetitions of a five-axle heavy vehicle. The heavy vehicle traffic counts were documented daily.

Figure 3.14 Cell 33 Transition at MnROAD (google earth).

Table 3.1 Sealant-treated Pavement Markings Installed at MnROAD

Date	Material	Fog Treatment	Cell	Position
9/5/2014	Permanent Tape	RePlay Longitudinal	Transition: Curve to Cell 33	1, Inside lane – right wheel path
9/5/2014	Permanent Tape	Biorestor A 0.015	Transition: Curve to Cell 33	2, Inside lane – right wheel path
9/5/2014	Permanent Tape	Biorestor B 0.015	Transition: Curve to Cell 33	3, Inside lane, right wheel path
9/5/2014	Permanent Tape	Biorestor C 0.020	Transition: Curve to Cell 33	4, Inside lane, right wheel path
9/5/2014	Permanent Tape	Biorestor D 0.020	Transition: Curve to Cell 33	5, Inside lane, right wheel path
10/23/2014	Permanent Tape	Jointbond A 0.08	Transition: Curve to Cell 33	6, Inside lane, right wheel path
10/23/2014	Permanent Tape	Jointbond B 0.08	Transition: Curve to Cell 33	1, Outside shoulder
9/5/2014	Permanent Tape	RePlay Longitudinal	Transition: Curve to Cell 33	2, Outside shoulder
9/5/2014	Permanent Tape	Biorestor A 0.015	Transition: Curve to Cell 33	3, Outside shoulder
9/5/2014	Permanent Tape	Biorestor D 0.020	Transition: Curve to Cell 33	4, Outside shoulder

3.2.3 Installation Costs

In order to produce the test sections described above, contacts were made with several manufacturers and vendors representing three nontraditional fog seal products and one installer of emulsified asphalt fog seal products. Quotes were presumably based on the value of the vendor's ability to participate in the research effort by delivering and installing product at their chosen application rate. Material loads were hauled from supplies within the state of Minnesota, except for PTI's material that was hauled from Ohio. The outcome is shown in Table 3.2 .

Table 3.2 Description of Fog Seal Materials

<table>
<tr><th>Material</th><th>Type</th><th>Manufacturer</th><th>Supplier</th><th>Coverage</th><th>Quoted Research Cost ($/sy)</th></tr>
<tr><td>Jointbond</td><td>Longitudinal Joint Stabilizer</td><td>Pavement Technology Inc.</td><td>PTI</td><td>0.5 mile x 8 ft</td><td>$6100 ($2.60)</td></tr>
<tr><td>RePlay</td><td>Preservation Agent</td><td>BioSpan Technologies, Inc.</td><td>Bargen</td><td>0.5 mile x 6 ft</td><td>$3960 ($2.25)</td></tr>
<tr><td rowspan="2">Biorestor</td><td>Asphalt Rejuvenator</td><td rowspan="2">BioBased Spray Systems, LLC</td><td rowspan="2">Bituminous Roadways</td><td rowspan="2">0.5 mile x 8 ft</td><td rowspan="2">$2640 ($1.13)</td></tr>
<tr><td>Construction Joint Stabilizer</td></tr>
<tr><td>CSS-1h</td><td>Astech</td><td>Various</td><td>Astech</td><td>1000 ft x 8 ft.</td><td>$0 ($0.23*)</td></tr>
<tr><td colspan="6">(*) MnDOT Typical. See Appendix.</td></tr>
</table>

3.2.4 Application Rates

Several convenient product application strategies are used by appliers of nontraditional sealers that include:

- Distributor truck with spray bar
- Off-road vehicle with spray bar
- Handheld spray equipment.

Target application rates for nontraditional fog seal products are often relatively low in comparison to those used for asphalt materials. Some fog seal customers may desire to perform a QA check of application rate because of the potential undesirable effect of windy conditions on the quantity of material delivered to the road surface or other reasons related to the chosen delivery method.

Application rate spot checks were performed on the CSAH 75 installations and compared to the metered values from the distributor trucks. Nonwoven geotextile pads were used to measure the application rates. The pad material was cut into 2-ft squares and their initial mass was recorded to the nearest 0.1 gram. Prior to the application the pads were secured to the shoulder in the center of the distributor bar's path. Two pads were used per treatment rate, and were separated by a distance of approximately one-third of the total treated length. The treated pads were immediately removed from the road, sealed in pre-weighed plastic bags to retain the maximum amount of sealant mass, and transported to the laboratory for weighing.

The application rate was determined using the following method:

$$Gallon\ per\ square\ yard = \frac{M_{Fog}}{A_{Pad}} \times \frac{9ft^2}{yd^2} \times \frac{lb}{453.59g} \times \frac{gal}{SG_{Fog} \times 8.345404lb}$$

Where:

M = mass of fog sealer retained on pad, grams

A = measured area of calibration pad, ft^2

SG = specific gravity of the sampled fog product

Application rates were also determined by gallons applied to the treated area. In this method the size of the treated section was measured with a foot meter, and the volume of fog treatment was taken from the distributor truck metering system.

Results from the two methods are compared in Table 3.3. It was found that the spot-check method was consistently lower than the target but the Gallon per Treated Area method was very close. Besides misrepresentation through rounding, some reasons for this may be:

- Collection pad permeability may be too great, allowing some fog material into the pavement before inspector arrives
- Mass may be lost through freezer bags during transport time if product vaporizes and can escape
- Deposition of fog product may be affected by low levels of wind due to the use of light application rate

Table 3.3 Treatment Rates as Measured With Two Methods

	Mass on 2x2 Collection Pad			Gallons on Treated Area		
Section (Target Rate)	**Sampled Specific Gravity**	**Gram applied**	**Gallon/sy**	**Gallons**	**Area**	**Gallon/sy**
RePlay A (0.020)	0.884	21.4	0.014	35.4	6ft x 2680ft	0.01998
RePlay B (0.020)	0.884	20	0.013			
Biorestor A (0.015)	0.864	14	0.01	37.78 x 42.9%	7ft x 1338ft	0.01557
Biorestor B (0.015)	0.864	11.1	0.008			
Biorestor C (0.020)	0.864	16.1	0.011	37.78 x 57.1%	7ft x1326ft	0.02092
Biorestor D (0.020)	0.864	16.4	0.011			
CSS-1h (0.10)	(a)	(a)	(a)	77.8	7ft x 1000ft	0.1
Jointbond A (0.08)	0.987	101.1	0.061	180	(b) 7.5ft x 2959ft	0.073
Jointbond B (0.08)	0.987	112.6	0.068			
(a) Did not measure. (b) 0.5ft accounted for on gravel shoulder.						

Table 3.4 offers cost of the research in terms of price per measured treated area. Note these costs are for construction of special test sections, and may differ from projects using greater quantities.

Table 3.4 Cost per Treated Test Section

Material	Treated Length, ft	Treated Width, ft	Price	$/sy Treated
Jointbond	2959	7.5	$6,100	$2.47
RePlay	2681	6	$3,960	$2.22
Biorestor 0.015	1338	7	$2,640 *42.9%	$1.09
Biorestor 0.020	1326	7	$2,640 *57.1%	$1.46
CSS-1h	1000	7	$0	$0.23 (a)
(a) MnDOT Typical. See Appendix.				

CHAPTER 4: MATERIAL EVALUATIONS

The MnDOT chemical laboratory evaluated the sealant products in this study with the Fourier Transform Infrared absorption spectroscopy (FTIR) methods.

FTIR evaluations were performed on the proprietary materials applied to CSAH 75 (Figure 4.1) and one emulsified asphalt sealant (not pictured). The materials were collected at the time of the application process. The goal of FTIR testing was to improve the understanding of the general makeup of the products for potential customers. The customers could then incorporate that basic information into their assessment of product suitability.

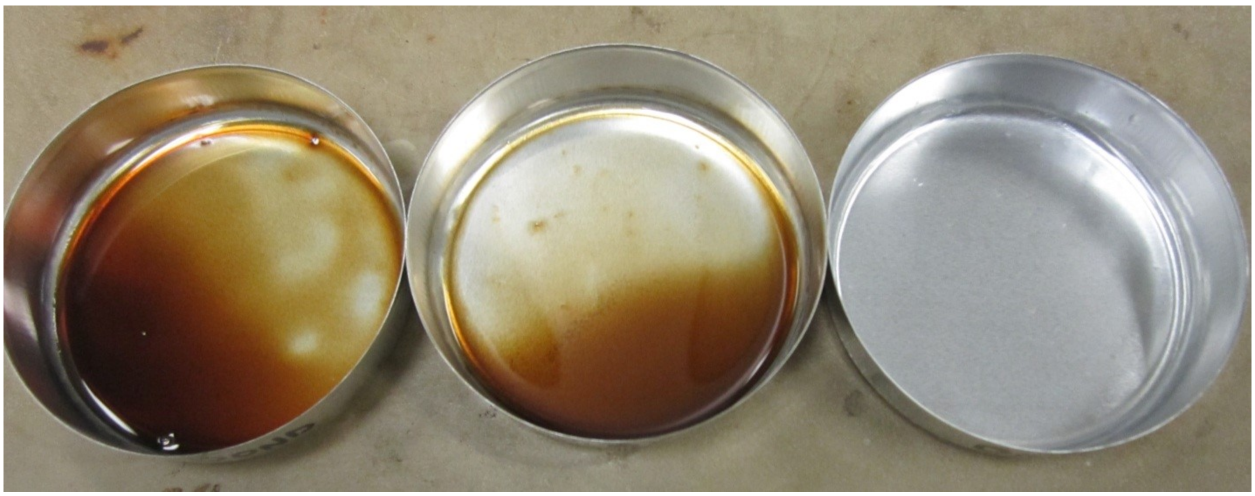

Figure 4.1 Residue from the three proprietary sealant products.

Specific gravity was also checked in the laboratory. The values were:

- Jointbond® specific gravity = 0.987
- RePlay™ specific gravity = 0.884
- Biorestor® specific gravity = 0.864
- Diluted CSS-1h specific gravity was not checked, but it is well-known that typical reported values for all types of cationic emulsions are between 1.00 and 1.05

4.1 FTIR SCAN RESULTS

Output from FTIR equipment can be used to compare features of an absorbance signature to those reference signatures that have been recorded for known chemical compounds. The comparison output includes a list of potential components along with correlation values. Although the list of potential components may be extensive they may not actually be used in the formulation.

Test specimens were prepared by evaporating residue from liquid samples and then configuring them as Cap Film on NaCl Window specimens for the FTIR evaluation. Percent Solids from the evaporation process were: Jointbond® 60.81 percent, Biorestor® 33.14 percent, and RePlay™ 41.95 percent.

Absorbance spectrum comparisons (Figure 4.2 to Figure 4.5) were reported for wavenumbers in the region between 455.13 and 3,995.85 cm-1.

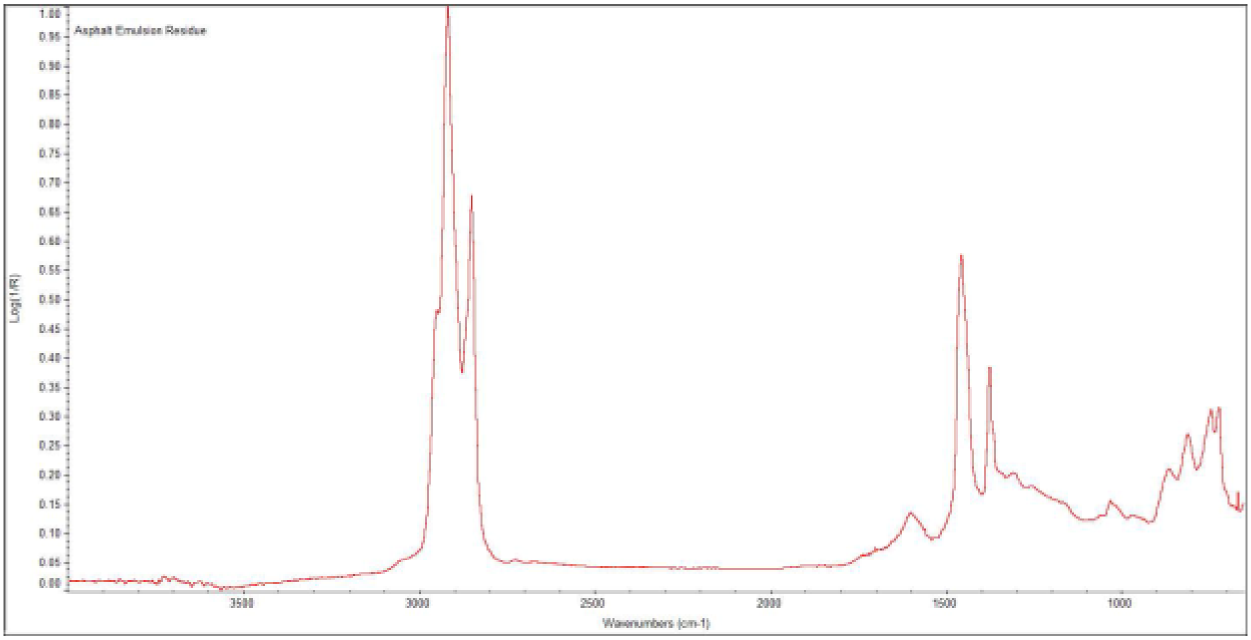

Figure 4.2 FTIR of a cured asphalt emulsion.

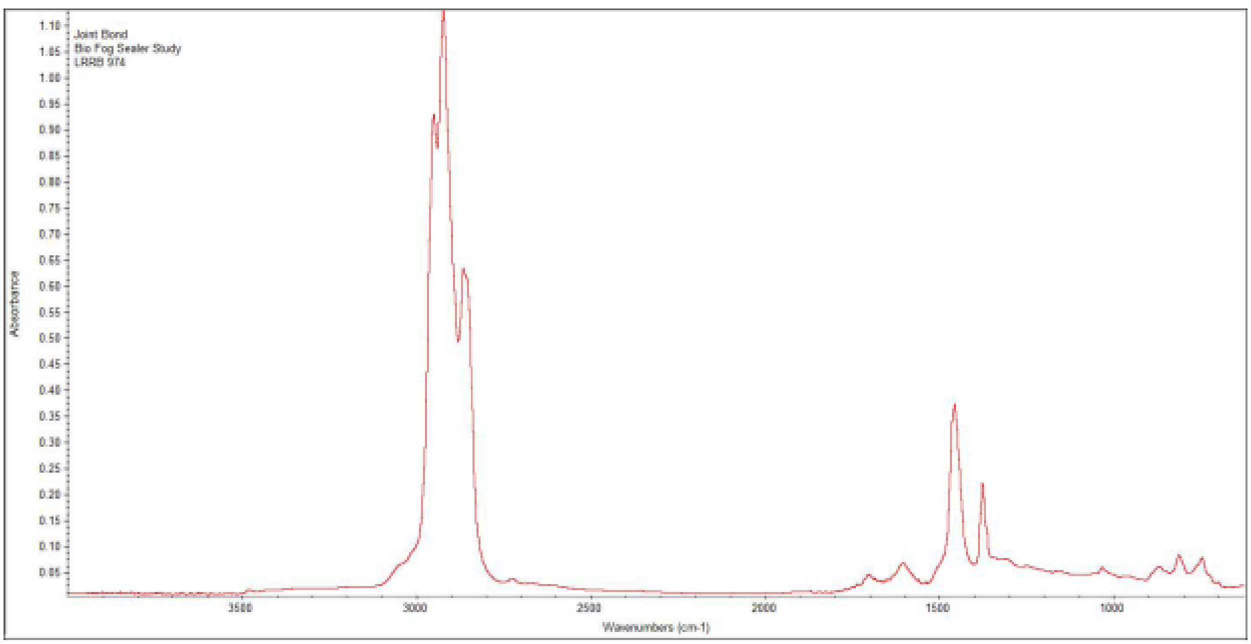

Figure 4.3 FTIR of Jointbond®.

Inspection of the FTIR absorbance spectrum of emulsified asphalt and Jointbond® found similar peaks and trends occurred at several points between 1,300 and 3,000 cm^{-1}. The profile of the asphalt sample for wavelengths lower than 1,000 cm^{-1} showed relatively higher absorbance values along with multiple peaks. Regarding the Jointbond® absorbance profile, the list of potential components correlated from FTIR catalogs (19) included several that have been used as cleaning and degreasing products as well as for emulsification, wetting, and dispersion of liquids (19, 20). A compound similar to asphalt was also a potential component (21).

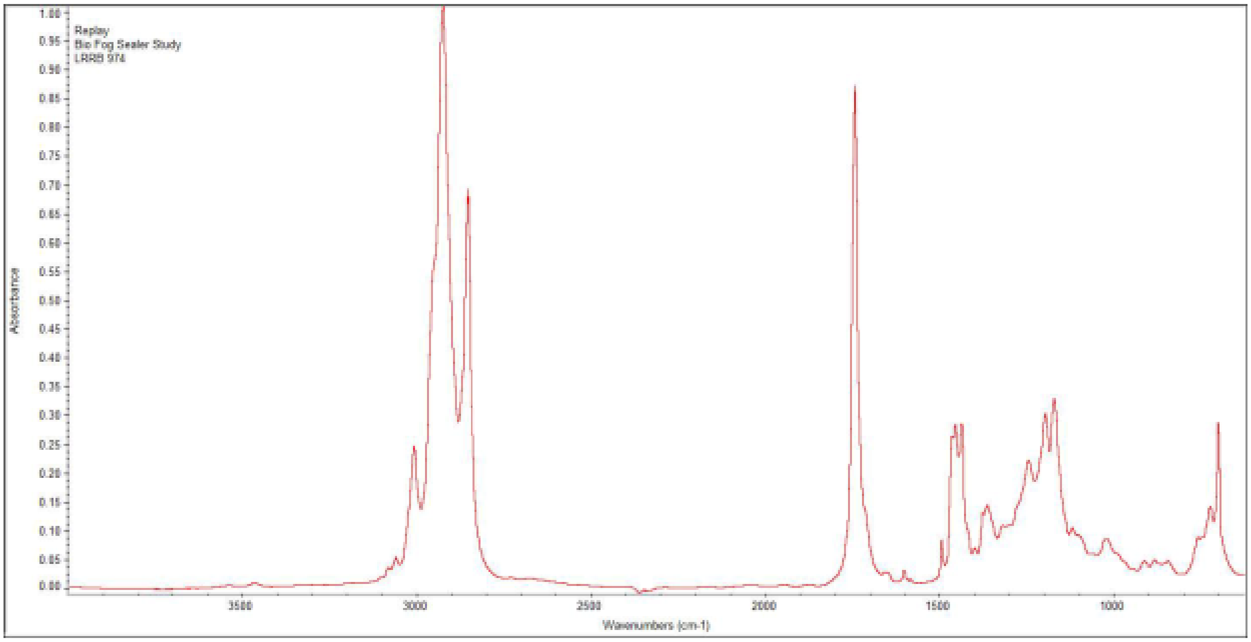

Figure 4.4 FTIR of RePlay™.

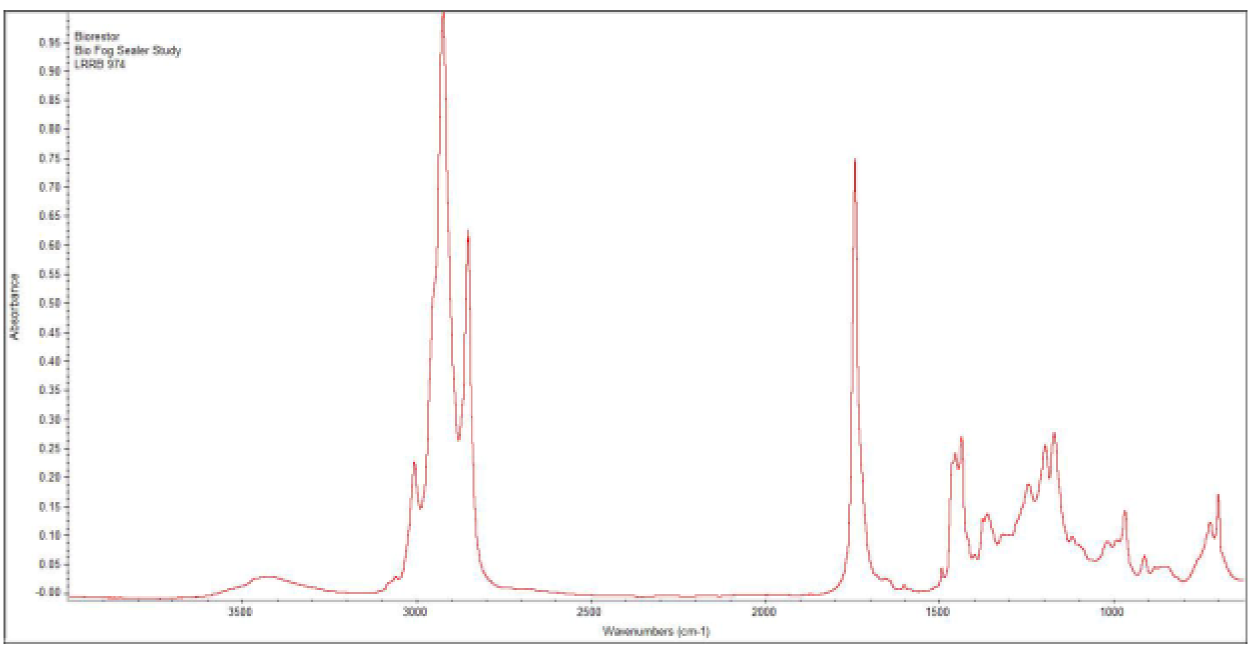

Figure 4.5 FTIR of Biorestor®.

Inspection of the FTIR absorbance for RePlay™ and Biorestor® shows the prominent peaks occurring near 1700 cm^{-1} are much different than the absorbance profile of the asphalt material. A comparison between RePlay and Biorestor shows that similar peaks and trends occurred at several points between 800 and 3,500 cm^{-1}.

Regarding the RePlay™ and Biorestor® profiles, similarities were identified with compounds found in biodiesel fuels, cleaners for oil spills (22), absorbents, agricultural chemicals, and components of lubricants and solvents (23), and as a fuel additive and in lubricants (24).

4.2 LABORATORY BINDER TESTING

Core sets were obtained from all sections at the conclusion of Year Three monitoring, but prior to application of the routine emulsified asphalt fog seal. The cores had a diameter of 6-in. and were between 4.0- and 4.5-in. tall.

The cores were used to produce material for asphalt binder testing with the goal of comparing the properties of aged binder from the pavement surface to the aged binder from mid-depth. The cores were cut into 1-in. thick HMA discs using a rotary wet-saw. Slices of mixture were obtained from the top and mid-depth of each core (Figure 4.6). Asphalt binder was extracted from the mixture, recovered, and prepared as specimens for Bending Beam Rheometer and Dynamic Shear Rheometer (BBR and DSR) testing. The recovered asphalt was not subjected to laboratory aging. Testing temperature used protocol for PG 58-34 binder.

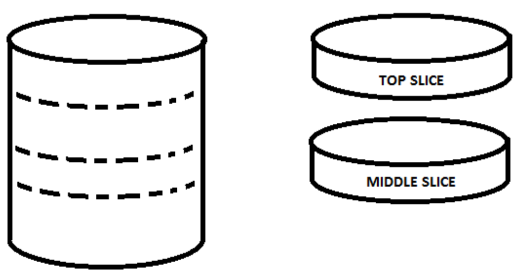

Figure 4.6 Core preparation diagram.

Control, Jointbond®, CSS-1h, and RePlay™-treated cores were selected for testing. Biorestor® treated cores were not tested. Similar binder test results were expected for Biorestor® and RePlay™ based on the FTIR results that showed similar chemistry for Biorestor® and RePlay™.

4.2.1 Results

Test results from Minnesota field aged sections are presented in Table 4.1, Figure 4.7, and Figure 4.8. In all cases the evaluation categorized the material as PG 64-34. Based on the precision and bias in AASHTO and ASTM Standards, the expected level of variation for a single operator is:

- COV for BBR Slope of m-value is 1 percent, translating to standard deviations of approximately 0.003 for the data set.

- COV for Stiffness in MPa is 2.5 percent, translating to standard deviations between 5.2 to 6.9 MPa for values in the data set.

- RMS standard deviation for DSR was 2.49 percent, translating to standard deviations between 0.66 to 0.97 MPa for values in the data set.

Table 4.1 Binder Test Results; Minnesota Year Three

Treatment	Slice, Core	DSR G*/Sin d, kPa	BBR Stiffness, MPa	BBR, m-Value	% AC	High PG	Low PG
Control	Middle C1 C2	2.83	206	0.322	5.1	66.1	-36.0
CSS-1h	Middle CS1 CS2	2.90	274	0.311	4.2	66.3	-34.6
Jointbond	Middle J1 J2	2.29	226	0.336	4.9	64.3	-36.1
RePlay	Middle R1 R2	2.67	220	0.323	4.7	65.6	-35.8
Control	Top C1 C2	3.74	255	0.319	4.5	68.3	-35.4
CSS-1h	Top CS1 CS2	3.88	249	0.322	4.7	68.7	-35.5
Jointbond	Top J1 J2	2.92	252	0.317	4.8	66.3	-35.6
RePlay	Top R1 R2	3.80	228	0.310	4.5	68.5	-35.0

Comparison of percentage of recovered asphalt binder from the middle and top core slices shows:

- Control cores had 12 percent less binder in the core surface.

- Cores treated with CSS-1h, an emulsified asphalt, had 12 percent more binder in the core surface.

- Cores treated with Jointbond® had 2 percent less binder in the core surface.

- Cores treated with RePlay™ had 4 percent less binder in the core surface. A similar result is expected for Biorestor®.

- When combining results by location with the core, the standard deviation of the recovered asphalt percentage from material taken from the middle was twice as large as the standard deviation from the top (0.386 percent versus 0.150 percent).

Parameters that can be obtained from DSR testing include the complex modulus (G*) and the phase angle (δ). Larger values of $\frac{G^*}{\sin(\delta)}$ indicate relatively better resistance to deformation.

Results for $\frac{G^*}{\sin(\delta)}$ show that at mid-depth the Control and CSS-1h performed similarly. RePlay™ was measured only six percent below the Control, and Jointbond® was measured 19 percent below the

Control. Test results from the core surface show similar trends. The percentage of stiffness change from the core surface slice compared to the middle was:

- Control surface, 32 percent higher
- CSS-1h surface, 34 percent higher
- Jointbond® surface, 28 percent higher
- RePlay™ surface, 42 percent higher

Measurements of $\frac{G^*}{\sin(\delta)}$ from the Jointbond® core top and middle, and RePlay™ middle produced lower values; however they were not below the standard of 1.98 kPa.

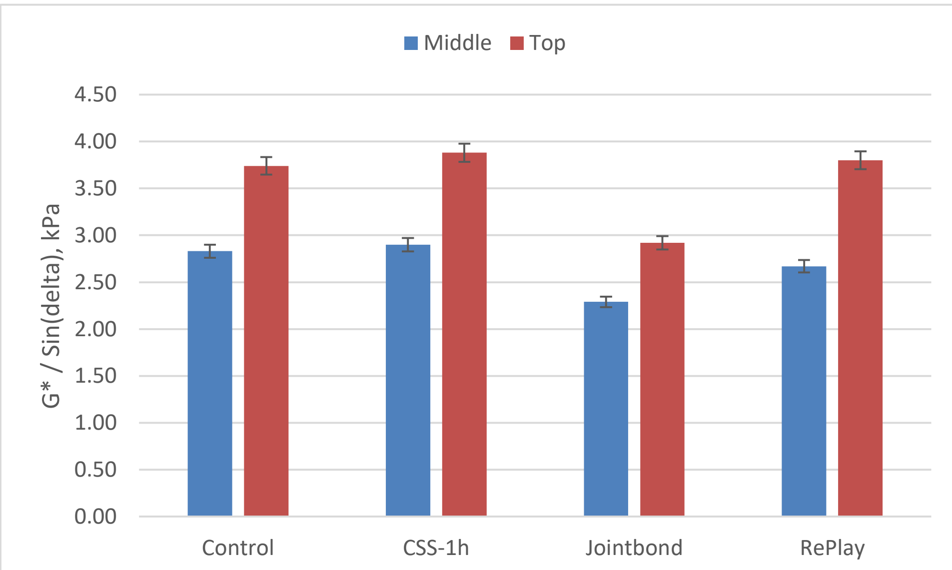

Figure 4.7 DSR results with single operator standard deviation.

It is generally more beneficial to achieve lower values of BBR stiffness because that will indicate the material will perform better in low temperatures. It is likewise more beneficial to have a larger value for the slope of the BBR relaxation curve (m-value) because it indicates the material had relatively better relaxation properties at low temperatures.

BBR test results from material at mid-depth show that the Control section had the lowest stiffness at mid-depth, with Jointbond® and RePlay™ about 5 to 10 percent higher. The BBR stiffness of the CSS-1h section measured over 30 percent higher than the Control. BBR tests of the core tops produced similar values for Control, CSS-1h, and Jointbond®. RePlay™ BBR stiffness was about 10 percent less than the Control. The percentage of BBR stiffness change from mid-depth to surface was:

- Control surface, 24 percent increase
- CSS-1h surface, 9 percent decrease that may be due to blending of PG64-34 and CSS-1h material
- Jointbond® surface, 12 percent increase
- RePlay™ surface, 4 percent increase

BBR m-values from material obtained at the core middle were more variable than those from the core top (0.010 versus 0.005). Results show m-values decreased from middle to top for all treatments except the CSS-1h section. The percent change of m-value was:

- Control surface, 1 percent decrease
- CSS-1h surface, 4 percent increase that may be due to blending of PG64-34 and CSS-1h material
- Jointbond® surface, 6 percent decrease
- RePlay™ surface, 4 percent decrease

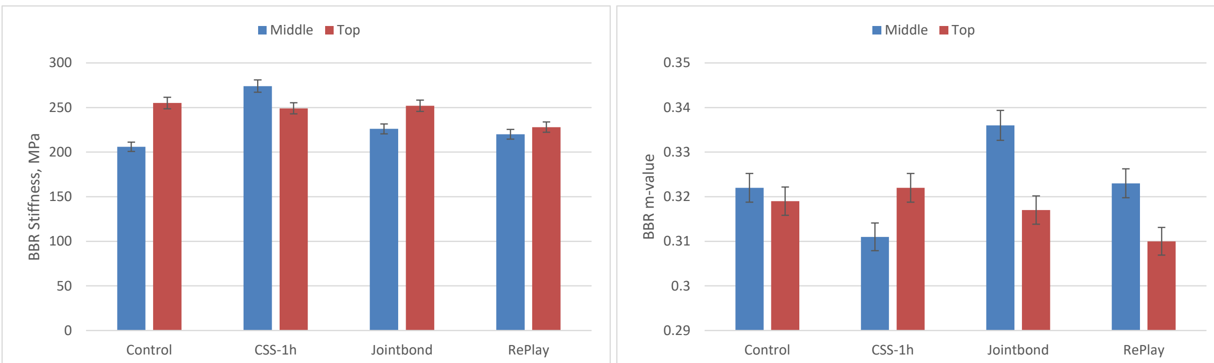

Figure 4.8 BBR results with single operator standard deviation.

CHAPTER 5: TEST SECTION PERFORMANCE

The following methods were used at various points in the experiment order to study the effect of fog seal products on bituminous pavement and pavement markings.

- Dry Retroreflectivity measurements of treated marking tapes using hand held instrument conforming to ASTM E1710
- Friction testing
    - Full-scale locked wheel skid testing with a ribbed tire at 40 mph ASTM E274
    - Small-scale friction testing with the dynamic friction test (DFT) device ASTM E1911
- Surface Texture
    - Circular Texture Meter, ASTM E2157
        - Mean Texture Depth
- Field permeability with a falling head permeameter
- Distress surveys and field inspections

5.1 FIELD TESTING

5.1.1 Retroreflectivity

Retroreflectivity testing was performed on pavement marking material installed at the MnROAD LVR as described in chapter 3.2.2 Retroreflectivity is a measure of the amount of light reflected from a test surface for a given amount of applied illuminance. It is usual to find that standard requirements for pavement marking retroreflectivity vary according to the material type, as shown in Table 5.1.

Table 5.1 Permanent Pavement Markings (MnDOT 2582, published 2014)

Table 2582-1 Minimum Initial Pavement Marking Retroreflectivity		
	White	**Yellow**
Tape	600 mcd/sq. m/lux	500 mcd/sq. m/lux
Epoxy	300 mcd/sq. m/lux	200 mcd/sq. m/lux
Latex	275 mcd/sq. m/lux	180 mcd/sq. m/lux

5.1.1.1 Methods

Retroreflectivity measurements were performed using a Flint Trading LTL Pavement Marking Reflectometer. The unit of measurement was mcd/m^2/lx.

Measurements were performed on white, permanent-mount striping tapes immediately before they were treated with fog products. The tapes were allowed to field cure for four hours and then moved to the laboratory, and measurements were performed again. Each tape was approximately 10 ft long so it was possible to obtain approximately six to eight readings for averaging.

5.1.1.2 Results

RETROREFLECTIVITY MASKING

The bar charts in Figure 5.1 through Figure 5.4 are boxplots of retroreflectivity measured before and after treatment using RePlay™, Biorestor®, and Jointbond®, respectively. All of the striping tapes had strong initial retroreflectivity performance. From these plots it is apparent that the fog treatments had at least a short-term effect on retroreflectivity.

- Tapes treated with RePlay™ (0.02 gsy) had an average pre-treatment retroreflectivity of 812.4 mcd/ m^2/lx. The post-treatment average was 305.3 mcd/ m^2/lx, a reduction of 62 percent.
- Tapes treated with Biorestor® (0.015 gsy) had an average pre-treatment retroreflectivity of 822.3 mcd/ m^2/lx. The post-treatment average was 516.4 mcd/ m^2/lx, a reduction of 37 percent.
- Tapes treated with Biorestor® (0.020 gsy) had an average pre-treatment retroreflectivity of 964.3 mcd/ m^2/lx. The post-treatment average was 568.2 mcd/ m^2/lx, a reduction of 41 percent.
- Tapes treated with Jointbond® (0.08 gsy) had an average pre-treatment retroreflectivity of 832.8 mcd/ m^2/lx. The post-treatment average was 216.0 mcd/ m^2/lx, a reduction of 74 percent. Fewer measurements were collected post-treatment.
- The CSS-1h (0.1 gsy) treatment was intentionally not included in this phase of the project due to the assumption that it would produce a non-retroreflective condition, reduction of 100 percent.

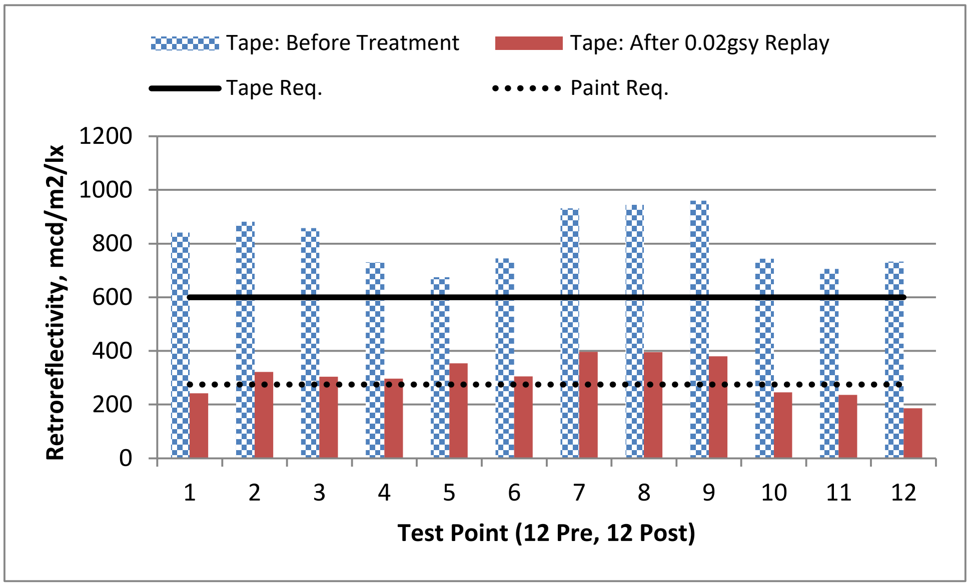

Figure 5.1 Retroreflectivity before/after RePlay™ application.

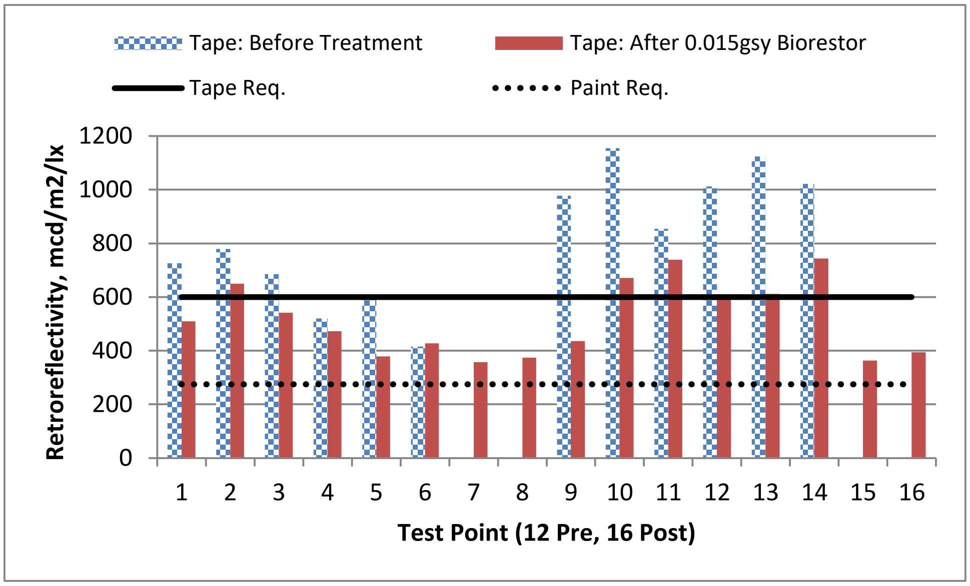

Figure 5.2 Retroreflectivity before/after Biorestor®015 application.

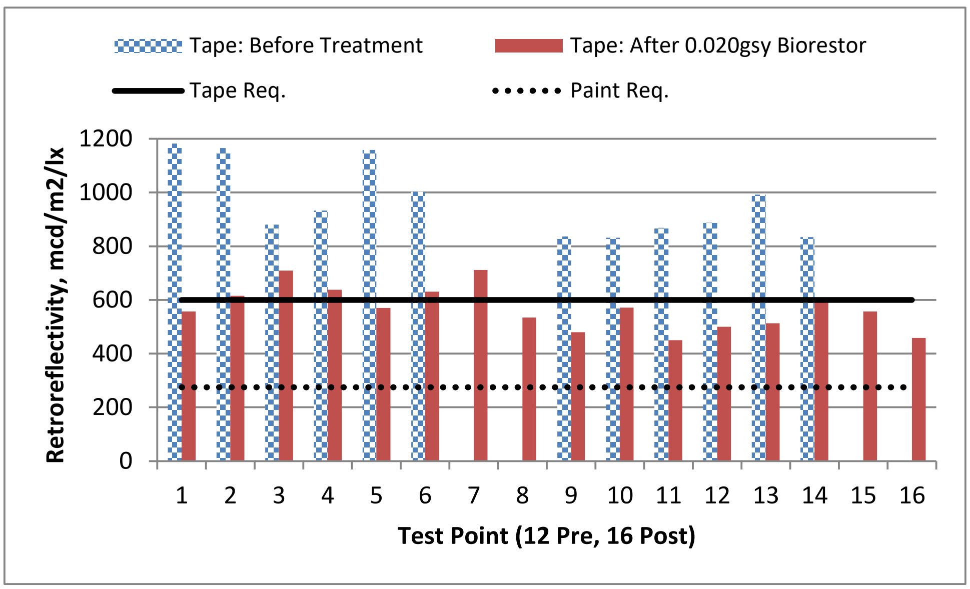

Figure 5.3 Retroreflectivity before/after Biorestor®020 application.

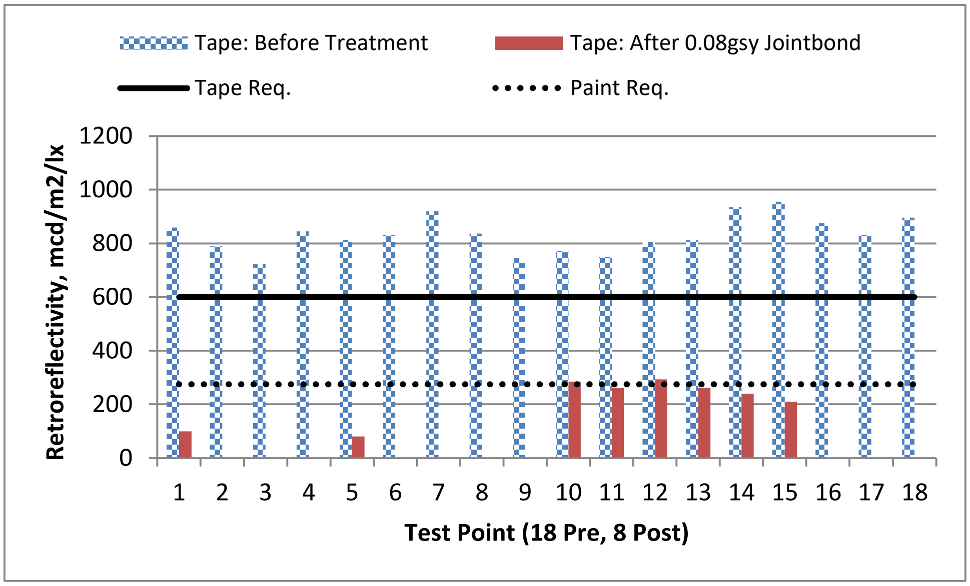

Figure 5.4 Retroreflectivity before/after Jointbond® application.

RETROREFLECTIVITY RECOVERY

All of the striping tapes had strong initial retroreflectivity performance, but it was shown in the previous section that fog seal treatments had at least a short-term effect on retroreflectivity. Because the marking tapes were new, it was anticipated that full recovery would occur as reflective surfaces became exposed by traffic wear. Retroreflectivity recovery was observed at MnROAD by taking periodic readings and collecting truck traffic counts over time. The plots in Figure 5.5 through Figure 5.7 show retroreflectivity performance of the initial untreated striping tape material and the fog-treated (test) tape as traffic was accumulated. Recovery observations included:

- Recovery for the tapes treated with Biorestor® was approximately 1,600 truck passes.
- Recovery for the tapes treated with Jointbond® was approximately 800 truck passes.
- Recovery for the tapes treated with RePlay™ was approximately 1,600 truck passes.
- All sets of tapes and fog materials developed maximum reflectivity at approximately 4,000 truck passes (20,000 tire passes).

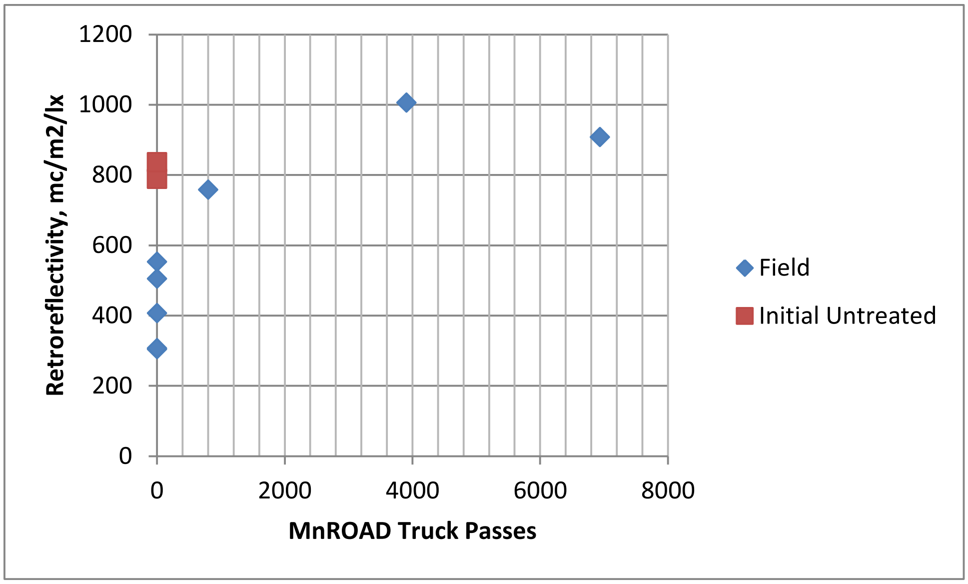

Figure 5.5 Retroreflectivity performance with RePlay™.

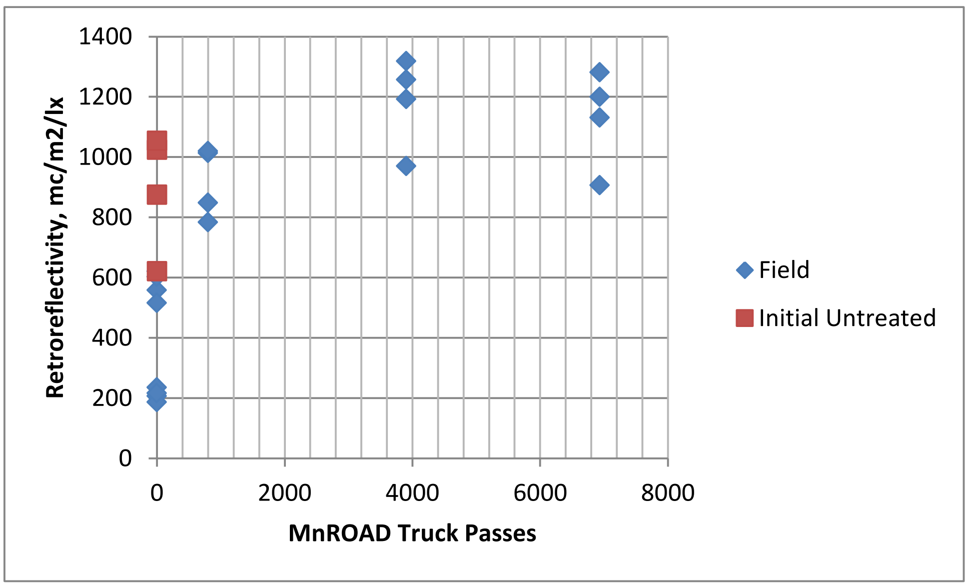

Figure 5.6 Retroreflectivity performance with Biorestor®.

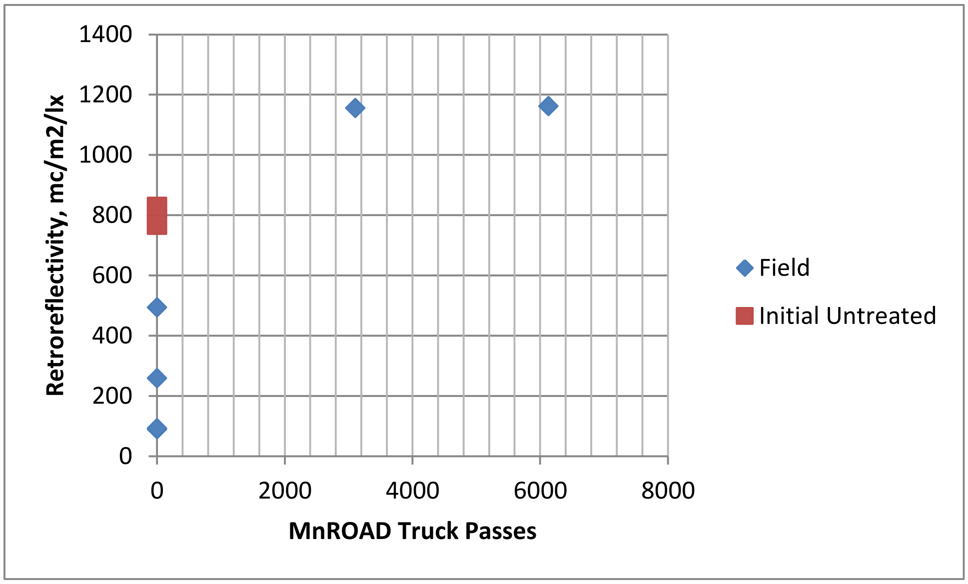

Figure 5.7 Retroreflectivity performance with Jointbond®.

5.1.2 Friction

Because of the importance of safety, roadway pavement-tire friction becomes a topic of interest any time surface alterations occur due to traffic wear or when surface treatments are applied. The goal of friction testing in this study was to measure the short-tern impact of applying fog seal products to the bituminous surface, then perform follow up measurements to determine the extent of friction recovery, if any. It was anticipated that the fog sealed test sections of CSAH 75 would receive little traffic because of their location on 8-ft wide shoulders, so recovery would be the result of inherent product performance coupled with environmental exposure.

5.1.2.1 Methods

Locked wheel tests (ASTM E274 ribbed tire) were performed several times after installation of the fog seals and Dynamic Friction Tester (DFT) tests were performed at frequent intervals after the installation of the fog seals. Test locations of locked wheel tests may vary during the course of a long term study due to the nature of the test method. The DFT is a portable device that allows test locations to be precisely replicated.

The locked wheel test (ASTM E274) collects measurements from a moving vehicle. The standard method states that the test is performed using a trailer containing one or more test wheels, a water supply, and data collection equipment. Measurement of torque begins once the conditions of test speed (40 mph), water application, and tire locking have been achieved. The resulting torque force is converted to a “FN40” value.

The DFT (ASTM E1911) equipment measures the work of friction that a surface performs against a known system consisting of a set of rubber pads that are attached to a freely spinning glass plate. The

DFT mechanism rotates the pad/plate system above and parallel to the surface until a target velocity (80 kph) is attained, and then lowers it to the surface and collects measurements until velocity is zero. An external water supply lubricates the surface during the test. An example of DFT test output is given in Figure 5.8, with velocity along the horizontal axis and the coefficient of dynamic friction on the vertical. DFT software can be used to identify coefficient of dynamic friction values (μ) that correspond to a velocity of 40 mph (64 kph), the same velocity that used for locked-wheel skid trailer testing.

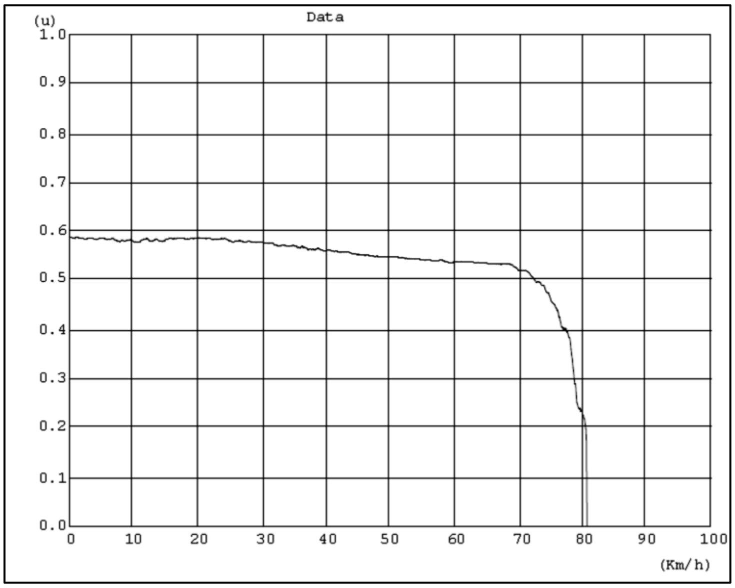

Figure 5.8 DFT test output for a plant mixed asphalt surface.

5.1.2.2 Results

The timing of the initial friction evaluation was chosen to mimic conditions that drivers would encounter when newly-treated roadways are opened to traffic. Initial locked wheel testing occurred on the CSS-1h and Control sections after the fog seal had cured for three days, and was expected to represent performance of a new treatment. Corresponding DFT tests were performed after six days. Initial DFT tests of Jointbond®, RePlay™, and Biorestor® were performed at one and four hours after the products were installed. Table 5.2 shows the initial values for FN40 and DFT μ40mph coefficients differed by two orders of magnitude, but otherwise showed similar performance.

Table 5.2 Friction Results on New Fog Treatments (ASTM E274 and E1911)

Section	FN40 Ribbed avg	DFT at 40 mph
Control	62.3	0.634
CSS-1h	18.8	0.209
Jointbond	NA	0.527
RePlay	NA	0.545
Biorestor 015	NA	0.564
Biorestor 020	NA	0.567

As expected, all treatments reduced friction measurements relative to the control section. Measurements of the CSS-1h sections declined by 67 percent; the greatest observed effect. Sections treated with Jointbond® declined by 17 percent, and RePlay™ declined 14 percent. Sections treated with Biorestor® declined by 11 percent. It was found that the Biorestor® treatment rates used in this study produced nearly the same effect on friction measurements.

The Control section µ40mph measurements were stable during the three-year time period (Figure 5.9), with a mere 4.9 percent coefficient of variation and a range between 0.611 and 0.736. Subsequent measurements found that recovery began immediately in all treated test sections, but there was some difference in the rate of recovery between treatment types.

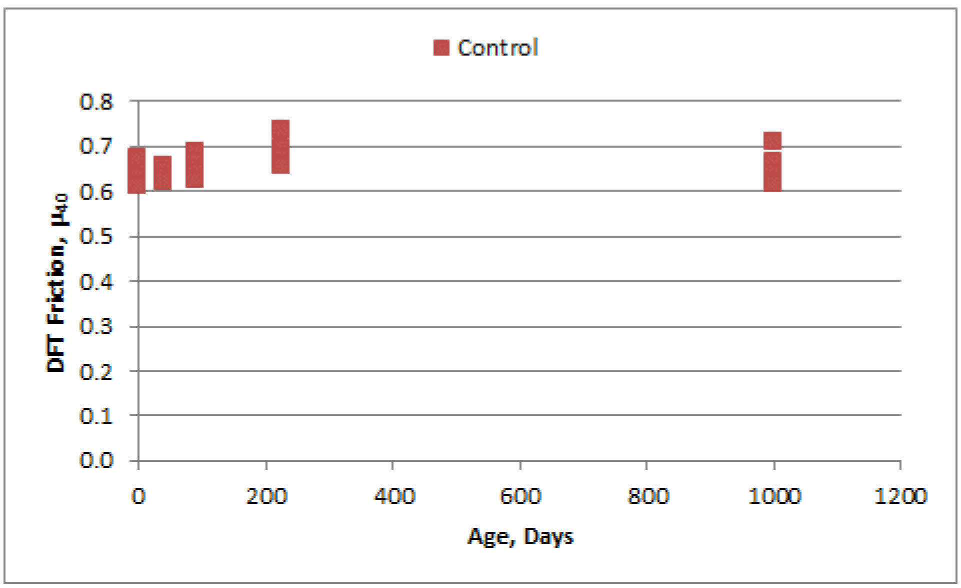

Figure 5.9 DFT Data from CSAH 75: Control section.

At the conclusion of one year of monitoring the DFT friction performance for all the treatments except diluted CSS-1h had recovered to the level of the untreated control section (Figure 5.10), so subsequent testing was delayed until the next year. Note that the values obtained during Year Three showed all sections had recovered friction performance similar to the Control section.

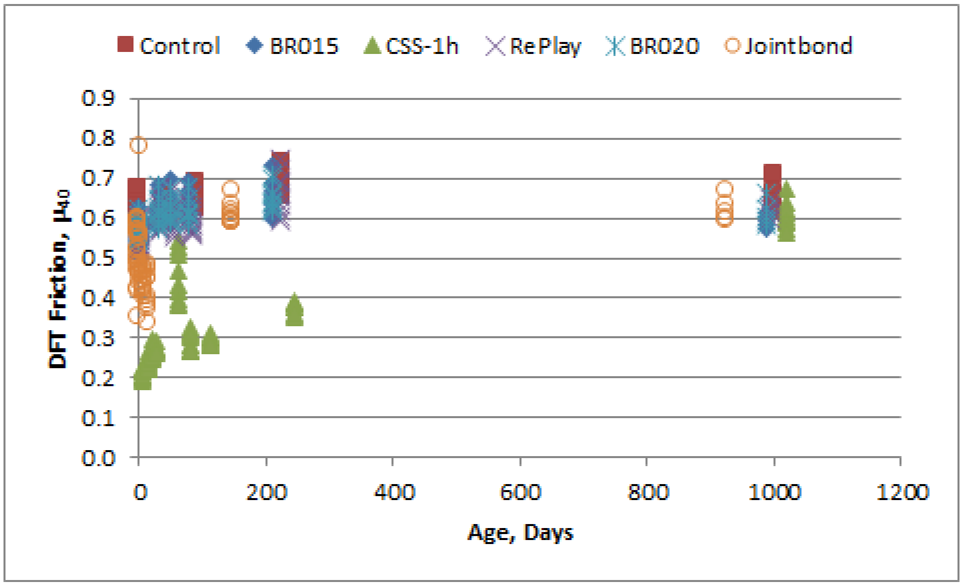

Figure 5.10 DFT Data from CSAH 75: HMA with various fog treatments.

5.1.3 Macrotexture

Results from FTIR testing is shown in other sections of this report. FTIR signatures from several of the fog seal materials correlated to compounds like those used in degreasers or solvents. This information created interest in evaluating changes in macrotexture for test sections treated with fog seal products. Macrotexture measurements in this study were performed during Year Two and Three.

5.1.3.1 Methods

The Circular Track Meter (ASTM E2157), or CTM, was used to evaluate macrotexture. The CTM is a portable device. Components include a laser that travels in a circular track, sensor, and a computer interface. The analysis software generates graphical traces of the texture profile and reports results in terms of Mean Profile Depth (MPD). Some versions of the software generated CTM-files could be opened as text files.

MPD is defined in ASTM E1845 as "The average of all the mean segment depths of all of the segments of the profile." The CTM uses a laser to measure the profile of a circle having a 284 mm (11.2 in.) diameter, or 892 mm (35 in.) in circumference. The laser performs 1024 discrete measurements along the circle and the scan is divided into eight equal segments (octants A – H). The average mean profile depth (MPD) is determined for each of the segments.

Test points were selected so they contained no segregation or other unusual qualities. Each evaluation cycle used multiple CTM readings at each test point that were collected and averaged. Each test point was marked so the point could be retested during future evaluation cycles.

5.1.3.2 Results

While analyzing the CTM data the authors discovered that the device had developed intermittent tracking problems occurring in the octants E – H, but that octants A – D were unaffected. Therefore, the data produced from octants A – D were included in the analysis and E – H were excluded. Average MPD's for each location tested during both years are shown in Table 5.3. It is apparent from the results that MPD values varied for different test locations.

In Year Two the Biorestor® 0.015 Point 1 and RePlay™ Point 2 had narrow ranges of MPD's with minimum and maximum of 0.28-0.38 and 0.33-0.42 mm, respectively. RePlay™ Point 1 had the widest MPD range (0.24-0.75mm). The average range of MPD values was 0.23 mm. During Year Two the average MPD of the treated sections was 0.35 mm, and 0.51 mm for the control section.

In Year Three RePlay™ Point 1and Jointbond® Point 2 had narrow ranges of MPD's with minimum and maximum of 0.37-0.44 and 0.31-0.42 mm, respectively. Biorestor® Point 2 had the widest MPD range (0.44-1.12mm). The average range of MPD values was 0.26 mm. During Year Three the average MPD of the control section was 0.51 mm while the treated sections were 0.43 mm; a 21 percent increase over Year Two.

Table 5.3 Mean Profile Depth

Treatment	Test	Number	CTM Mean Profile Depth Year Two					CTM Mean Profile Depth Year Three				
			Octant A	Octant B	Octant C	Octant D	Average	Octant A	Octant B	Octant C	Octant D	Average
Biorestor	Biorestor 015 Point 1	1	0.37	0.32	0.35	0.28		0.43	0.67	0.57	0.36	
	Biorestor 015 Point 1	2	0.38	0.3	0.35	0.32		0.42	0.65	0.57	0.37	
	Biorestor 015 Point 1	3	0.37	0.31	0.36	0.3	0.33	0.42	0.68	0.56	0.37	0.51
	Biorestor 015 Point 2	4	0.45	0.66	0.39	0.4		1.12	0.79	0.52	0.44	
	Biorestor 015 Point 2	5	0.44	0.64	0.39	0.41		1.08	0.81	0.52	0.53	
	Biorestor 015 Point 2	6	0.45	0.66	0.39	0.4	0.47	1.09	0.8	0.52	0.54	0.73
	Biorestor 020 Point 1	1	0.28	0.4	0.3	0.34		0.49	0.53	0.41	0.35	
	Biorestor 020 Point 1	2	0.29	0.4	0.29	0.33		0.48	0.51	0.4	0.39	
	Biorestor 020 Point 1	3	0.29	0.43	0.3	0.35	0.33	0.46	0.52	0.4	0.36	0.44
	Biorestor 020 Point 2	4	0.48	0.29	0.47	0.53		0.53	0.45	0.58	0.68	
	Biorestor 020 Point 2	5	0.49	0.3	0.48	0.52		0.53	0.46	0.58	0.68	
	Biorestor 020 Point 2	6	0.47	0.3	0.45	0.52	0.44	0.52	0.45	0.59	0.71	0.56
Control	Control	1	0.6	0.47	0.28	0.66		0.49	0.46	0.59	0.49	
	Control	2	0.61	0.58	0.28	0.63		0.47	0.44	0.59	0.5	
	Control	3	0.6	0.47	0.31	0.64	0.51	0.49	0.46	0.61	0.49	0.51
CSS 1-h	CSS-1h Point 1	1	0.41	0.46	0.46	0.29		0.37	0.57	0.44	0.32	
	CSS-1h Point 1	2	0.43	0.45	0.41	0.29		0.38	0.55	0.46	0.31	
	CSS-1h Point 1	3	0.41	0.45	0.43	0.3	0.40	0.36	0.55	0.45	0.32	0.42
	CSS-1h Point 2	4	0.48	0.39	0.34	0.31		0.58	0.37	0.4	0.32	
	CSS-1h Point 2	5	0.49	0.43	0.32	0.3		0.62	0.37	0.37	0.33	
	CSS-1h Point 2	6	0.44	0.41	0.37	0.31	0.38	0.6	0.38	0.36	0.32	0.42
Jointbond	Jointbond Point 1	1	0.3	0.27	0.19	0.41		0.46	0.35	0.28	0.33	
	Jointbond Point 1	2	0.31	0.21	0.19	0.41		0.46	0.35	0.26	0.37	
	Jointbond Point 1	3	0.32	0.2	0.18	0.39	0.28	0.47	0.34	0.27	0.35	0.36
	Jointbond Point 2	4	0.26	0.35	0.46	0.29		0.34	0.33	0.39	0.4	
	Jointbond Point 2	5	0.28	0.37	0.48	0.29		0.33	0.31	0.37	0.41	
	Jointbond Point 2	6	0.24	0.39	0.47	0.3	0.35	0.33	0.32	0.35	0.42	0.36
Replay	Replay Point 1	1	0.74	0.29	0.25	0.35		0.39	0.43	0.4	0.41	
	Replay Point 1	2	0.74	0.3	0.24			0.41	0.44	0.4	0.42	
	Replay Point 1	3	0.75	0.29	0.26	0.34	0.41	0.37	0.44	0.4	0.42	0.41
	Replay Point 2	4	0.36	0.35	0.41	0.33		0.38	0.44	0.65	0.42	
	Replay Point 2	5	0.36	0.36	0.41	0.34		0.39	0.47	0.66	0.44	
	Replay Point 2	6	0.38	0.38	0.42	0.33	0.37	0.42	0.44	0.66	0.42	0.48

Standard deviations were calculated for each product at each octant, and are presented in Figure 5.11. Some spikes were visible in the analysis, such as the one occurring at Octant B of the Control section in Year Two. In this case the MPD set included a value that was just 0.1mm greater than the rest. Year Three spikes occurred at Octant D of the Biorestor® 015 section and the RePlay™ Point 2. In the Biorestor® 015 case the MPD set included a value that was just 0.09mm less than the rest and there was a measurement 0.01mm larger than others in the RePlay™ 2 set.

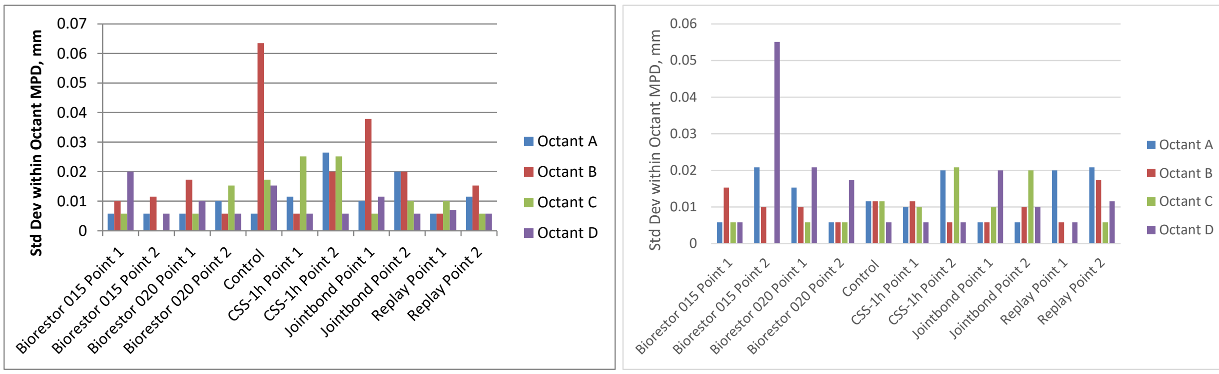

Figure 5.11 CTM standard deviations for treatment location and octant, Year Two (left) and Year Three (right).

Figure 5.12 presents the MPD averages from Table 5.3. The error bars show the standard deviation for each treatment, and some influence of the spikiness identified in Figure 5.11 can be seen here. The mean values of test section MPD's showed a tendency to increase during the study. Overlapping error bars suggest there was little significance in the differences between mean values.

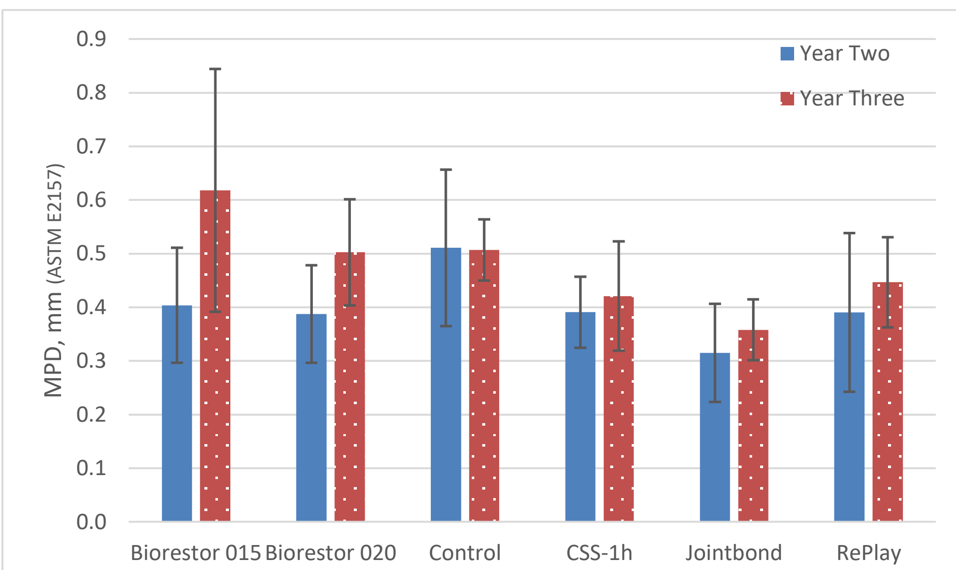

Figure 5.12 Mean Profile Depth by Treatment.

5.1.4 Permeability

Falling-head field tests were performed using a commercially available Gilson-NCAT field permeameter.

5.1.4.1 Methods

The field permeameter was composed of a rugged, clear plastic material. The device had a four-tier configuration, with the diameter of the tiers becoming progressively larger from bottom to top. The basic steps of use include: affixing the permeameter to the roadway surface to provide a water-tight seal, filling with water then monitoring change of head in each tier using a stopwatch, and organizing the data for analysis with Darcy's falling head equation.

$$K = \left(\frac{aL}{At}\right) \ln\left(\frac{h_1}{h_2}\right)$$

Where:

K is the coefficient of permeability (cm/s), and
a = inside cross-sectional area of standpipe, or tier (cm^2)
L = length of the sample (thickness of the asphalt mat) (cm)
A = contact area, permeameter to pavement (cm^2)
t = Elapsed time between h1 and h2 (s)
h1 = Initial head (cm)
h2 = Final head (cm)

The following figure shows the expected range of permeability obtained at given air void levels when testing coarse 12.5 mm asphalt mixtures with this equipment. Note that relatively good performance is found in the range below 50 x10^{-5} cm/s, corresponding to 6.5 percent air voids.

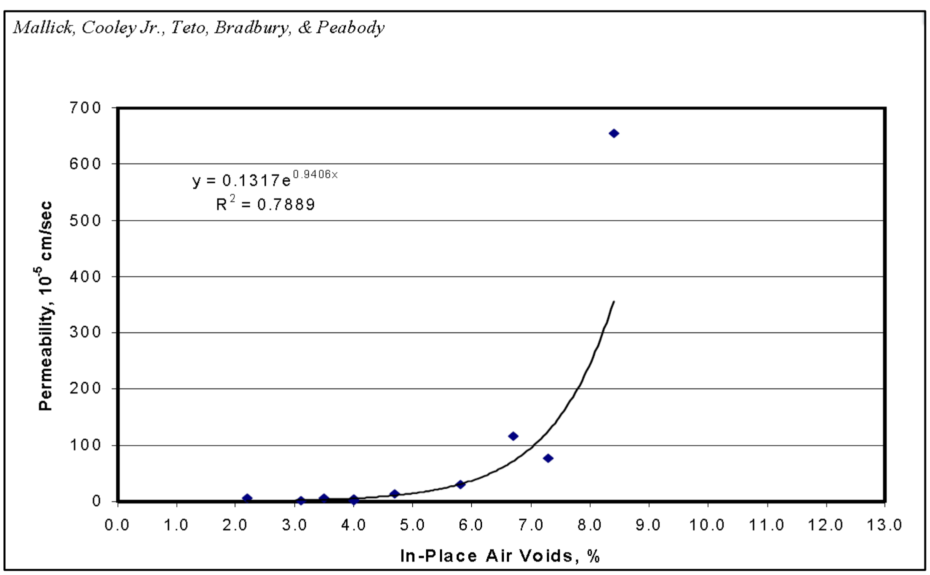

Figure 5.13 Plot of In-Place Air Voids versus Permeability for 12.5mm coarse mix (25).

5.1.4.2 Results

Permeability was measured during years one and two.

YEAR ONE FIELD PERMEABILITY

Prior to installation of fog treatments, a baseline permeability was taken within the same area that would later become the CSS-1h test section. Other readings were obtained (Figure 5.14) after fog products were installed. The initial results showed good performance of the control and fog sealed sections, with nearly all field permeability values below 100 cm/s. Other observations included:

- A test was performed on the CSS-1h within 1 week of application. Results were obtained without problem.
- A test was performed on the RePlay™ section on the day after application. During removal of the permeameter base the adhesive pulled a ring of asphalt mix from the surface of the pavement, indicating that testing was performed too early. A second test was performed after a cure period of over one month, and no problems were encountered.
- A test was performed on the Biorestor® section after one month. The waiting period was due to the results observed from the other sections. No problems were encountered.
- A test was performed on the Jointbond® section one week after application. No problems were encountered.

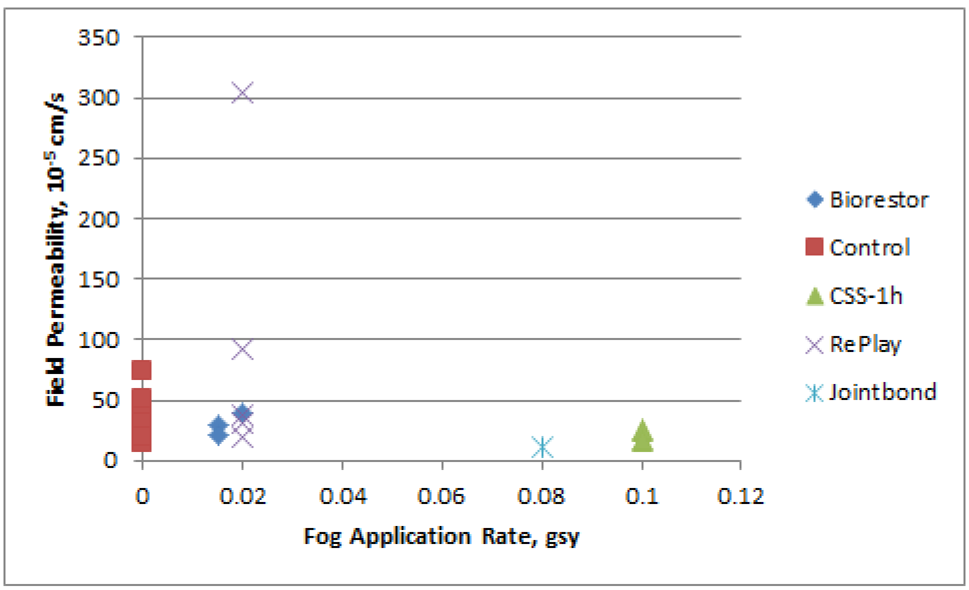

Figure 5.14 Field permeability of Fog sections: Year One.

YEAR TWO FIELD PERMEABILITY

Follow-up testing was performed in Year Two to compare sealant performance on areas of the bituminous shoulder that were constructed with and without aggregate segregation.

- Segregated areas were identified during distress rating. The CSS-1h section did not have easily identifiable areas of segregation. The most severe areas were selected for testing.
- Tests were performed at or near the middle of the shoulder.
- No problems were noted, including leaks or removal of the permeameter.

Permeability data is presented in Table 5.4, Table 5.5, and Figure 5.15. Measurements showed that all of the treatment types had an initial positive effect on the permeability of aggregate-segregated mixture when compared to similar conditions on the untreated control section.

The results also show that the fog treatments generally had an initial positive effect on permeability of non-segregated mixture at this test site when compared to similar areas of the control.

Table 5.4 Field Permeability Values: Year Two

Treatment	Segregation Present	Rate, gsy	k, 10^{-5} cm/s	Tier
Biorestor	No	0.015	29	k1
Biorestor	No	0.015	14	k2
Biorestor	Yes	0.015	160	k2
Biorestor	Yes	0.015	100	k3
Biorestor	No	0.02	35	k1
Biorestor	No	0.02	16	k2
Biorestor	Yes	0.02	200	k2
Biorestor	Yes	0.02	110	k3
CSS1-h	No	0.1	1.2	k1
Jointbond	No	0.08	3.5	k1
Jointbond	Yes	0.08	240	k2
Jointbond	Yes	0.08	180	k2
Jointbond	Yes	0.08	87	k3
None	No	0	46	k2
None	No	0	23	k2
None	Yes	0	670	k2
None	Yes	0	410	k3
RePlay	No	0.02	77	k1
RePlay	No	0.02	47	k2
RePlay	No	0.02	44	k3
RePlay	Yes	0.02	560	k2
RePlay	Yes	0.02	360	k3
RePlay	Yes	0.02	99	k4

Table 5.5 Permeability Reductions: Year Two

Treatment	Rate, gsy	Permeability Reduction on Nonsegregated Surface	Permeability Reduction on Segregated Surface
Control	0	0.0%	0.0%
RePlay fog	0.02	-30.4%	36.8%
Jointbond fog	0.08	90.0%	68.9%
Biorestor fog	0.02	25.7%	70.4%
Biorestor fog	0.015	38.0%	75.4%
CSS-1h fog	0.1	93.2%	93.2%†
† Estimated value, segregation not located on this section.			

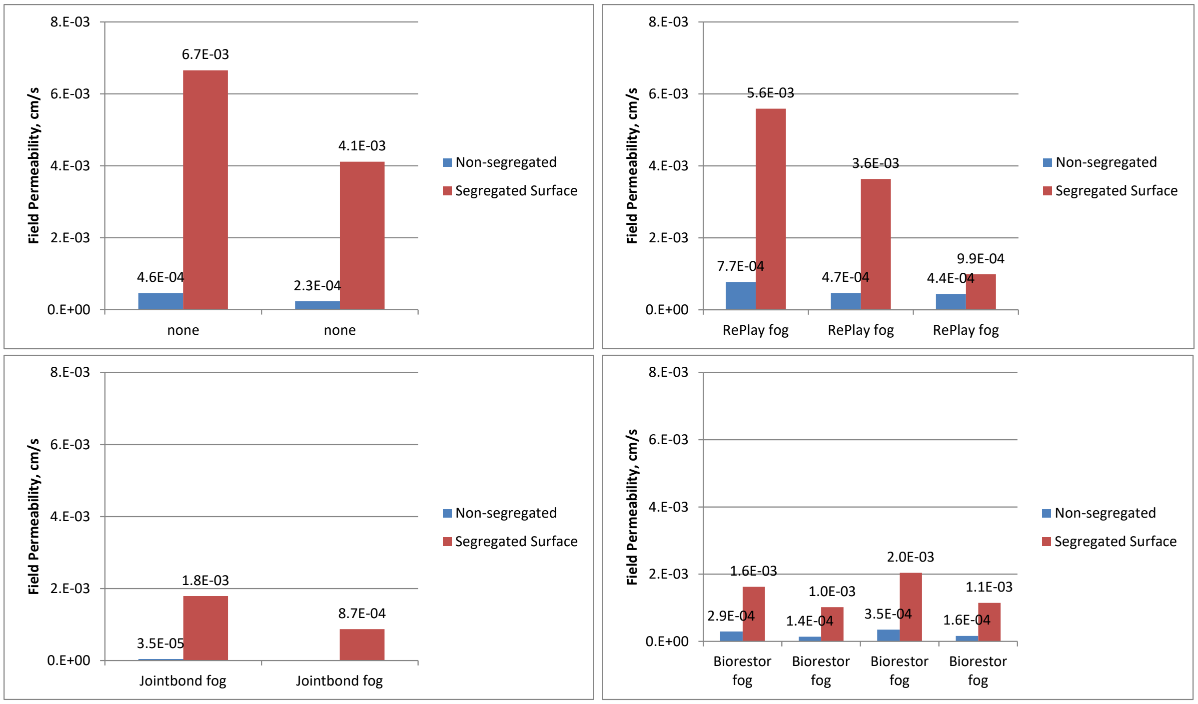

Figure 5.15 Field permeability of Fog sections: Year Two.

5.1.5 Moisture-Runoff Characteristics

By the time of the second anniversary of the installation date most of the test products were barely visible. At this time a simple experiment was performed in order to gather information that could aid in describing whether or not the sealant treatments were performing as expected. Because field permeability, friction, and texture had been evaluated elsewhere, a simple effort was made to assess whether the sealants functioned better than the control with regard to rate of water absorption.

5.1.5.1 Moisture – Runoff Experiment

Others have described these characteristics of properly performing surface sealer treatments:

- At a minimum, a pavement sealer should provide some degree of protection from the environment. Sealants and seal coats can retard intrusion of water and air, provide friction, and enhance roadway appearance (30).
- Longer term benefits of preventive maintenance include extended pavement service life and reduced life cycle costs (31). These are beyond the scope of this task report.

Conditions of this experiment were:

- The test area was on the 8-ft shoulder, approximately 3 feet from the fog line.
- A 3-oz. container was filled with tap water that was applied to the road surface from a height of 6-in. Duration of the application time was between 5 and 10 seconds.

- Times were recorded for application, edge runoff, and the time when the water was no longer ponded and had apparently receded to within the surface texture.

Experimental results are contained in (Table 5.6).

During this experiment it was observed that:

- All sections, including control shed some water. This ability was likely due to presence of proper cross section slope than the presence of a fog treatment.
- Control surfaces showed the most rapid soak time.
- Soak times of all the treatments were longer than the control. The dilute CSS-1h fog treatment had the longest, therefore best, soak time.

Table 5.6 Field Observations: Infiltration and Runoff

Treatment	Applied t=0, hh:mm	Edge Runoff, hh:mm	Damp Condition, hh:mm	Time to Soak, minutes
CSS-1h dilute	13:28	13:29	13:41	13
Control (none)	13:38	13:38	13:39	1
Replay	13:52	13:52	13:56	4
Biorestor 0.015	14:14	14:14	14:16	2
Biorestor 0.020	14:23	14:24	14:26	3
Jointbond	14:38	14:38	14:42	4

Figure 5.16 Ponded water soaking into surface texture (left, right).

The method assumes that infiltration may more easily occur once a given surface texture has been soaked. The assumption has a weakness; surface texture may be independent of seal quality, and infiltration may not occur after the surface texture is soaked.

Following the definition given for functioning surface sealer treatments, the CSAH 75 fog seal test sections all seemed to be functioning at some level. Trade-offs for retroreflectivity and friction may occur when selecting asphalt emulsion for better moisture retarding qualities. A qualitative summary is offered in Table 5.7.

Table 5.7 Basic Sealant Functionality on CSAH 75 Test Sections: Years 2 and 3

Criteria	Control	CSS-1h dilute	Replay	Biorestor		Jointbond
				0.015	0.02	
SHED WATER	X	X	X	X	X	X
RETARD INFILTRATION	1 min	13 min	4 min	2 min	3 min	4 min
FRICTION = CONTROL	NA	No initial recovery Recovery documented, YEAR 3	Recovers	Recovers	Recovers	Recovers
APPEARANCE	NA	Black. Fades to gray over several years.	Wet. Fades to dry over several months.	Wet. Fades to dry over several months.	Wet. Fades to dry over several months.	Wet. Fades to dry over several months.
RETROREFLECTIVITY (marking tape)	NA	No recovery	Recovers	Recovers	Recovers	Recovers

5.2 FIELD REVIEWS

The results of distress surveys and field inspections are presented in chronologic order.

5.2.1 Distress Surveys

5.2.1.1 Methods

Annual distress surveys were performed on all test sections. The type, quantity, and severity of cracking, raveling, and segregation was recorded for each test section. LTPP severity definitions were applied. The initial distress survey of CSAH 75 shoulder test sections was performed after product installations were completed.

5.2.1.2 Results

Some sections had developed very low severity transverse cracking prior to the fog seal installation. It was also observed that all sections contained segregated areas that had a coarse appearance, but the test stations for DFT and permeability were not located in those areas. The pre-installation conditions were recorded for each section and, for the purpose of the study, were considered the as-built baseline values.

YEAR ONE

Distress surveys of CSAH 75 shoulder test sections were performed immediately after product installations then again the following spring. Results showed that the construction project contained some segregated areas that had a coarse appearance, but the test stations for DFT and permeability were not located in those areas. During the spring survey areas of segregation were located within each test section and severe cases were selected for field permeability testing.

At this time some sections had developed very low severity transverse cracking, and the extent of the distress was recorded. The tabled data in Table 5.8 summarizes the relative performance of cracking values from Year One as compared to baseline values. General trends showed the number of cracks increased.

YEAR TWO

A distress survey of CSAH 75 shoulder test sections was performed during spring of Year Two. Some sections had developed very low severity transverse cracking, and the extent of the distress was recorded and is presented in the tabled data below. General trends showed the number of cracks increased. A comparison of the cracking history of the shoulder treatments is plotted in Figure 5.17. Data from 2014 represents the condition prior to treatment. Values were simply normalized according to cracks per mile.

$$T = \frac{\text{Count i}}{\text{Length i}}$$

Where:

T = number of transverse cracks per mile

Count i = surveyed crack count for section i

Length i = corresponding length of section, miles

Inspection of Table 5.8 and Figure 5.17 shows that the set of test sections were initially composed of two subsets having types of cracking performance: the first with less than 20 cracks per mile, and the second with 40 or more cracks per mile.

YEAR THREE

A distress survey of CSAH 75 shoulder test sections was performed during April 2017. Some sections had developed very low severity transverse cracking, and the extent of the distress was recorded. Raveling distress was quantified in 2017 (Table 5.8). Table 5.9 summarizes the relative performance of cracking values from 2017 as compared to values from 2016. General trends showed an increase in cracking along with an expected decrease in crack spacing.

Table 5.8 Distress Surveys of Test Sections

Date	Direction	Section	Survey Length, ft	Cracks	Lineal ft Cracking	Average Spacing, ft	Segregation
9/18/2014	EB	Biorestor 0.015	1334	5	21	267	Noted
9/18/2014	EB	Biorestor 0.020	1321	1	4	1321	Noted
9/18/2014	WB	CSS-1h	1000	8	64	125	Noted
9/18/2014	EB	Replay	2680	3	12	893	Noted
9/18/2014	EB	Control	500	4	12	125	Noted
9/18/2014	WB	Control	1321	0	0	none	Noted
10/26/2014	EB	Jointbond	2959	30	215	95	Noted
2014 Overall			11115	51	328	218	
4/23/2015	EB	Biorestor 0.015	1319	6	28	220	Located/rated L or M
4/23/2015	EB	Biorestor 0.020	1324	2	13	662	Located/rated L or M
4/23/2015	WB	CSS-1h	1000	10	72	100	Could not locate
4/23/2015	EB	Replay	2683	7	33	383	Located/rated L or M
4/23/2015	EB	Control	505	1	2	505	Located/rated L or M
4/23/2015	WB	Control	2641	2	9	1321	Located/rated L or M
4/23/2015	EB	Jointbond	2946	35	230	84	Located/rated L or M
2015 Overall			12418	63	387	197	
4/14/2016	EB	Biorestor 0.015	1320	4	23	330	Noted
4/14/2016	EB	Biorestor 0.020	1321	2	12	661	Noted
4/14/2016	WB	CSS-1h	1000	11	77	91	Noted
4/14/2016	EB	Replay	2582	11	51	235	Noted
4/14/2016	EB	Control	505	3	11	268	Noted
4/14/2016	WB	Control	2641	3	20	880	Noted
4/14/2016	EB	Jointbond	2949	31	212	95	Noted
2016 Overall			12318	65	406	190	
4/4/2017	EB	Biorestor 0.015	1320	6	35	220	418*
4/4/2017	EB	Biorestor 0.020	1321	3	19	440	142*
4/4/2017	WB	CSS-1h	1000	11	82	91	0*
4/4/2017	EB	Replay	2685	9	55	298	319*
4/4/2017	EB	Control	505	3	18	168	3*
4/4/2017	WB	Control	2641	4	30	660	211*
4/10/2017	EB	Jointbond	2949	33	237	89	76*
2017 Overall			12421	69	476	180	1169*
(*) Raveling, square foot							

Table 5.9 Relative Cracking Performance in Year Three

Direction	Section	Crack Count Increase	Lin. Ft. Increase	Spacing Increase
EB	Biorestor 0.015	50%	52%	-33%
EB	Biorestor 0.020	50%	58%	-33%
WB	CSS-1h	0%	6%	0%
EB	Replay	-18%	8%	27%
EB	Control	0%	64%	0%
WB	Control	33%	50%	-25%
EB	Jointbond	6%	12%	-6%
	Overall	6.20%	17.20%	-5.00%

A comparison of the cracking history of the shoulder treatments is plotted in Figure 5.17. Data from 2014 represents the condition prior to treatment. Values were simply normalized according to cracks per mile. Among the control sections, the eastbound crack count appeared to have stabilized during Year Three (2017) at about 30 cracks per mile while the westbound showed continued growth.

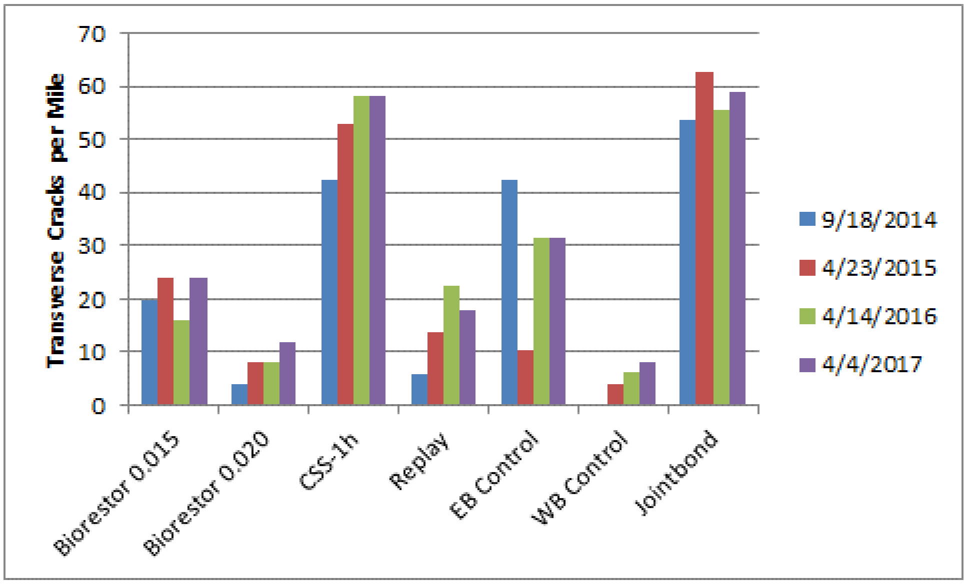

Figure 5.17 Transverse Cracking Histories.

The cracking rate on each section was compared by fitting linear least squares from the cracking history data to produce slope and intercept values in units of cracks per mile per year. Figure 5.18 is a plot of the difference between those cracking rates when compared to the eastbound control section. The greatest rate difference values occurred in the CSS-1h and RePlay™ sections. Note that the CSS-1h and RePlay™ sections were located in the same mile of roadway.

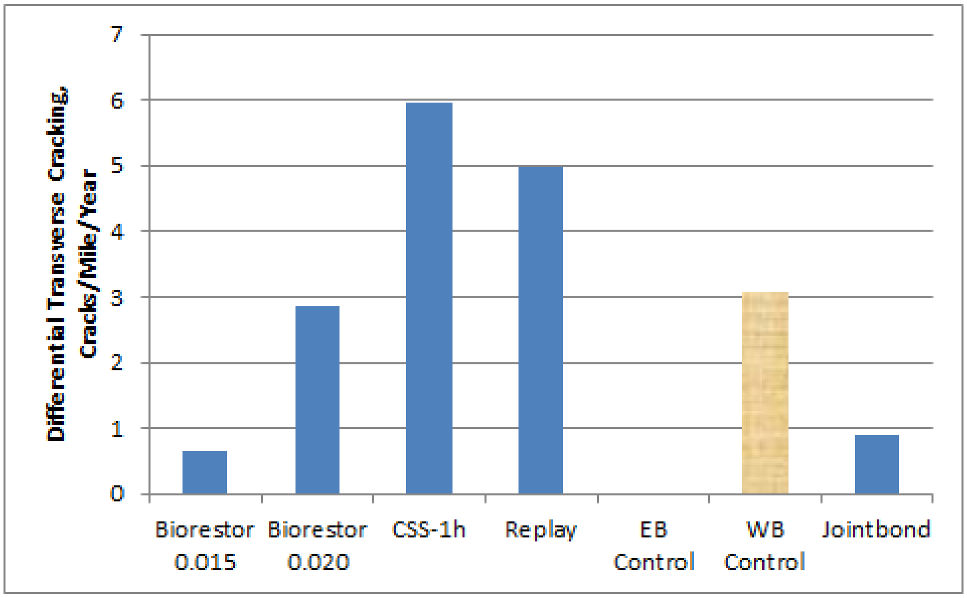

Figure 5.18 Differential Cracking Rates Relative to EB Control.

5.2.2 Field Inspections

Several inspections were performed during the life of this research project. Inspections were performed to gather anecdotal evidence of performance in wet and dry conditions over time. The goal of field inspections was to collect general information regarding the influence of the nontraditional fog seals on the roadway or on other surface treatments.

5.2.2.1 Year One Field Inspections

The first wet-weather inspections were held in January of Year One. Field inspection conditions were good, with overcast skies, and air temperatures near 30 °F. There was no snow on road or shoulders but the road surface held minor dampness; and it was found that moisture had accumulated on roadways early in the day. See Figure 5.19.

YEAR ONE OBSERVATIONS

- The surface of the untreated Control sections appeared moist, but the surface did not feel slippery for walking and turning.
- The Jointbond® section appeared to be dry or nearly dry in the treated area. The surface did not feel slippery for walking and turning.
- Biorestor® sections also appeared to be dry or nearly dry in the treated area. The surface did not feel slippery for walking and turning although blotches of moisture were observed.
- The RePlay™ section appeared to retain spots or blotches in the surface of the mixture in the treated area. More moisture was present in the untreated area. The surface did not feel slippery for walking and turning.

- The CSS-1h section appeared coated with moisture in the treated area. The surface did not feel slippery for walking, but did feel slippery for turning. In this section the amount of moisture standing on the surface was evidence that the fog seal had prevented moisture intrusion.

Figure 5.19 Year One wet-condition photos clockwise from upper left: WB Control, Jointbond®, Biorestor® 0.015, CSS-1h, RePlay™, and Biorestor® 0.020.

5.2.2.2 Year Two Field Inspections

Wet- and dry-weather field inspections were respectively held in March and April of Year Two. Inspection conditions were good on both occasions, with no snow on the road or shoulders. The March inspection occurred shortly after a rain event, and surface moisture conditions were similar to those from the previous year's wet-weather inspection. The road surface was completely dry during the April inspection. See Figure 5.20 and Figure 5.21.

YEAR TWO OBSERVATIONS

- Control shoulder sections were untreated.
  - WET: The control shoulders appeared to retain moisture in the surface of the mixture. The surface did not feel slippery for walking and turning.
  - DRY: Good condition.
- Jointbond® shoulder sections were treated from 1-ft outside of the fog line to the edge of pavement.
  - WET: The shoulder appeared to be dry or nearly dry in the treated area. The surface did not feel slippery for walking and turning.
  - DRY: Bounds of the spray application were visible.
- Biorestor® 0.020 shoulder sections were treated from 1-ft outside of the fog line to the edge of pavement.
  - WET: Shoulder appeared to retain moisture in the treated area. The surface did not feel slippery for walking and turning.
  - DRY: Bounds of the spray 0.020 application were not visible.
- Biorestor® 0.015 shoulder sections were treated from 1-ft outside of the fog line to the edge of pavement.
  - WET: Shoulder appeared to retain spots or blotches of moisture in the surface of the mixture in the treated area. The surface did not feel slippery for walking and turning.
  - DRY: Starting point of the 0.015 spray application remained visible.
- RePlay™ shoulder sections were treated from 1-ft outside of the fog line to 1-ft inside the edge of pavement.
  - WET: The shoulder appeared to retain spots or blotches in the surface of the mixture in the first 100-ft of treated area, but was mostly dry in the rest of the test section. More moisture was present in the untreated area. The surface did not feel slippery for walking and turning.
  - DRY: Bounds of the spray application were visible.
- CSS-1h shoulder sections were treated from 1-ft outside of the fog line to the edge of pavement.
  - WET: The shoulder appeared coated with moisture in the treated area. The surface did not feel slippery for walking, but did feel slippery for turning. In this section the amount of moisture standing on the surface was evidence that the fog seal had prevented moisture intrusion.
  - DRY: Bounds of the spray application were visible. The perimeter of the application was less defined, and the color had faded from black to dark gray at this location. The scraping effect of snow plowing was visible at transverse cracks.

Figure 5.20 Year Two wet-condition photos clockwise from upper left: WB Control, Jointbond®, Biorestor® 0.015, CSS-1h, RePlay™, and Biorestor® 0.020.

Figure 5.21 Year Two dry-condition photos clockwise from upper left: WB Control, Jointbond®, Biorestor® 0.015, CSS-1h, RePlay™, and Biorestor® 0.020.

5.2.2.3 Year Three Field Inspections

The Year Three field inspections were held in May. Inspection conditions were good on both occasions, with no snow on the road or shoulders. The road surface was completely dry during each inspection. See Figure 5.22.

YEAR THREE OBSERVATIONS

- Control shoulder sections were untreated and appeared in good condition.

- Jointbond® shoulder appeared in good condition. Bounds of the spray application were not visible.
- Biorestor® shoulder appeared in good condition. Bounds of the spray application were not visible.
- RePlay™ shoulder sections were treated from 1-ft outside of the fog line to 1-ft inside the edge of pavement. Bounds of the spray application were not visible.
- CSS-1h shoulder sections were treated from 1-ft outside of the fog line to the edge of pavement. Bounds of the spray application were visible. The perimeter of the application was less defined than during prior inspections, and the color had faded from black to dark gray at this location. Some plow scraping was apparent, especially at transverse cracks

Figure 5.22 Year Three dry-condition photos clockwise from upper left: WB Control, Jointbond®, Biorestor® 0.015, CSS-1h, RePlay™, and Biorestor® 0.020.

5.3 YEAR THREE AND FOUR INSPECTIONS FOLLOWING ROUTINE FOG SEALING OVER PROJECT TEST SECTIONS

As part of the county routine preventive maintenance program, a chip seal and bituminous fog seal was applied to CSAH 75 in Year Three. Inspections were performed after the routine seal coat, during Year Three and Four. The shoulder test sections received the fog seal in May of Year Three.

5.3.1 Inspection Results

At the time of the visit, the experimental treatments did not appear to affect the newly placed fog seal.

5.3.1.1 Site visit: July of Year Three

Conditions: Clear, dry weather and clear roadway.

- Test sections of fog sealant had been applied to five shoulder sections in the summer/fall of 2014 (Year One).
- CSAH 75 received a chip seal on the driving lanes and a fog seal on the 8-ft shoulders in May of Year Three, thereby covering the LRRB 974 test sections.
- In July of Year Three the paint marks for the LRRB 974 sections were visible through the fog seal.
- All sections appeared to have similar quality of fog seal, including Control, CSS-1h, Biorestor®, RePlay™, and Jointbond®.

Recommendations: Re-paint section begin/end points and re-review prior to final report.

5.3.1.2 Site visit: March of Year Four

Conditions: Clear, dry weather and clear roadway.

- The routine fog seal appeared to be performing well over all of the test sections. See Figure 5.23.
- The limits of the Control test section were not visible through the routine fog seal. The section appeared no different compared to other adjacent shoulders.
- The CSS-1h test section application was visible through the routine fog seal. The section appeared much darker in color compared to other adjacent shoulders.
- The RePlay™ test section application was not visible through the routine fog seal. There was no visible difference between the section and other adjacent shoulders.
- The Biorestor® test section applications were not visible through the routine fog seal. There was no visible difference between the section and other adjacent shoulders.
- There was no visible difference between sections with differing Biorestor® application rates.
- The Jointbond® test section was visible through the routine fog seal. The section appeared somewhat darker in color compared to other adjacent shoulders.

Figure 5.23 Year Four following routine fog seal, condition photos clockwise from upper left: WB Control, Jointbond®, Biorestor® 0.015, CSS-1h, RePlay™, and Biorestor® 0.020.

CHAPTER 6: SURVEY OF NONTRADITIONAL FOG SEALING

A survey of local road agencies was performed during the third year of the project. The intent was to estimate the types of nonstandard fog seal products are used in Minnesota, the frequency of their use, and their performance. The format of the survey was multiple-choice and short answer. It used the following definitions for traditional and nontraditional fog sealers:

- In the traditional sense, fog seal materials for bituminous streets and highways include a type of emulsified asphalt as the main ingredient. Sources define fogs seals as: "… an application of asphalt emulsion sprayed onto a pavement surface with or without a sand cover" (1), and "… a light application to an existing surface of a slow setting asphalt emulsion diluted with water." (2) It is commonly known that asphalt material is a byproduct generated from the crude oil refining process. Furthermore, modern generic fog seal standards focus on materials where asphalt is the main ingredient.
- For the purpose of the survey nontraditional, nonstandard fog seal materials were broadly represented. They were be said to contain main ingredients having: (1) a main material not derived from petroleum, or (2) only a fraction of asphalt, or (3) maltenes (resins, aromatic oil, saturate oil) or similar compounds found in asphalt, or (4) any sealer material having a special formulation.

6.1 RESPONSES

There were 57 responses to the agency survey.

QUESTION 1: DOES YOUR AGENCY USE AGRICULTURAL-BASED, OR OTHER NONSTANDARD MATERIAL FOR SPRAY APPLIED TREATMENT OF ASPHALT PAVEMENT SURFACES?

This was a question where respondents could choose only one option. If "No" was selected the survey closed. The responses show that 32 percent of the respondents used nonstandard fog seal materials.

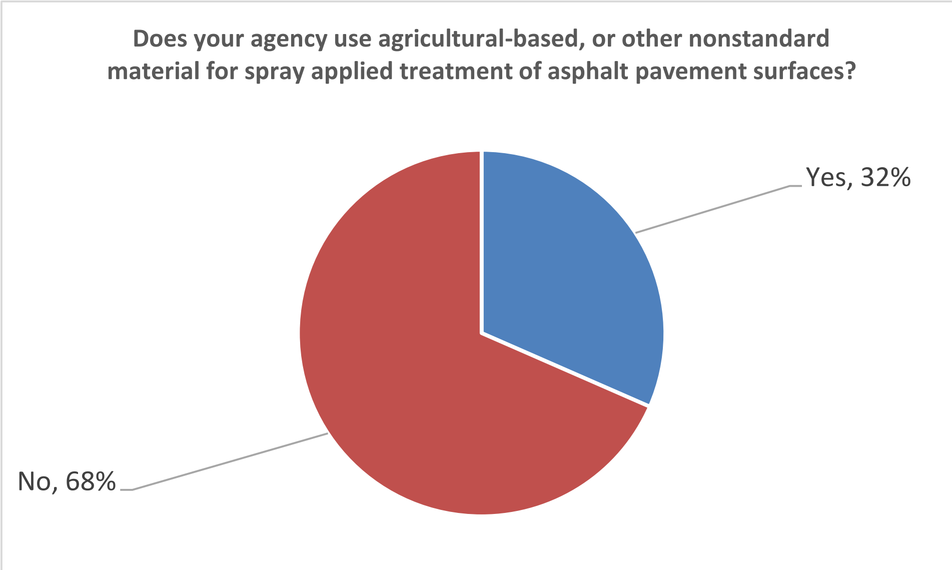

Figure 6.1 Use of nonstandard fog seal material among Minnesota Cities and Counties.

QUESTION 2: IF YES; PLEASE LIST THE NONSTANDARD PRODUCTS USED ALONG WITH THE APPROXIMATE NUMBER OF LANE MILES TREATED.

This was a short answer question. The most frequently used nonstandard product was RePlay™, which appeared in 73 percent of the responses. Biorestor® was the next, with 14 percent of the responses. Responses for several other engineered products occurred at lower frequencies, including: GSB®, CS-41 Proprietary Asphalt Rejuvenator manufactured for Allied Blacktop Co., and Micropave Pro Blend®. The manufacturer's detailed application specification for Micropave Pro shows the product is applied by both hand and machine methods (29).

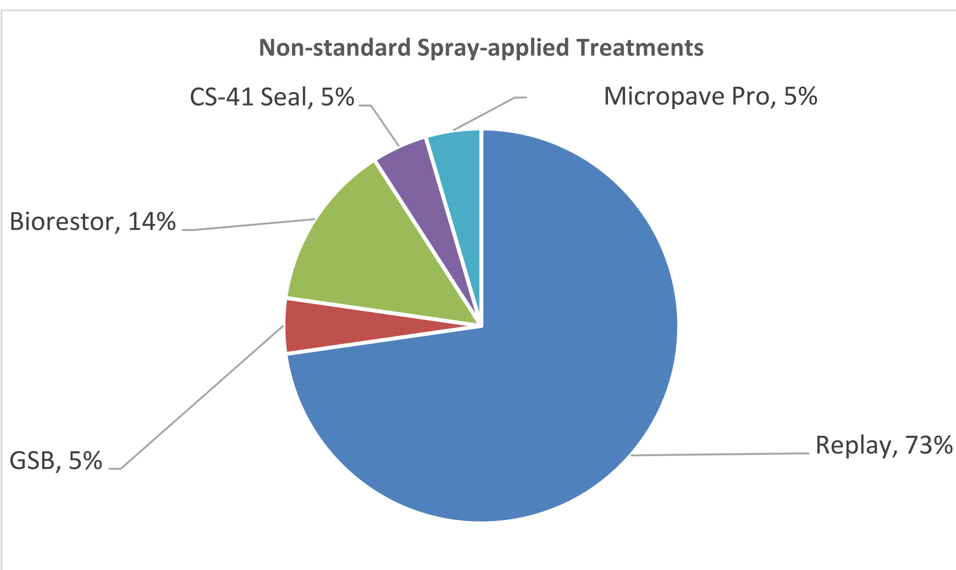

Figure 6.2 Nonstandard products used by MN cities and counties.

RePlay™ was also reported to be the most widely used in terms of lane miles, followed by GSB®. Responses totaled less than six combined miles for Biorestor®, CS-41, and Micropave Pro Blend®.

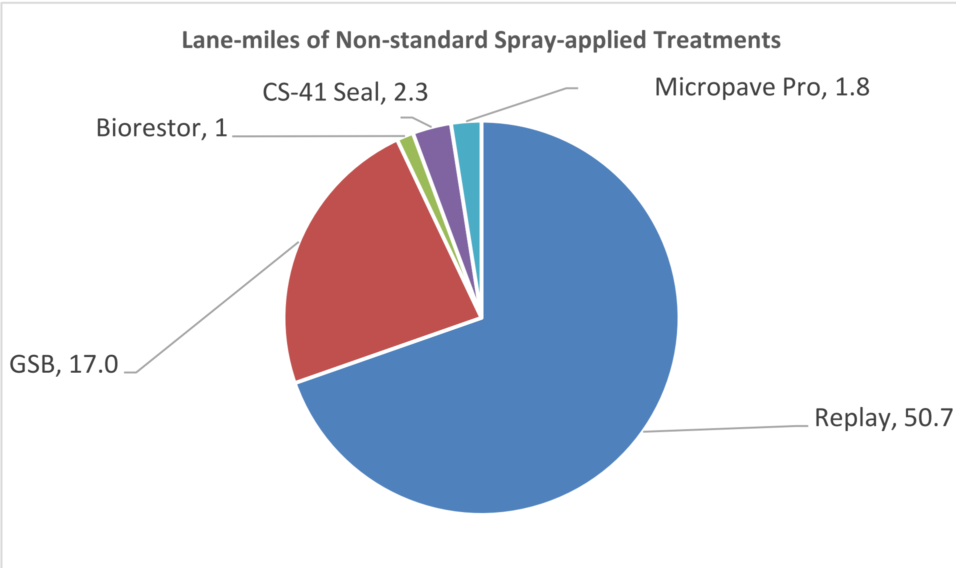

Figure 6.3 Miles of treatment by type.

QUESTION 3: HOW IS THE PERFORMANCE MEASURED?

This was a multiple choice question allowing more than one answer. Some of respondents selected up to three choices. Fifty-five percent of the responses measured performance of a nonstandard fog seal by comparing it to either an untreated road, or a road with a standard surface treatment. Twenty seven percent used a visual rating or condition survey, but 10 percent of those had sections too new to be rated. Seven percent performed tests on pavement cores. No agencies used ride quality as a rating method. Thirteen percent of the respondents did not measure performance.

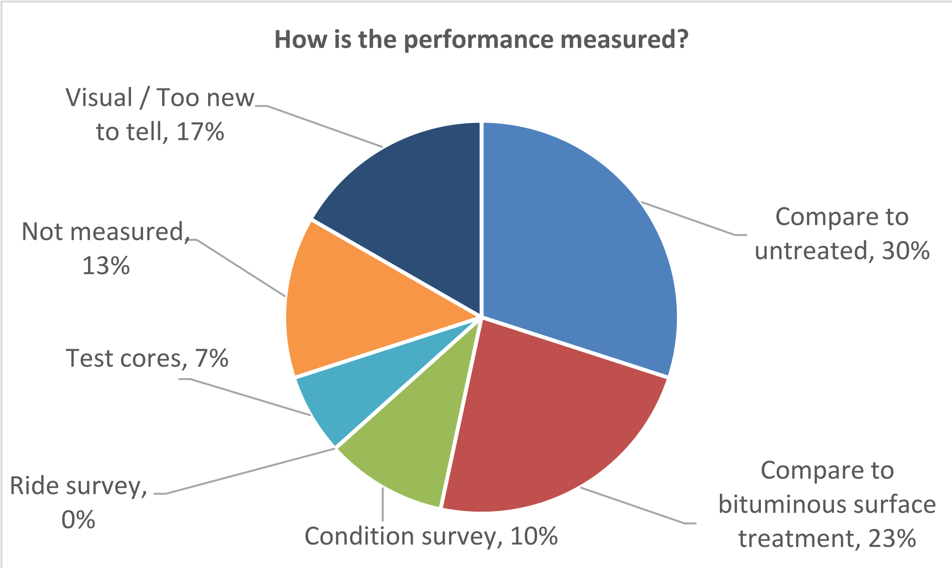

Figure 6.4 Performance measures.

QUESTION 4: WERE THE INSTALLATIONS DONE AS TEST SECTIONS OR PART OF REGULAR MAINTENANCE TREATMENT?

This was a multiple choice question allowing only one option. Sixty-one percent of the respondents had installed nonstandard fog seal treatments as test sections, and 39 percent had used them as a regular maintenance option.

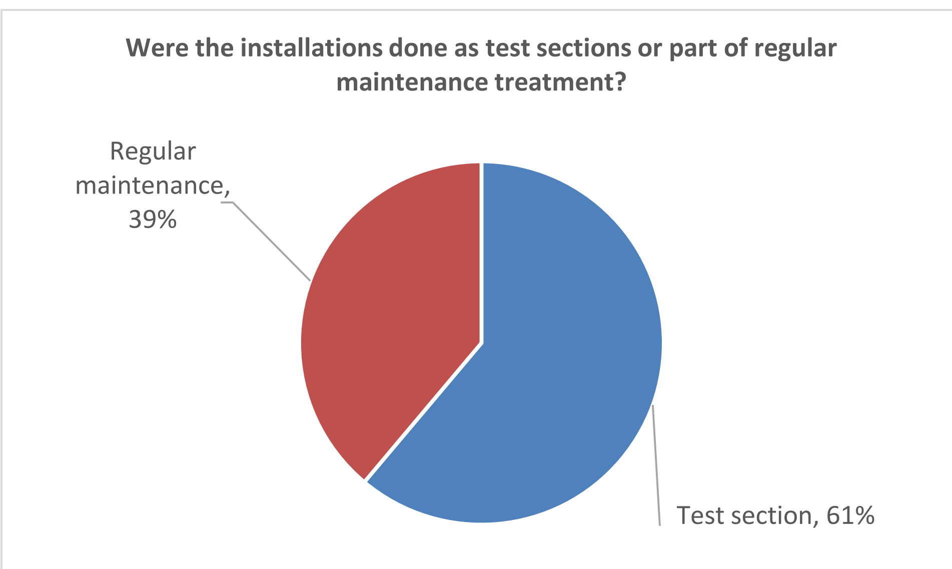

Figure 6.5 Regular maintenance vs. test section.

QUESTION 5: WHAT ARE THE CURRENT AGES OF THE NONSTANDARD PRODUCTS, AND HOW ARE THEY PERFORMING?

This was a short answer question where respondents could choose to comment on the age and performance of any type of product. Responses covered the age and performance of at least 27 installations. With respect to the set of age data, the range was from one-half to six years and the average age was two years.

The set of performance comments contained either specific observations or described performance relative to control sections. Performance quality was observed for 14 cases, but the remaining 13 cases were new installations and those comments were limited to “empty response = No Comment”, “New”, or “Unknown”. Table 6.1 gives all the age and performance details provided by the respondents. Table 6.2 is a condensed version of the same information that is arranged to show the composite performance of each product.

Table 6.1 Product Age and Performance

Case	Product	Age, Yr	Performance
1	Biorestor	New	Unknown
2	Biorestor	3	Low application rate: Cracking better than control, texture worse than control, friction equal to control
3	Biorestor	3	High application rate: Cracking equal to control, texture better than control, friction equal to control
4	Biorestor	5	Equal to control
5	CS-41	1	No Comment
6	GSB	2	Wearing off in wheel paths at surface and at intersections
7	GSB	3.5	Wearing off in wheel paths at surface and at intersections
8	Jointbond	3	Cracking and texture better than control, friction equal to control
9	Micropave Pro	1	Unknown
10	Replay	New	Unknown
11	Replay	New	No Comment
12	Replay	New	Unknown
13	Replay	New	Unknown
14	Replay	New	Unknown
15	Replay	1	Performing very well
16	Replay	1	No Comment
17	Replay	1	No Comment
18	Replay	2	Equal to control
19	Replay	2	Performing very well
20	Replay	2	Performing well
21	Replay	2.3	Equal to control
22	Replay	3	No Comment
23	Replay	3	Cracking worse than control, texture and friction better than or equal to control
24	Replay	3	Equal to control
25	Replay	3	No Comment
26	Replay	5	Unknown
27	Replay	6	Prevents some cracking

Table 6.2 Composite Performance Summary

Product	New	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Biorestor	Equal to control			Slight variability with application rate.		Equal to control	
CS-41	Equal to control	No comment					
GSB	Equal to control		Worn by traffic				
Jointbond	Equal to control			Equal or better than control.			
Micropave Pro	Equal to control	Unknown					
Replay	Equal to control		Equal to control	Variable			Better cracking performance.

QUESTION 6: DOES YOUR AGENCY REQUIRE MATERIAL TESTING OR OTHER DOCUMENTATION FOR ACCEPTANCE OF NONSTANDARD SURFACE TREATMENTS?

This was a multiple choice question allowing more than one answer. Among the agencies that have used nonstandard fog seal products, 73 percent used some type of material documentation. The documentation came from either Quality Assurance testing (5 percent), Safety Data Sheets (23 percent), or data provided by the manufacturer (45 percent). Five percent of the respondents included other user References as an input. Twenty three percent of the replies said non documentation had been used.

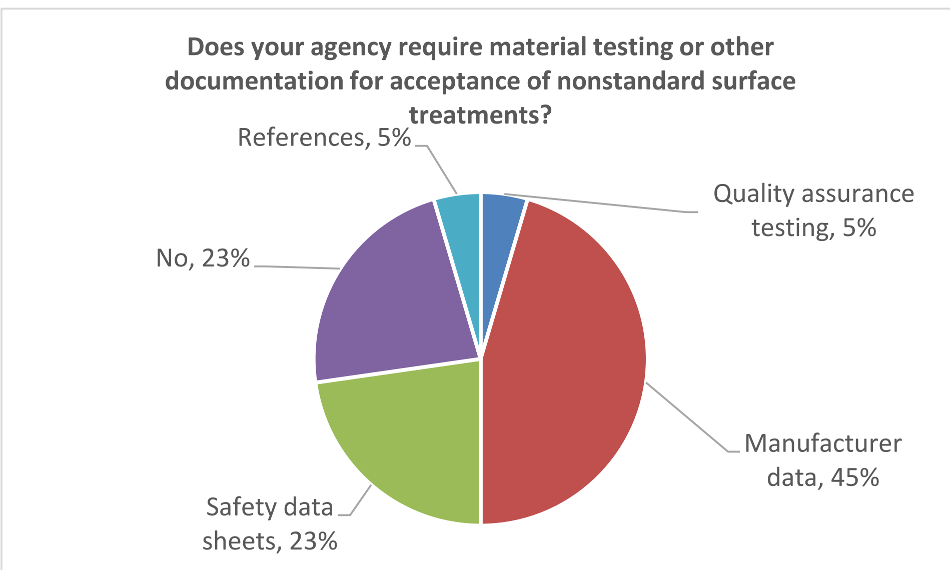

Figure 6.6 Material acceptance method.

QUESTION 7: BASED SOLELY ON YOUR EXPERIENCE, WOULD YOU RECOMMEND THAT OTHER AGENCIES TRY THESE TREATMENTS?

This was an optional multiple choice question allowing one response. Fifty six percent of the respondents replied “Yes” to recommending that others could try these treatments. Twenty two percent replied “No”. The remaining 22 percent did not answer, and are shown in the chart as “No Comment”.

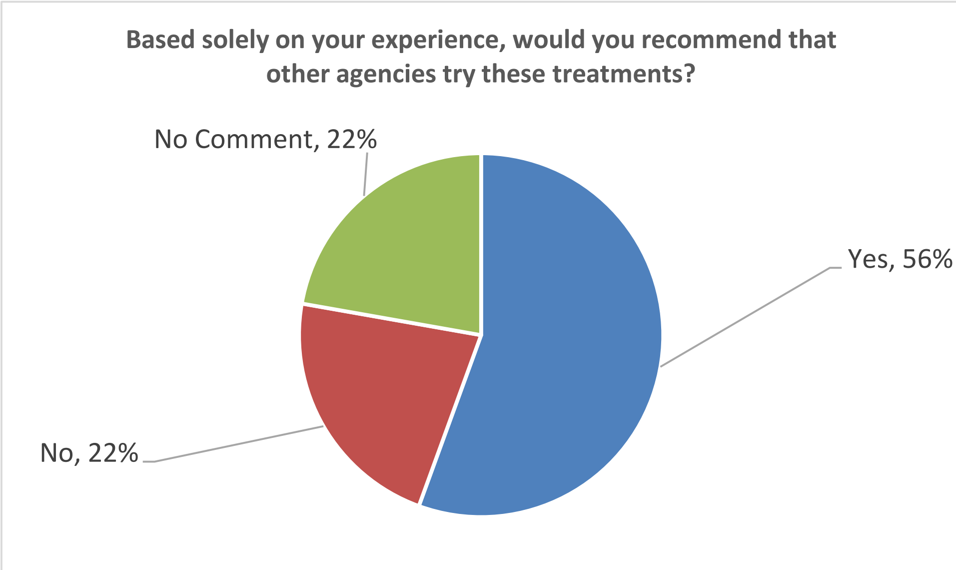

Figure 6.7 Respondent opinion on other agencies trying similar treatments.

QUESTION 8 PART 1: MAY THE RESEARCHERS CONTACT YOU ABOUT YOUR EXPERIENCE?

This was a multiple choice question allowing one response. Seventy eight percent of the respondents replied “Yes” to providing researchers more information about their experience with nonstandard fog seal products. Eleven percent replied “No”. The remaining 11 percent did not answer, and are shown in the chart as “No Comment”.

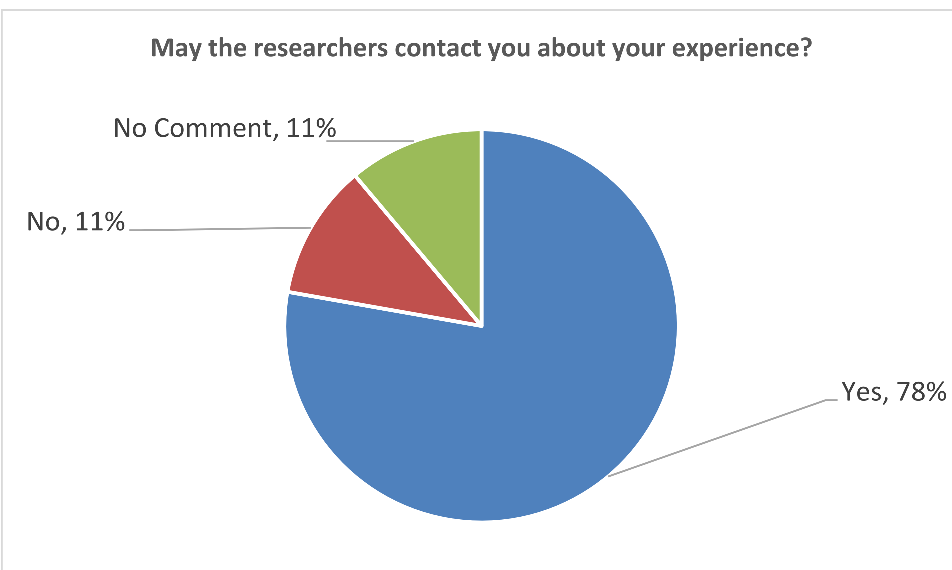

Figure 6.8 Respondents able to provide more information.

QUESTION 9: IF YES, PLEASE PROVIDE YOUR CONTACT INFORMATION.

This question contained fields for Name, Agency/Company Address, Address 2, City/Town State/Province, ZIP/Postal Code, Country, Email Address, and Phone Number. The respondent could leave the question unanswered. Responses were collected, but are not reported here.

CHAPTER 7: CONCLUSION

7.1 SUMMARY

In recent years a number of products have been introduced as alternative surface sealers for streets, highways, shoulders, and recreation trails. Traditional fog seal treatments are asphalt-based. The new proprietary nontraditional fog seal materials products may use agricultural-derived oils. In this study several proprietary nontraditional fog seal products were applied to bituminous shoulders then evaluated for performance over a three-year period. This report includes:

- Summary of related literature regarding equipment, binder modification, and performance evaluations
- Description of the materials used in the Minnesota test sections and their installation
- Material evaluations: FTIR scan of fog products, and rheological tests of field aged binder as extracted from fog seal test sections
- Field performance of test sections: nondestructive testing, distress, and other inspection results
- Survey of nontraditional fog seal use in Minnesota

An examination of related literature (CHAPTER 2: found that a number of products have been evaluated as rejuvenators and modifiers. One source studied how a rejuvenator material diffuses through a bituminous mixture, and the results showed that time between mixing and testing is critical and that the diffusion process can persist past the point of mix production; any potential rejuvenator or modifier should be evaluated for an effect on pavement performance measures. Another source found that a significant softening effect was observed in laboratory specimens treated with proprietary nontraditional sealants.

Several reports have been authored by highway agencies and academia on the field and laboratory performance of proprietary nontraditional fog seal materials. Highlights include:

- Proprietary nontraditional agricultural-oil fog seal and found some mixture softening and a temporary decrease in friction had occurred.
- Proprietary fog seal products provided some benefit as a longitudinal joint treatment to reduce water absorption. Similar findings, with reduction of permeability, were the outcome of an unrelated study by another highway department.
- A four-year performance study documented reduction and partial recovery of friction properties, along with initial decrease of surface texture and highly variable field permeability. Over time, the treated sections developed slightly less cracking and raveling distress than the controls. Use of penetrating sealers were recommended for roads where the respective added costs for each year of additional service life is less than $15,000, but were not recommended on roads where friction is an issue.

Several manufacturers have performed or sponsored testing of sections treated with proprietary nontraditional products. It was reported that for one product friction decreased for 50 hours then began to recover. Another report stated that treatments on Minnesota's CSAH 75 generally increased the phase angle, and lowered binder viscosity and stiffness with respect to the untreated pavement. A test report from another field study documented that dynamic shear rheometer measurements indicated relatively stronger effect from the treatment in the top 3/8-in. of the overlay core. The effect was somewhat less in the middle 3/8-in. of the core, and negligible at the core bottom.

Test sections were installed in Minnesota to evaluate the field performance of nontraditional fog seal applications (CHAPTER 3:). The test sections were installed on the shoulder of a rural section of CSAH 75, and were monitored over a three-year period. Installation of each product was performed in an appropriate manner, with metered distributor equipment. Installation of emulsified asphalt was accomplished with a typical asphalt distributor. Installation of nonstandard products was done with equipment more similar to agricultural sprayers and better suited to the lower application rates. Installation costs were reported for the research sections.

Product samples and road cores were obtained at various times for this research and for other related projects. CHAPTER 4: described testing of samples and extracted binders. A round of FTIR scans were performed on the product samples and results were correlated to other substances found in an FTIR catalog. FTIR absorbance spectrums showed Jointbond® and asphalt shared certain features. Absorbance spectrums showed that Biorestor® and RePlay™ had certain similarities.

Field cores were obtained during the third year of the study. The cores were sliced to yield material from the top and middle of the pavement structure. The field-aged asphalt binder was extracted and recovered from the slices, then tested using bending beam rheometer and dynamic shear rheometer methods (BBR and DSR). DSR results showed that the high-temperature stiffness parameters were greater in the top of the structure than the middle. Stiffness of the Control, CSS-1h, and Jointbond® top sections were approximately 32 percent higher than the middle. Stiffness of the RePlay™ top slice was approximately 42 percent higher. BBR results showed that the low-temperature stiffness of all except the CSS-1h treatment was higher in the top slice than in the middle. Corresponding BBR m-values were all lower except for the CSS-1h treatment.

Field performance was described in CHAPTER 5: A temporary reduction and subsequent recovery of pavement marking retroreflectivity was documented for the nontraditional fog seal products. Markings treated with Jointbond® recovered retroreflectivity after 800 vehicle passes, and those treated with RePlay™ and Biorestor® recovered after 1,600 passes. Similarly, the temporary reduction and subsequent recovery was documented for pavement friction. Nontraditional treatments recovered friction over a period of 200 days with no traffic. CSS-1h had the greatest effect on friction and the longest recovery period without traffic. Measurements of pavement texture showed that except for the Control section, MPD increased over a two-year evaluation cycle. Field permeability tests during the first two years of service showed all treatments provided some benefit on areas with and without mixture segregation. After two years of service, a simple measurement of moisture "soak time" illustrated the CSS-1h treatment provided more protection than the other treatments. Distress reviews showed that cracking in the Jointbond® and Biorestor® sections compared well with the westbound

Control section. Other inspections found that asphalt fog seals over CSS-1h and Jointbond® test treatments appeared darker; a potential indicator of a residual effect from the test treatment.

A survey of Minnesota agencies (CHAPTER 6: found that 32 percent of respondents had used some type of nontraditional fog sealant for pavement preservation. The majority of these respondents were currently comparing products to untreated control sections. Respondents stated they had tried proprietary products other than those in the CSAH 75 study. The survey found that for some products the performance was regarded as equal to the control for up to six years. Other products were found to show wear after two years. Based on their own experience, 56 percent of respondents recommended that others should try a nontraditional fog seal product.

7.2 RECOMMENDATIONS

The objective of this study was to evaluate the field performance of several nontraditional, or "bio-sealer" fog applications relative to that of a standard product and untreated control. Survey responses from Minnesota agencies experienced with nontraditional fog seals found that performance varied between "showing wear after two years" to "equal to control after six years" and respondents recommend additional trials. The following recommendations are based on results from over three-years of field performance.

APPLICATION: There are few concerns for agencies that desire to install nontraditional products in situations where distributor trucks can be operated. Agencies should perform acceptance checks of application rates and compare to the vendors metered volume or tank level. This study did not evaluate broom-applied or wand-applied methods. Agencies should use the product at rates recommended by the manufacturer.

EFFECT ON PAVEMENT MARKINGS: All of the nontraditional products in the study caused reductions of retroreflectivity. Recovery should be expected for new markings or those in like-new condition. Agencies should consider the condition of their marking materials prior to application.

EFFECT ON PAVEMENT PERMEABILITY, TEXTURE, and FRICTION: Measurements showed that all products in the study reduced the permeability of areas with and without mixture segregation. All of the products in the study also caused an increase in MPD surface texture over two years, while the control section remained unchanged. Although the cause of texture change has not been studied, the authors speculate it may be related either to loss of fog coating material (and fine aggregate) or the exposure of aggregate texture due to mild solvent properties of some products. All of the products in the study caused a temporary reduction in friction. The nontraditional products caused relatively smaller reductions and more rapid recovery without benefit of traffic, compared to CSS-1h. Agencies should consider the current condition of their candidate roads and posted speeds prior to installing the products in this study.

EFFECT ON ASHPALT BINDER PERFORMANCE: The binder tests performed during this study showed similar performance between the field-aged specimens treated with nontraditional fog products and the control specimens. Analysis of binders recovered from CSAH 75 test sections showed the spray applied fog sealers did not affect the high-temperature performance. Recovered binder from the CSS-1h treatment showed better low-temperature performance relative to the control and nontraditional sections.

EFFECT ON CRACKING PERFORMANCE: Based on this study, agencies considering applications over similar dense-graded asphalt mixtures may find reduced cracking during the first several years of service. Future work should be performed to compare performance on mill-and-overlay sections.

COMPATIBILITY WITH FUTURE BITUMINOUS TREATEMENTS: Agencies should not expect to encounter problems when using an emulsified asphalt to over-seal sections treated with these nontraditional fog sealers. No problems were observed for a period of eight months after a routine bituminous fog seal.

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APPENDIX A
SCREENING REVIEW, BID PRICE FOR BITUMINOUS FOG SEAL, PHOTOS OF NONTRADITIONAL FOG MATERIAL SAMPLES

Item 1. Environmental Screening Review

Item 2. Price of Bituminous Fog Seal

Item 3. Photo of RePlay, Jointbond, and Biorestor.

ITEM 1

From: Edstrom, Robert (DOT)
Sent: Tuesday, August 19, 2014 2:45 PM
To: Johnson, Eddie N (DOT)
Subject: Biorestor, RePlay, Jointbond: Screening Review

Eddie:

These are my initial findings on the three sealer products:

Biorestor - This product has d-limonene which has significant aquatic toxicities to freshwater fish and invertebrates. The alkyl methyl esters are not of great concern. It would be best if this product were not used over surface water.

RePlay (Agricultural Oil Seal) – This product appears to be favorable however there must be other components not stated on the MSDS. Both stated components are not water soluble yet the MSDS says "miscible" in water. The pH range is a concern near surface water if a spill were to occur. If 0.02 gal/sq yd is typical spraying, this should limit any drift impacts.

Jointbond – The product composition is quite vague. Hard to tell what is in this product. The pH range is somewhat on the low side and would be a concern if spilled into surface water. My initial recommendation would be not to use over surface water until more is known about the composition.

If the product manufacturers want to submit for a full product review, they should submit the New Product Information Form. Each product would need the RCRA metals analyzed plus copper and zinc. If the products are to be sprayed over surface water, other testing may be necessary.

My initial impressions are that RePlay is of less environmental concern that the other two.

Let me know if you need more discussion.

Bob

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ITEM 2 - MnDOT Bid Prices for Bituminous Fog Seal Material: 2013-14

Award Year	Spec Year	Gallons	Price	$/gal	Running Average
2013	2005	315,705	$636,000	$2.01	$2.01
2013	2005	19,253	$58,000	$3.01	$2.07
2013	2014	67,818	$281,000	$4.14	$2.42
2014	2014	259,684	$524,000	$2.02	$2.26
2014	2014	958	$21,000	$21.92	$2.29

ITEM 3 – Photo of (left to right) RePlay™, Jointbond®, and Biorestor® field samples.

APPENDIX B
SURVEY LETTER

Items: Letter to Cities and Counties.

ITEM 1

From: Johnson, Eddie N (DOT)
Sent: Tuesday, December 19, 2017 11:29 AM
Subject: MnDOT/LRRB Project: Use of Non-Traditional Asphalt Sealers - Short Survey

Dear Minnesota City and County Engineers,

We are seeking information on the type and extent of non-traditional surface sealant used on asphalt roads in Minnesota cities and counties.

As part of Investigation 974 MnDOT has been performing research funded by the Minnesota LRRB in order to learn about non-traditional spray-applied surface sealant materials for asphalt pavements. These and other related materials may have been marketed as pavement sealers, or possibly as rejuvenators. The current LRRB research project has focused on several proprietary products (Jointbond, Replay, and Biorestor).

Please link to this short survey and share your experience with LRRB < https://www.surveymonkey.com/r/D22ZDJK >. All information is valuable, whether or not you have used a non-traditional product.

Thank you for your participation. Feel free to contact me with any questions.

Ed Johnson

Research Project Engineer

MnDOT Office of Materials and Road Research

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