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Pavement Preservation Best Practices Technical Briefs

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Abstract

Preservation treatments are used throughout the United States to mitigate the aging and degradation of pavements. These treatments should be designed to obtain maximum life and for this to occur, the treatments must be designed and constructed properly. This project summarizes current Quality Assurance “best” practices used by selected state transportation agencies to construct chip seal, slurry seal, micro surfacing and thin lift asphalt overlay preservation treatments. These practices, when followed, can result in long-lasting and high-quality treatments, hence the term “best”. There were several identified similarities between the treatments, particularly the micro surfacing and slurry seal treatments. This is not unexpected, as micro surfacing treatments are considered to be a more specialized slurry seal. Some similarities included asphalt binder selection, aggregate gradation, mix design method and verification, equipment and construction inspection and Quality Assurance requirements. Many agencies did not specify seasonal construction limits for construction, even ones that experience drastic changes between seasons. Thus, specific dates should be set to increase treatment performance. All of the selected agencies had Quality Assurance requirements of varying degrees of detail. This is important, as the main goal of this project is to determine Quality Assurance best practices.

Interestingly, there is an appreciable difference in specification practices with changes in climate zones. This is also expected, as different climates present different construction challenges. The main practice that showed this difference was in asphalt binder selection—emulsions vs. PG grades. Other differences were observed in the equipment specification requirements, particularly in the calibration requirements.

Some agencies have extensive details, and others were broad in detail. Another important difference was observed in the inspection processes followed by each of the agencies for all four treatments. The main differences were in test strip requirements and areas of the construction process that were to be inspected. Some agencies did not require test strips at any time during a project, whereas others required test strips before and even during construction. Finally,

All of these similarities and differences help to illustrate that there are several items that must be used when considering what constitutes a “best” practice. Thus, some of these practices were common to the agencies, and others were unique to one agency. By selecting a broad range of practices, both common and unique, one can achieve a well-rounded synthesis that truly can be applied everywhere.

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Chapter 1 Introduction

Every year, the United States roadway system undergoes a process normally associated with biological organisms—the pavements used to construct the roads age and begin to deteriorate. This deterioration leads to the large cracks that begin to appear in roadways, causing roughness while driving, moisture intrusion—leading to further degradation and roughness—and finally, to potholes, which can damage automobiles if left unchecked. It is apparent that this deterioration is not acceptable. Once the pavements come to this end-stage in life, major reconstructions are necessary to correct the issue. In times of economic hardships, these reconstructions are a hefty price, one that may not be possible to absorb. Further, as the cost of paving materials—both for asphalt concrete and Portland cement concrete—increase, so too do the costs of the pavement, leading to costs that, even in times of economic boom, can be daunting. If the entire network of pavements requires reconstruction, the costs could be exorbitant. This is especially true for areas such as Los Angeles, California, with over 23,000 lane-miles¹ of roadway. Thus, there is a need for a method that can prevent or at least mitigate the rate of deterioration of pavements. This method is the pavement preservation treatment.

Currently, there are more than nine types of asphalt pavement preservation treatments. These treatments include Chip Seals, Cape Seals, Crack Sealing, Fog Seals, Micro Surfacing, Otta Seals, Sandwich Seals, Slurry Seals and Thin Lift Asphalt Overlays. This work focuses on Chip Seals, Slurry Seals, Micro Surfacing and Thin Lift Asphalt Overlays. Chip Seals are defined as “a single application of

¹ Sources: <http://www.laalmanac.com/transport/tr01.php>, California Dept. of Transportation 2015 Public Road Data, <http://www.dot.ca.gov/hq/tsip/hpms/datalibrary.php>

asphaltic material on a roadway surface followed immediately by a single cover application of aggregate.”[1] Slurry Seals are defined as “a fine mixture of aggregate, asphaltic emulsion, water, mineral fillers and additives that has been mixed and spread onto a roadway surface.”[2] A Micro Surfacing is defined as “a mixture of polymer-modified asphalt emulsion, well-graded crushed mineral aggregate, fillers, additives and water that is proportioned, mixed and uniformly spread atop a prepared pavement surface.”[3] A Micro Surfacing is similar to a Slurry Seal. However, it differs in the gradation—size distribution of aggregate—that is used, the proportions of aggregate, emulsion, water and fillers, and the type of asphalt emulsion. While Slurry Seal emulsions may or may not be modified with polymers, Micro Surfacing emulsions are always modified with polymers—usually latex. Thin Lift Asphalt Overlays are “fine-graded hot-mix asphalt mixtures that are mixed at the plant and paved to a thickness of less than 1.5 inches onto an existing surface.”[4] However, for this work, the maximum thin lift asphalt overlay thickness is 1 inch or less.

As can be seen, each of these treatments involve very different materials and construction methods. Thus, there will be a difference in how the quality and performance of each of these treatments is monitored. This leads to a difference in specifications between treatments. Further, the specifications laid out by one state or local transportation agency can have different available materials, use different construction methods and require different quality assurance specifications, compared to another, as each agency possesses differing climates, networks sizes and priorities. Despite the slight difference in methods, the overall construction process remains the same. Due to this small facet of consistency, there are construction practices within each agency’s specifications that are considered to be key to the overall success of a

preservation treatment. These practices have been named the “best practices.” This work discusses the best practices for the construction of these preservation treatments.

Project Background and Scope

This work derives its facts from extensive literature reviews, with the goal of collecting and summarizing current preservation treatment specification practices. The true purpose of the project is to present alternative preservation treatments to the Nevada Department of Transportation (NDOT). This project is intended to show NDOT some of the practices that other state agencies are following to construct high-quality treatments, ultimately leading to informed decisions when selecting the proper treatment for a given project.

The items to be determined from the study include current treatment use by a select group of agencies (identified as “lead” agencies during two separate surveys), current agency standard specifications for constructing the treatments, items that each agency considers when constructing a preservation treatment, any Quality Assurance specifications that the agency uses to monitor the quality of a treatment and any construction practices that each agency uses that could be deemed “best” practices. These are identified during phone interviews.

It is important to note that, during the course of the project, at the suggestion of members from an expert panel, the term “best practices” was changed to “state of the practice”. This is due to a concern that declaring the lead agencies’ practices as “the best” would inadvertently cause other agencies to begin using only these practices and if the practices are deemed ineffective to accommodate any agency’s unique challenges, any benefits that could be derived from using the practices would be negated. The ultimate intent of this project is not to “tell people what to do”, but

rather to inform agencies who are experiencing issues with preservation treatment performance about what other agencies—who are experiencing good preservation treatment performance—are doing during the Quality Assurance portions of preservation treatment projects. This is essentially detailing the current state of the practice for preservation treatments, whereas “best” practice indicates that these practices are state-of-the-art, which may not be the case. Hence the reason for the change in terminology. In this work, the term “best” practice will continue to be used, but the reader is informed to remember the term “state of the practice.”

Research Objective

The primary objective of this project is to identify best practices within current State Highway Agency (SHA) Quality Assurance specifications. The best practices can then be used to supplement other agencies’ specifications, particularly those whose use of some of the treatments may not have resulted in successful, long-lasting preservation treatments. As was mentioned earlier, this objective is achieved by identifying lead agencies that have successful experiences constructing these treatments, as was indicated by these agencies during the survey process. Agency experience will be confirmed through case study documentation.

Progress of Work

The tasks of the project were laid out in the Request for Proposal (RFP) submitted by the UNR research team to NDOT. These tasks include selecting members to sit on the expert panel, conducting a literature review of the current industry standards for each treatment, drafting the survey questions, interviewing state agencies and collecting information (specifications and project documents), and writing the final report and technical briefs.

Literature Review

An extensive literature review of several preservation treatment documents was conducted first. The documents include design standards and research efforts into treatment best practices. These documents are separate from this one in that the main goal of this document is to discuss current agency Quality Assurance specification best practices, whereas the others focus solely on design and construction practices, without necessarily discussing agency specifications.

Chip Seal

The International Slurry Surfacing Association (ISSA) publication A165—Recommended Performance Guidelines for Chip Seal design standard gives recommended design criteria for chip seals.[1] The material types and quality, application rates, equipment calibration, and construction practices are all included. The National Cooperative Highway Research Program's (NCHRP's) Synthesis 342—Chip Seal Best Practices surveyed several state highway agencies (SHAs) and agencies in Canada to determine current construction practices used.[5] It defines chip seal types, discusses materials, construction equipment and practices and Quality Control (QC) during construction.

The California Chip Seal Association (CCSA)'s Six Steps to a Better Chip Seal document summarizes six identified best practices for chip seal construction.[6] The six steps outlined include materials (particularly the aggregate), climate, surface preparation, traffic control, spread rates and construction techniques. The aggregate should be clean and dry. Hot, dry weather is best for proper curing. The road surface must be cleaned and repaired prior to application. Repairs include filling depressions, sealing cracks and repair other distresses. The document states that if a chip seal is

placed over any of these distresses, these distresses will propagate into the new treatment.

If using emulsions, traffic should be controlled such that the speed will be at or below 25 mph until sweeping has been completed. Spread rates are project-specific. Equipment that is calibrated and maintained, timing of construction and communication all aid in the construction of chip seals.

Slurry Seal

The ISSA A105—Recommended Performance Guideline for Emulsified Asphalt Slurry Seal design standard gives details regarding the proper design and construction of slurry seals.[2] It discusses aggregate requirements, including size and gradation, asphalt emulsion binder grades, mineral fillers, material quality testing, construction practices, equipment calibration and project payment.

The South African Bitumen Association's (Sabita's) Manual 28—Best Practices for the Design and Construction of Slurry Seals discusses best slurry seal construction practices, specific to the treatment's use in South Africa.[7] Many of the practices outlined can be implemented in similar U.S. climates. South Africa's recognised slurry seal types and application are defined. Best practices in this document include materials and mix design testing, climate, surface preparation, construction practices and Quality Assurance.

Micro Surfacing

The ISSA A143—Recommended Performance Guidelines for Polymer-Modified Micro Surfacing is the final ISSA design standard that was reviewed.[3] It

discusses the use and properties of polymer-modified emulsion, aggregate types and sizes, mineral fillers, climate conditions, equipment and construction practices.

The NCHRP Synthesis 411—Micro Surfacing, A Synthesis of Highway Practice is a survey-based research project that discusses micro surfacing construction practices, focussing on project selection, materials, equipment and contracting practices and Quality Assurance.[8] The main point of the study is to select the “right application for the right project at the right time.”[8]

Thin Lift Asphalt Overlay

The NCHRP Synthesis 464—Thin Asphalt Overlays is another survey-based research project that investigated the criteria used by many SHAs for using thin lift asphalt overlay treatments.[9] The main topics are the mix designs, distresses that the treatment can remedy, service life, and other factors.

The National Asphalt Pavement Association (NAPA) Information Series (IS) 135—Thin Asphalt Overlays for Pavement Preventive maintenance publication also discusses the process for selecting and designing thin lift asphalt overlays.[4] Project and materials selection, mix design, construction operations QC practices, and performance life are all discussed. Thin lift asphalt overlay mix designs that specify smaller maximum aggregate sizes and higher asphalt content than thicker-lift mixes will result in a well-performing overlay. This study found that thin lift asphalt overlays can address bleeding, ravelling, non-fatigue-related longitudinal cracking, and transverse cracking. Other functional distresses can be addressed, provided there is no loss in structural integrity. Any cracking will eventually become an issue in the thin lift asphalt overlay surface. For example, if rutting is a primary mode of distress, cores must show that the rutting is present only in the surface layer, as opposed to

full-depth rutting. The key finding of this study is that thin lift asphalt overlays were reported to be extending pavement service lives.

The National Center for Asphalt Technologies (NCAT) publication *Thin Hot Mix Asphalt (HMA) Overlays for Pavement Preventive Maintenance and Low Volume Asphalt Roads* is the final study that discusses the use of thin lift asphalt overlays, focussing primarily on the treatment's use on low-traffic-volume roads.[10] The study analyzed cost reductions using various treatments. Some details include various types of pavement preventive maintenance treatments. The study discusses both chip seals and thin lift asphalt overlays but focuses primarily on the design and application of thin lift asphalt overlays. The cost reduction analysis of thin lift asphalt overlays was examined by determining the effects of the use of warm mix asphalt (WMA) additives, recycled materials, and layer thickness reduction. The study's implications can apply to both low- and high-traffic-volume roads.

Lead Agency Selection

Using two separate agency surveys—Tier 1 and Tier 2, a set of agencies were selected as lead states for each of the preservation treatments. These agencies can be found in Table 1.1. The first survey was used to delineate between an agency's standard specifications preservation treatment sections and the agency's actual use of the treatment. For example, if an agency's standard specifications have a section for micro surfacing and slurry seal requirements, but the agency only uses slurry seal treatments for preservation activities, the Tier 1 survey will allow the agency to indicate as such.

Table 1.1 Lead Agency Selection

Treatment	Selected Agencies
Chip Seal	California Dept. of Transportation (Caltrans), Minnesota Dept. of Transportation (MnDOT), Spokane County Dept. of Transportation, Texas Dept. of Transportation (TxDOT)
Slurry Seal	Caltrans, City of Columbus Dept. of Transportation, Virginia Dept. of Transportation (VDOT)
Micro Surfacing	Caltrans, MnDOT, VDOT
Thin Lift Asphalt Overlay	Caltrans, Florida Dept. of Transportation (FDOT), Michigan Dept. of Transportation (MDOT), Ohio Dept. of Transportation (ODOT)

The Tier 1 survey asked the agencies which treatments are used for pavement preservation, how long the agencies have used those treatments, and how many lane-miles of the agencies' roadways per year are given preservation treatments. The results are used to then select the agencies that have the most experience placing each treatment to move forward with the Tier 2 survey.

The Tier 2 survey is more detailed and begins to consider the actual Quality Assurance specifications that each agency possesses. Key questions include discussing the presence or lack of Quality Assurance specifications, the intended use of each treatment, construction methods, primary distress modes, and areas of the specifications that could be improved upon. Another factor that was considered when selecting the lead agencies was the climate of the agency. It was desired to obtain lead

agencies from each of the four major climate zones: wet-freeze, wet-no freeze, dry-freeze and dry-no freeze. Wet or dry refers to the amount of annual precipitation and freeze or no-freeze refers to the average minimum air temperature in wintertime (above or below freezing).

As can be seen in Table 1.1, the agency selection includes four agencies for chip seals, three agencies for slurry seals and micro surfacing treatments, and four agencies for thin lift asphalt overlays. It is important to note that the California Department of Transportation (Caltrans) appears as a lead agency for all four treatments. This is due in part to the size of the state, the varying climates that can be encountered across the state, and overall experience that the agency possesses in using all four treatments. When one places these locations on a map, it is apparent that all of these agencies are in various parts of the country, thus achieving the goal of selecting at least one agency per climate zone.

Technical Brief Preparation

The final phase of the project included drafting the final project report, outlining all of the completed work and key findings from the study, as well as to draft the tech brief documents. The tech briefs are 10-15 pages in length and briefly summarize the specification details of the selected lead agencies, discusses key similarities and differences between the agencies and identifies the best construction Quality Assurance practices used by each agency. Each tech brief also presents case studies that showcase the practices used by the agencies in constructed projects.

It was intended to obtain case study documentation for two projects of each treatment type. This was achieved for all treatments, except for the micro surfacing, where documentation for only one case study could be obtained. The case study

documentation included inspection and mix design records, specifications and provisions and any other data that was used during the construction of successful, well-performing preservation treatments. For chip seals, case study documents were collected from Caltrans and Spokane County. The Caltrans documentation was obtained during a site visit that was conducted in July 2017. For slurry seals, case study documents were collected from the City of Columbus and VDOT. For micro surfacing, only VDOT was able to provide case study documentation. For thin lift asphalt overlays, case study documents were collected from FDOT and MDOT. Chapter 5 will present the findings from these studies.

Chapter 2 Current State Preservation Treatment Specifications

Introduction

This chapter will discuss the current standard specifications of all 50 states. This is a concise summary that will discuss the details regarding each state's preservation treatment use. It is important to note that this summary is only on the current published specifications and may not reflect each states' actual documented use of the treatments listed in the specifications. For example, a state agency's standard specifications may indicate requirements for chip seals and slurry seals. However, that agency may only actually use chip seals for all of that agency's maintenance projects and may very rarely—or never—use slurry seals for such activities. The actual use of each treatment by each agency was determined from the Tier 1 and 2 surveys. Each treatment indicated in the agencies' specifications is summarized in Figure 2.1.

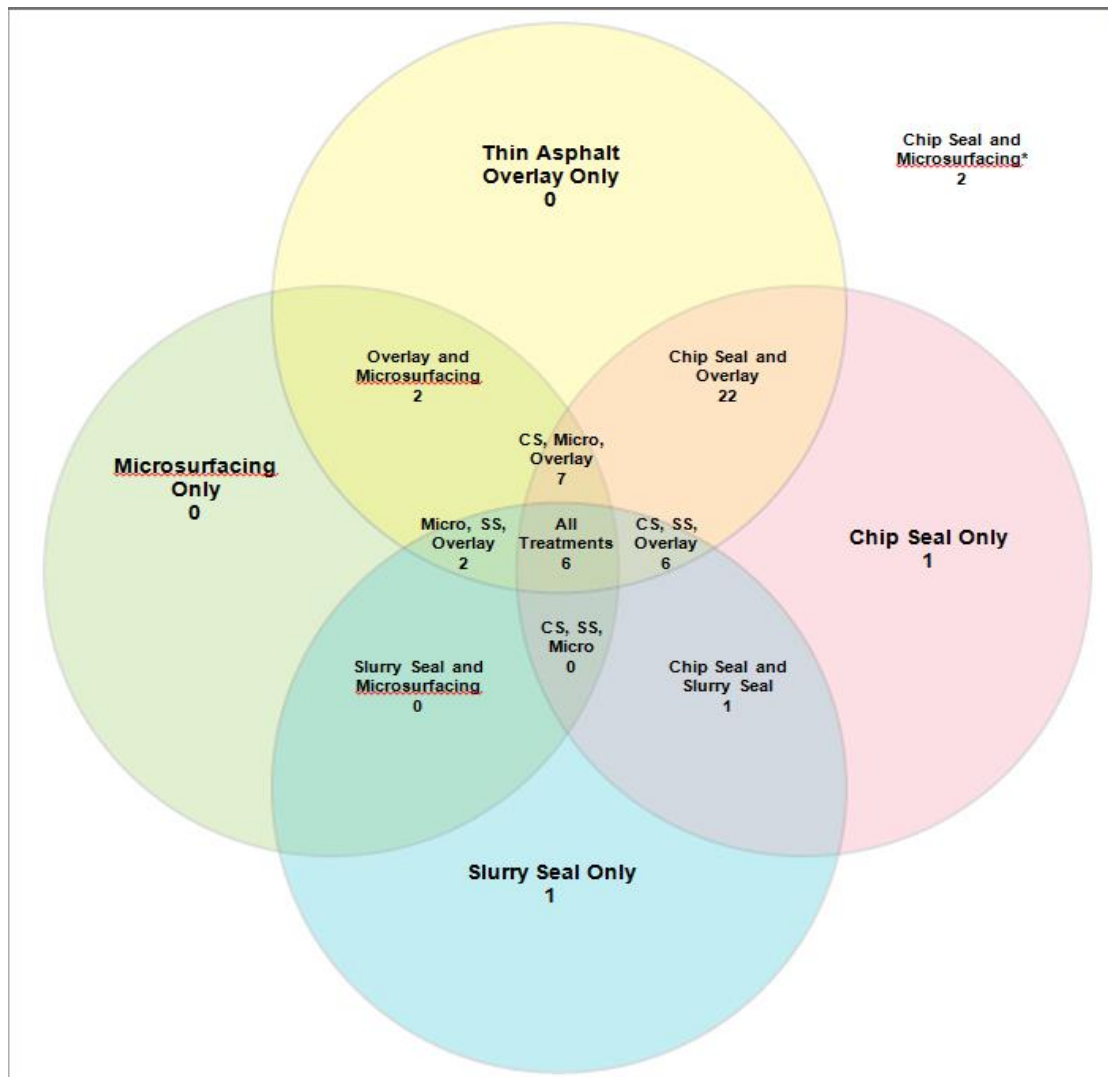


Figure 2.1 Venn Diagram. Figure depicting the number of states that have specifications for each treatment.

Figure 2.1 further illustrates that few agencies have specification requirements for only one treatment type. The most commonly specified treatments were chip seals and thin lift asphalt overlays. Only two states—South Dakota and Wyoming—have specification requirements for the unique combination of chip seals and microsurfacing. Six agencies have specifications for all preservation treatments. A concise summary of findings from the specifications review follows. Note that the overlaps show in Figure 2.1 are reflected in the tables, as those agencies with multiple

treatment specifications are listed in all of the applicable tables. Table 2.1 shows the summary of agency specifications for chip seals.

Table 2.1. Summary of Chip Seal Specifications

Agency	Publication Date	Specifications for				
		Material Selection	Mix Design	Construction Details ^a	Sampling & Testing ^b	QA Specifications ^c
California	2015 (Draft)	√		√	√	
Kansas	2007	√		√		√
Michigan	2012	√		√	√	√
New York	2014	√		√	√	
North Carolina ^d	2015	√		√		
North Dakota	2007	√		√		
Ohio	2013	√		√		√
South Carolina	2008	√		√	√	√
Utah	2010	√		√		
Virginia	2007	√		√	√	
Wyoming	2010	√		√	√	√

aIncludes traffic control, surface preparation, weather requirements, equipment, etc.

b Includes testing requirements, sampling and testing frequency, etc.

c Includes quality control plan, quality acceptance requirements, etc.

d Twelve months warranty period.

As can be seen, none of the agencies' specifications currently indicate using a mix design for chip seals. However, all of the agencies' specifications currently have provisions for both materials selection and construction details. Only seven states have Quality Assurance (QA) provisions. Table 2.2 summarizes the current specifications for slurry seal.

Table 2.2. Summary of Slurry Seal Specifications.

Agency	Publication Date	Specifications for				
		Material Selection	Mix Design	Construction Details ^a	Sampling & Testing ^b	QA Specifications ^c
Alabama	2012	√		√		
Alaska	2009	√		√	√	
California	2015 (Draft)	√	√	√		
Hawaii	2005	√	√	√	√	
Colorado	2009	√	√	√	√	√
Ohio	2013			√	√	√
Michigan	2012	√	√	√	√	
North Dakota	2014	√	√	√	√	
Utah	2010	√	√	√		
Georgia	2013	√	√	√		
Maryland	2008	√		√	√	
Montana	2005	√	√	√		√
Tennessee	2015	√	√	√	√	√

^a Includes traffic control, surface preparation, weather requirements, equipment, etc.

^b Includes testing requirements, sampling and testing frequency, etc.

^c Includes quality control plan, quality acceptance requirements, etc

Here, all of the agencies have specification provisions for the Slurry Seal construction details, and all but one agency have specification provisions for materials selection. Only four states' standard specifications have QA provisions. Table 2.3 is the summary of micro surfacing agency specifications.

Table 2.3. Summary of Micro Surfacing Specifications.

Agency	Publication Date	Specifications for				
		Material Selection	Mix Design	Construction Details ^a	Sampling & Testing ^b	QA Specifications ^c
California	2015 (Draft)	√	√	√		√
Colorado	2009	√	√	√	√	
Georgia	2013	√	√	√	√	√
Indiana ^d	2014	√	√	√		
Kansas	2007	√	√	√	√	
Michigan	2012	√	√	√	√	√
Minnesota	2015	√	√	√		√
Missouri	2014	√	√	√		
Montana	2006	√	√	√	√	√
Nebraska	2007	√	√	√	√	
Nevada	2010	√	√	√		
North Dakota	2014	√	√	√	√	
Ohio	2013	√	√	√	√	
South Carolina	2007	√	√	√	√	
Texas	2004	√	√	√		
Utah	2010	√	√	√	√	√
Virginia	2007	√	√	√	√	√
Wyoming	2010			√	√	√

^a Includes traffic control, surface preparation, weather requirements, equipment, etc.

^b Includes testing requirements, sampling and testing frequency, etc.

^c Includes quality control plan, quality acceptance requirements, etc.

^d Warranted micro surfacing specification

Here, all but one of the agencies have provisions for both materials selection and mix design. Again, all agency specifications have provisions for construction detail. Eight agencies have QA provisions in each states' respective standard specifications. Table 2.4 shows the summary of the specifications for thin lift asphalt overlays.

Table 2.4. Summary of Thin Lift Asphalt Overlay Specifications

Agency	Publication Date	Specifications for				
		Material Selection	Mix Design	Construction Details ^a	Sampling & Testing ^b	QA Specifications ^c
California	2015 (Draft)	√	√	√	√	√
Colorado	2009	√	√	√	√	
Georgia	2013	√	√	√	√	√
Indiana	2014	√	√	√		
Kansas	2007	√	√	√	√	
Kentucky	2012	√	√	√	√	√
Minnesota	2015	√	√	√		√
Montana	2006	√	√	√	√	√
Nebraska	2007	√	√	√	√	
Nevada	2010	√	√	√		
North Dakota	2014	√	√	√	√	
Ohio	2013	√	√	√	√	
South Carolina	2007	√	√	√	√	
Texas	2004	√	√	√		
Utah	2010	√	√	√	√	√
Virginia	2007	√		√	√	√
Washington	2010		√	√	√	√

^a Includes traffic control, surface preparation, weather requirements, equipment, etc.

^b Includes testing requirements, sampling and testing frequency, etc.

^c Includes quality control plan, quality acceptance requirements, etc.

Here, all agencies have specifications for construction and mix design, and all but one agency has specifications for materials selection and sampling and testing.

Eight agencies have QA specifications. This may be due to the extensive use of hot-mix asphalt by all of the above agencies and the long-time experience that is obtained.

Chapter 3 Lead Agency Preservation Treatment Specifications

Introduction

This chapter details the identified lead agencies' current standard specifications and special provisions for construction and QA practices of all four pavement preservation treatments. This chapter is separated by treatment. Within each treatment, materials and mix design practices are discussed first, followed by equipment requirements, climatic conditions, surface preparation practices, construction inspection, adjustments, opening to traffic and monitoring, and QA.

Chip Seal

The chip seal specifications for Caltrans, MnDOT, Spokane County and TxDOT are outlined in this section. The reference materials are Caltrans' 2015 Standard Specifications and 2015 Revised Standard Specifications, MnDOT's Standard Specifications for Construction, Schedule of Materials Control for 2016 Standard Specifications, Seal Coat Handbook, the Washington Department of Transportation's Standard Specifications for Road, Bridge, and Municipal Construction (2016), and TxDOT's Standard Specifications for Construction and Maintenance for Highways, Streets and Bridges and Seal Coat and Surface Treatment Manual. [11,12,13,14,15,16,17]

MnDOT and TxDOT refer to chip seals as "seal coats." Thus, all treatments that fit the chip seal definition that was outlined in Chapter 1 is considered a chip seal and will henceforth be referred to as such.[4] The lead agencies have the following alternative definitions:

- Caltrans: definition is bituminous material-specific “...includes applying an asphaltic emulsion—polymer-modified or not—followed by aggregate and then a flush coat.” For asphalt rubber binder chip seals, defined as “applying asphalt rubber binder followed by heated aggregate pre-coated with asphalt binder followed by flush coat.”
- MnDOT: “An application of applying bituminous material, a single layer of aggregate and a fog seal on a prepared surface.”
- Spokane County: “This method requires the placing of one application of emulsified asphalt and one or more sizes of aggregate as specified to an existing pavement to seal and rejuvenate the surface and to produce a uniform Roadway surface with acceptable non-skid characteristics.”
- TxDOT: “A surface treatment consisting of one or more applications of asphalt material covered with a single layer of aggregate.”

Materials

Caltrans allows several bituminous materials to be used. Emulsions—both unmodified and polymer-modified, and asphalt binders—again, both unmodified and polymer modified may be used. Polymer-modified emulsion grades are PMRS-2, PMRS-2h, PMCRS-2, and PMCRS-2h. Asphalt binders are PG grade binders that are either modified with asphalt rubber or unmodified. The asphalt rubber binder is modified with Crumb-Rubber Modifier (CRM).

MnDOT uses only polymer-modified CRS-2P emulsion. All emulsion sampling and testing is done per the requirements of a multi-DOT collaborative known as the “Combined State Binder Group.” The emulsion supplier oversees the QC tests on the emulsion. Random sampling is conducted and arranged by the

MnDOT Chemical Laboratory for Acceptance testing. Spokane County also uses only CRS-2P emulsion for chip seals.

TxDOT uses paving grade asphalts, emulsions and cutbacks for chip seals. The TxDOT Manual identifies AC-5, AC-10, AC-5 with 2% polymer, AC-15P, AC-15-5TR and Asphalt Rubber (AR) types AR-II and AR-III. Emulsions include HFRS-2, MS-2, CRS-2, CRS-2h, HFRS-2P and CRS-2P. The following emulsions and cutbacks can be used for cool weather conditions: RS-1P, CRS-1P, RC-250, RC-800, RC-3000, MC-250, MC-800, MC-3000 and MC-2400L. Currently, TxDOT is the only lead agency that has specification details for using cutbacks in chip seal treatments. This may be due to the environmental concerns that arise from using cutbacks. It is not clear whether these specifications will be altered. Binder tests to be conducted depend on the binder type.

There are two ways in which aggregates that can be used for chip seals. The aggregate cover can be either graded (i.e., contains aggregate from multiple sieve sizes) or single-size (i.e., contains aggregate from one or two sieve sizes). Caltrans uses broken stone, crushed gravel or a blend of the two for aggregates. The gradation varies based on the chip seal type. For both non-polymer and polymer-modified asphalt emulsion chip seals, the aggregate is graded only, with coarse, medium, medium-fine and fine gradations. The Maximum Aggregate Sizes (MAS) for each gradation are $\frac{3}{4}$ inch, $\frac{1}{2}$ inch, $\frac{3}{8}$ inch and $\frac{3}{8}$ -inch, respectively. For asphalt binder chip seals, the aggregate is graded, with either a coarse, medium or fine gradation. All three gradations have a $\frac{3}{4}$ inch MAS.

Caltrans mandates the use of pre-coated aggregate for asphalt rubber binder chip seals. Caltrans requires that the pre-coating operation be done at a plant that is

certified under the Material Plant Quality Plan (MPQP).[18] The aggregate must be pre-heated to 260-325°F and mixed with 0.5-1% PG-grade binder. This material must be used immediately.

MnDOT uses Class-A—crushed quarry source, Class-B—Other or Class-C—Crushed Gravel aggregates. These aggregates are to be fine (passes the ½ inch sieve) and graded. The five gradations to be used are FA-1, 2, 2½, 3 and 3½. The MAS is ¼ inch sieve for FA-1 and FA-2. The MAS is 3/8 inch sieve for FA-2½ and FA-3. The MAS is ½ inch sieve for FA-3½.

Spokane County uses only single-sized basalt with sizes of 5/8 inch by No. 4, 1/2 inch by No. 4, and 3/8 inch by No. 4. If using choke stone, the size is No.4. Per an interview, it was indicated that typically 3/8 inch aggregate is used on arterials and ¼ inch by No. 10 aggregates are used on lower volume roads.[19] Also, there have been some projects that used 3/8 inch aggregate in the actual lanes and 1/4 inch by No. 10 on shoulders when high bicycle traffic is expected. These gradation bands are narrow. Spokane County does not allow pre-coated aggregate. Spokane County owns the basalt quarries used for chip seal aggregate sources.[19] The aggregate gradation is checked prior to production.

TxDOT uses Type B Surface Aggregate Classification for chip seals. This classification includes crushed gravel, slag or stone, or a pre-coated limestone aggregate called Limestone Rock Asphalt (LRA). Type A aggregates may also be used, depending on the traffic levels of the project. The aggregate types included in this classification are gravel, crushed slag or stone, or LRA. The aggregate may be graded, or single-size and the gradations are 1, 2, 3S, 3, 4S, 4, 5S and 5, where the S denotes a single-size gradation. The MAS is 7/8 inch for Grade 1 and Grade 2, ¾ inch

for Grades 3 and 3S, 5/8 inch for Grade 4 and 4S, and 1/2 inch for Grade 5 and 5S, respectively. In practice, Grade 4 is the most commonly used, with some use of Grades 3 and 5. TxDOT also allows for pre-coated aggregate, provided no lightweight aggregates are used. The aggregate must be uniformly coated with an asphalt material and must meet the quality requirements.

Caltrans does not use other additives aside from those that are added to the emulsion or asphalt binder (polymer or CRM). MnDOT uses clean water as an additive. Spokane County also does not use additives. TxDOT's standard specifications do not state the use of additives. An anti-strip additive may be used when using pre-coated aggregate to prevent moisture damage in the finished product.

Mix Design and Verification

Caltrans is the only agency that does not have a mix design method. MnDOT uses a modified McLeod Method, which is detailed in the MnDOT Seal Coat Handbook. The modification allows for more asphalt emulsion to be used in the non-wheel path areas to prevent snowplow damage. The mix design method considers the traffic volume and surface conditions of the project. The traffic volume controls the amount of residue needed to achieve a chip embedment of 70%. If there is a higher traffic volume, then less residue is needed, as traffic will ensure that the 70% embedment criteria is met, while also mitigating the occurrence of bleeding or flushing. The surface conditions of the existing pavement also control the amount of emulsion. A flushed, bleeding surface requires much less emulsion than a dry or oxidised surface. Finally, the application rate of the emulsion depends on the consensus properties of the aggregate, i.e., gradation, shape and absorption. More porous aggregate will require more emulsion than one with fewer surface voids. The

Contractor must submit the aggregate gradation and quality test results from the durability test—among others, design application rates for emulsion and aggregate and a 150-lb sample of aggregate from each quarry source.

Spokane County uses the McLeod mix design method as a basis for determining application rates.[19] TxDOT's Seal Coat and Surface Treatment Manual shows that the Modified Kearby Design Method is the primary method.[17] TxDOT also uses the Modified McLeod Method, although its use is less common in Texas. The Modified Kearby Method relies more heavily on the volumetric properties of the aggregate to determine the target binder application rate. As with the McLeod method, the Modified Kearby method also relies on the conditions of the existing pavement.

Caltrans uses the results of the Vialit test for mix verification. The Vialit test is a measure of the chip retention as a function of asphalt content. The binder must be at the field application temperatures and rate when conducting the test. This test is to be conducted by an authorized laboratory. MnDOT uses the Schedule of Materials Control for 2016 Standard Specifications to verify the mix design.[13] MnDOT verifies the Contractor's mix design by testing a complete design that is to be submitted to the Engineer two weeks prior to the start of work. Spokane County does not currently have mix verification practices.

TxDOT tests the aggregate and binder material separately to verify the mix design. Aggregate tests include Deleterious Material, Decantation, Flakiness Index, Gradation, L.A. Abrasion, MgSO₄ Soundness, Micro-Deval Abrasion, Aggregate Angularity, Dry Loose Unit Weight, Pressure Slaking, Freeze-Thaw Loss, and 24-hour Water Absorption tests. Stockpiles are sampled and tested for Dry Loose Unit

Weight, Bulk Specific Gravity, and aggregate spread rate via the “Board Test.” The binder is tested based on the type of binder being used. For Asphalt Cements, the tests are Aged Viscosity, Penetration, and Virgin Viscosity. For Cutback Asphalts, the tests are Viscosity, Flash Point, Distillation, Specific Gravity (for in-field temperature-volume corrections), and Penetration/Ductility. For Emulsions, the tests are Viscosity, the Sieve Test, Demulsibility, Distillation, Penetration, Ductility, and the Float Test.

Equipment, Calibration and Construction Requirements

This section details the required pieces of equipment, any calibration procedures that need to be conducted prior to using the equipment, and construction requirements. Construction requirements include construction inspection and test strip construction.

Equipment and Calibration

All of the agencies indicated that binder distributors, haul trucks, aggregate spreader, pneumatic-tire rollers, and brooms be used in the construction of chip seal treatments. Calibration procedures varied among the agencies, with most of the agencies not including calibration in the specifications. Caltrans does not have required calibration procedures. The Contractor may be required to follow the equipment manufacturers’ recommended calibration procedures. One practice that has been observed is that Caltrans covers the distributor’s nozzles with an emissions capture device when constructing asphalt rubber binder chip seals. This is a good initiative to mitigate the project’s air pollution.

As with Caltrans, MnDOT does not have required calibration procedures. In MnDOT’s Seal Coat Handbook, equipment calibration was mentioned and is recommended for the spreader and distributor.[14] Calibration should be done early in

the project, well before construction but can be done as late as one day prior to the start of work under certain extenuating circumstances. Spokane County conducts calibration, as the agency owns its construction equipment. The actual calibration process is not available at this time. TxDOT requires equipment calibration prior to construction. The actual calibration procedures are not written in the TxDOT specifications.

Temperature and Seasonal Limits

Temperature limits refer to minimum air and pavement surface temperatures for chip seal construction. If the temperature is too cold, the bituminous material will set up before the chips can be applied and rolled, thus causing chip loss and rendering the treatment ineffective. Seasonal limits refer to calendar dates, between which, chip seals can be constructed. These limits increase the likelihood that the proper air and surface temperatures will be met on any given construction date. Some discretion may be allowed for unseasonably warm or cool temperatures.

Caltrans' allowable temperatures are based upon whether emulsion or hot asphalt binder is used. For unmodified emulsions, the ambient temperature must be 65-110°F and surface temperature must be at least 80°F. For modified emulsions, the ambient temperature must be 60-105°F and surface temperature must be a minimum of 80°F. For both emulsion types, if the air temperature is forecasted to drop below 39°F within the next 24 hours, construction is to be postponed. For asphalt rubber binders, the air temperature must be 60-105°F and the surface temperature must be a minimum of 55°F. If the pavement is damp, or there are excessive windy conditions, construction may be postponed. It is important to note that Caltrans is the only agency to mandate a maximum temperature. Excessively high temperatures prolong curing

and can cause bleeding and other related distresses to become an issue after construction. Caltrans does not specify any seasonal limitations.

MnDOT has seasonal limits for chip seal construction, which depend on the project's location. If the project is in the North or North Central Zone, the construction season is from May 15 to August 10. Any location south of these zones has a construction season from May 15 to August 31. The air and surface temperatures must be 60°F and rising. MnDOT does not allow for night time construction of chip seals. If there is foggy weather or if the forecast indicates impending precipitation, construction must be postponed.

Spokane County's seasonal limits are from May 1 to August 31. The surface temperature must be at least 55°F but must not exceed 130°F. The air temperature 60°F and rising, but not less than 70°F when falling and the wind must be less than 10 mph. Spokane County also does not allow for night time construction.

As with Caltrans, TxDOT bases minimum temperatures on the binder type. For all chip seals, the air temperature must be at least 50°F and rising. The chip seal is not to be constructed if the air temperature is 60°F and falling or if the surface temperature is below 60°F. For polymer-modified asphalt, the air temperature must be at least 70°F but not 80°F and falling. The surface temperature must not be below 70°F. For asphalt-rubber binders, the air temperature must be at least 70°F and rising or above 80°F. Again, the surface temperature must not be below 70°F. TxDOT does not specify seasonal limitations in the standard specifications. However, the Seal Coat Manual mentions that the best season is one with "low wind and higher temperatures," which usually occurs from June to September.[17] The TxDOT

specification indicates that night-time paving operations are permitted. The allowable temperature ranges for application vary by the type of binder.

Surface Preparation

Surface preparation in general requires thoroughly cleaning the surface of loose and deleterious materials and covering exposed roadway structures. This preparation is to be conducted as close to the construction date as is practical or conducted immediately prior to construction. Some of the lead agencies have additional preparation practices. In addition to the general surface preparation practices outlined above, Caltrans also requires that the surface is to be cleaned just before constructing the treatment. MnDOT recommends using a tack coat, which would be applied after cleaning the surface and prior to construction.

Spokane County conducts surface repairs according to the applicable section of the Washington DOT specifications. Repaired areas are to be fog sealed prior to construction. HMA-repaired areas may require a second fog seal depending on the surface texture of the repair. The pavement surface must be dry prior to fog sealing. Spokane County crack-seals cracked pavements with rubberized crack sealer one year before the anticipated construction date.[19] This practice ensures that the crack sealing material will not swell under the newly constructed treatment.

TxDOT's surface preparation practices include the standard surface preparation process, as well as removing all existing pavement markers—repairing any damage incurred during this operation as directed, and applying a tack coat, if directed. If crack sealing is required, the tack coats are to be applied before applying rubberized asphalt.

Construction Inspection Process

Construction inspection includes monitoring certain aspects of the construction process that are major factors affecting the success or failure of the treatment. This is the job of either an agency inspector or an independent inspector. Caltrans requires that the application rates is the primary area to be inspected. The binder temperature is also to be monitored. Application temperatures vary by binder type. Asphalt rubber binder has an application temperature range of 375-415°F. Once the asphalt rubber binder has been applied, the aggregate cover must follow within 2 minutes of the binder's application. The aggregate must be spread at a rate that is within 10% of the target application rate. The cover must be uniform, encompassing the full width of one lane in one operation. Any excess aggregate must be swept from joints before beginning construction on the adjacent lane. For asphalt rubber binder chip seals that use pre-coated aggregates, the aggregates must be heated to a temperature of 225-325°F. Longitudinal joint overlap must not exceed four inches, unless such overlap is authorized.

Rolling begins prior to sweeping. The rollers must be operated at such a speed as to prevent the aggregate from rolling over onto its flattest side. When this occurs, the aggregate will be susceptible to fracturing. The Contractor performs initial rolling with one coverage of a pneumatic-tire roller and final rolling with two coverages. For asphalt rubber binder chip seals, initial rolling is performed with pneumatic-tire rollers, within 90 seconds of spreading aggregate. An 8- to 10-ton steel-wheel roller for final rolling may be used, if authorized. Once rolling is completed, sweeping must commence.

After sweeping, a flush coat—or sand seal—may be applied. This treatment consists of a cover application of emulsion followed by a cover coat of sandy fine aggregates. The time when sweeping is to begin depends on the roadway type: two-lane rural or multi-lane urban highways. Sweeping takes place after two to four hours of opening the treatment to pilot car-controlled traffic on two-lane, two-way roads, and two to four hours after aggregate placement for multi-lane roads. Final sweeping is to be done immediately before opening lane to free-flowing traffic.

MnDOT's inspection practices include requiring the Contractor to verify the target application rates. The initial targets come from the mix design and must be checked using a 200-foot test strip. The rates may be influenced by the surface characteristics of the pavement. The Seal Coat Handbook recommends that a Field Inspector inspect the wheel path areas for proper aggregate embedment during the test strip placement.[14] Adjustments can be made to the application rates if the embedment is inadequate. The Contractor must construct another 200-foot test strip, to verify that the revised rates will achieve the proper embedment. Once the test strip has been constructed and the application rates deemed adequate (or have been adjusted), construction can begin. The asphalt emulsion must be applied uniformly and at a constant temperature of 140°F. Within one minute of applying the emulsion, the aggregate is to be dampened and spread, at a rate maintained within ± 1 lb/yd² of the target rate.

Initial rolling must be done within two minutes of spreading the aggregate. The operating speed must be five mph or less. Rolling must be completed in three full-width passes. The finished surface is swept using motorized brooms. Excess aggregate must be removed and disposed of at the Engineer's direction. A fog seal is

recommended to be applied after construction, consisting of a CSS-1h or CFS-1h emulsion. If CSS-1h is used, the emulsion is to be diluted in a 1:1 ratio. If using CFS-1h, the emulsion must meet the requirements of AASHTO M208—Standard Specification for Cationic Emulsified Asphalt and must contain 29% asphalt residue or higher.[20] The emulsion is to be heated to 100°F at a target application rate between 0.05-0.10 gal/yd². As 100% inspection does not occur, the quantity yield is checked once per day by the Contractor and verified once per day by a MnDOT representative.[21]

Spokane County performs its own chip seal construction work. Prior to construction, a 1,000-foot test strip is constructed. Each time a section new section begins, Washington DOT's specifications state that another test strip is to be constructed. It is not clear if this is a practice that is followed by Spokane County. The emulsion is heated to 125-195°F and all aggregate stockpiles are dampened to provide aggregates that are uniformly damp at the time of placement.

The aggregate must be spread in one operation to allow an eight-inch strip of emulsion to be exposed along the longitudinal joint. This forms a lap for the succeeding applications of emulsion. Aggregate may be added with the spreader or by hand to areas that are not completely covered. The individual responsible for determining this is not stated, but it is implied that the Engineer determines the addition of aggregates.

Three pneumatic tire rollers will complete at least two coverages. The maximum roller speed eight miles per hour. If using choke stone, it is to be applied immediately after initial rolling, unless otherwise specified, followed again by one full-width pass. Haul trucks must not damage freshly applied chip seal treatment. The

completed surface must be allowed to cure and then swept as soon as practical. If the sweeping causes the aggregate to be turned or if the Engineer determines that additional curing time is needed, the treatment will be swept when directed. Dust control during sweeping operations must be used when safety or environmental concerns arise.

TxDOT begins the construction inspection process with calculations of material quantities via rock land and shot. The “rock land” is the area of the pavement surface that is covered by one truckload of aggregate and “shot” is the area of roadway covered by one distributor load of binder) lengths must be calculated. The shot length must be an even multiple of rock land. The maximum shot width is that of the current transverse distribution of the emulsion distributor, or the aggregate spreader box, whichever is least. The shot width may be adjusted to prevent traffic encroachment. The binder application temperature is selected, depending on type of binder and maintain that temperature to within $\pm 15^{\circ}\text{F}$ but not above the maximum allowed.

The binder application rate is checked to ensure that it is uniform. The distributor nozzles must fully flair while applying the binder material. If the binder begins to show streaking, ridging, puddling or if it is flowing off the road surface, application must stop. The equipment, binder temperature and material properties must all be verified and altered if needed. If the non-uniformity is due to the emulsion’s viscosity, it must be replaced with an alternative binder material that corrects the issue. Test strips may be required at any time at the Contractor’s expense if non-uniformity continues after corrective action has been taken. Test strips may also be constructed if the binder application rate varies by more than 0.03 gal/yd^2

from the target on three or more consecutive shot lengths or if the application rate on any one shot differs from the target by more than 0.05 gal/yd². Test strips will be reconstructed until it is proven that the non-uniformity issue is corrected. Non-uniformity in the aggregate application follows a similar process, with the exception that test strips are not necessarily required to check that corrective actions are appropriate. This may indicate that TxDOT considers the binder application to be more critical to the success of a chip seal treatment.

Aggregates are also applied uniformly at the directed rate. Aggregate roll-over should not occur. The aggregate rate should be within ± 1 lb/yd² of the target rate in the transverse direction. Any uncovered areas are to be patched prior to rolling using an approved method. Rolling begins as soon as aggregates are applied, using sufficient rollers in staggered pattern to cover the entire mat width in one pass. Five passes are to be completed. This number is reduced to three if using emulsion. Stop the treatment application if the rollers are unable to keep up with the aggregate spreader, allow the rollers to catch up and resume application. Apply racked-in aggregates after patching after rolling and before opening to traffic.

Application Adjustments

Application adjustments occur in the event of uniformity issues, or if there are issues with any of the materials. Some of the agencies require test strips to be constructed after each adjustment, whereas others do not. Caltrans allows for reducing the asphalt rubber binder application rate in the wheel path by 0.050 gal/yd². This may aid in reducing the potential for flushing/bleeding. MnDOT allows for adjustments to be made to the materials application rates, both before and during construction. The first adjustments are made during the test strip phase, to determine the appropriate

rates based upon current pavement conditions. If additional adjustments are made during construction, another test strip is to be constructed to ensure that the alterations do not introduce any uniformity issues. During the first day of construction, the equipment application rates should be checked and adjusted “frequently”. “Frequently” is not defined in this sense, and it is not clear in the MnDOT specifications if these adjustments require an additional test strip.

Spokane County only adjusts the mix prior to the construction of a new section. The actual adjustments are not readily available. TxDOT requires mix adjustments in order to correct non-uniform application or if current conditions necessitate adjusting the application rates. Any adjustments require a test strip to be constructed to verify that the adjustments achieve an adequate treatment application.

Opening to Traffic

Caltrans opens the new treatment to traffic depending on the type of roadway being treated. On two-lane two-way roads, traffic must be controlled with a pilot car for two to four hours after the aggregate application before opening to un-controlled traffic. For multi-lane highways, traffic is controlled with pilot cars. Only one lane can be open in the direction of travel. Traffic can be un-controlled two hours after the sweeping operation. MnDOT recommends applying a CSS-1h emulsion fog seal one day after construction. Once the fog seal emulsion has set, a final sweep is conducted and then the roadway is opened to un-controlled traffic. Spokane County does not allow traffic pre-prepared surface after the first application of emulsified asphalt and aggregate has been completed. Wait durations are not available.

TxDOT’s Seal Coat Manual states that opening to traffic depends on the traffic volume, design speed and binder type.[17] Asphalt cements harden earlier,

allowing for quicker curing. In the summer, emulsions also cure earlier than when it is placed in cool areas or in areas with 50% relative humidity or higher. Roads with lower traffic volumes and speeds can be opened earlier than higher-volume, higher-speed roads. Beneficial aggregate orientation can be obtained when the treatment is allowed to be opened to pilot-controlled traffic. The Manual allows for the treatment to be placed if there is impending precipitation. However, in the event of precipitation traffic is not to be permitted on the new treatment until it ceases and the treatment cures fully.

Treatment Monitoring

Caltrans requires the Contractor to monitor the treatment for, and correct, any distresses until final acceptance for four consecutive days after applying the aggregate. The Contractor must perform a final sweep the morning after application on lanes opened to un-controlled traffic. The Contractor must sweep and keep the surface free of loose aggregate and prevent corrugations.

MnDOT imposes the responsibility for vehicle damage on the Contractor post-construction until complete sweeping has occurred, all loose aggregates are removed and permanent markings are placed. If MnDOT is going to place the permanent markings, then these activities do not need to be undertaken and the Contractor is relieved of responsibility after fog sealing.

As with Caltrans and MnDOT, Spokane County monitors and repair any damages incurred until final acceptance. TxDOT requires Contractor to maintain the treatment until final acceptance repairing any damages incurred until final acceptance, a practice that is undertaken by the former three agencies.

Quality Assurance Specifications

Quality Control

Quality Control (QC) refers to the testing and control activities that the Contractor must carry out to ensure the quality of the individual materials and the final product. Caltrans has submittal requirements that include submitting material samples and QC test results prior to starting the project. Submittal requirements include submitting the following prior to construction: asphalt binder samples and test results (submitted 15 days before starting work); a 50-lb sample of uncoated aggregate and the test results for Gradation, L.A. Abrasion, Percent Crushed Particles, Flat and Elongated Particles, Film-stripping (if using pre-coated aggregate), Cleanness Value and Durability; Vialit test results (tested per Caltrans' Method of Test for Vialit Test for Aggregate Retention in Chip Seals "French Chip"), which shows the percent of chip retention as a function of the binder content.[22] All test results are to be submitted within 24-48 hours of the test's completion

QC requirements for the binder depends on binder type. Tests for emulsions include Saybolt-Furol Viscosity, Sieve Test, 24-hour Storage Stability, Residue by Distillation, Particle Charge, Penetration at 25°C and at 4°C, Ductility, Solubility, Torsional Recovery and Ring and Ball Softening Point (last two are for polymer-modified emulsion). These tests are conducted on samples taken from the distributor. If using emulsion, the emulsion spread rate is tested once per day per distributor.

If asphalt rubber binder is used, QC tests include Descending Viscosity (readings taken starting 45 minutes after rubber addition, taken every 30 minutes until 2 consecutive readings are the same. This is tested once per lot from the reaction vessel), Viscosity at 375°F (readings taken 15 minutes before use per lot from the

distribution truck), Cone Penetration and Resilience at 25°C and Softening Point (all taken once per lot from the distribution truck and tested in the laboratory). Each sample taken represents five lots or 1 day's production, whichever is greater. The samples are given to Caltrans for Acceptance testing.

Seven days before construction, the Contractor must submit a detailed list of existing defective areas in the pavement, identifying the location and type of defect. Defects include rutting in excess of 3/8 inch and flushing. Caltrans' final acceptance does not apply to defective areas of the existing surface.

MnDOT's QC specifications require the Contractor must conduct sampling and testing per the MnDOT Schedule for Materials Control (SMC). Test results are to be submitted within 24 hours of the test's completion. The Contractor is responsible for QC testing on all materials except for the emulsion, which is the responsibility of the emulsion supplier. The first load of emulsion is sampled and tested. Thereafter, sampling is reduced to once per 50,000 gallons. The QC tests to be conducted are not available in the specifications or the SMC. Gradation is conducted on samples taken from the aggregate stockpiles once per day or once per 1,500 tons of aggregate and once per day from the chip spreader hopper.

Spokane County has informal QC criteria for chip seals.[19] The foreman is responsible for production quality, equipment calibrations and chip seal workmanship. Actual testing that is conducted is not available.

TxDOT requires that the Contractor test materials to be used in the project, submit the equipment calibration records, have a process for constructing temporary storage placement and its removal, submit blend designs for asphalt rubber binder, if

using, adjust application rates using test strips for non-uniformity, and maintain the new treatment until acceptance.

Acceptance

Caltrans' Acceptance for the final chip seal is based on visual inspection of the finished surface, ensuring that the chip seal has a uniform surface texture and does not have ravelling with an area greater than 0.5 ft². Flushing or bleeding or streaking must also not be present with an area greater than 0.5 ft². Other Acceptance items includes accepting the asphalt and aggregate material based on the sampling and testing performed by Caltrans for compliance to the specification quality characteristic as described in Caltrans' QC section.

As a part of MnDOT's Acceptance process, the agency evaluates aggregate during the aggregate producer's production testing. MnDOT samples aggregate from the aggregate stockpile prior to the project's start and conducts testing on a 30 lb sample taken from the spreader hopper during construction. MnDOT samples and tests aggregate according to the SMC. Once the project is complete, MnDOT pays for emulsion by the gallon and aggregate by the square yard. MnDOT does not allow for materials or workmanship warranties because the materials are already accepted by certification prior to the chip seal's construction.

Spokane County accepts emulsion on Certificates of Compliance. Aggregates are accepted based on Gradation, tested annually during crushing operations or from a sample from material supplier. TxDOT's Acceptance includes reviewing the Contractor's calibration data prior to construction, verifying application rates during construction and final acceptance.

Slurry Seal

The slurry seal specifications for Caltrans, City of Columbus, and VDOT are outlined in this section. The information obtained for each of the agencies was found in Caltrans' 2015 Standard Specifications and 2015 Revised Standard Specifications, City of Columbus' 2012 Construction and Materials Specifications, and VDOT's Special Provisions for 2016 Road and Bridge Specifications. [11,23,24]

Slurry seals “consist of a mixture of asphalt emulsion, well-graded crushed aggregate, fillers, additives and water that is proportioned, mixed and uniformly spread on a prepared surface.”[5] Slurry seal definitions indicated in each agency's specifications are listed below.

- Caltrans: “consists of spreading a mixture of asphaltic emulsion or polymer-modified asphaltic emulsion, aggregate, set-control additives, and water on a surface or pavement.”
- City of Columbus: “consists of a mixture of emulsified asphalt, mineral aggregate, and water; properly proportioned, mixed, and spread evenly on the surface.”
- VDOT: Definition not available.

Materials

Caltrans requires that PMCQS-1h is to be used. The modification must be done with a homogeneous polymer that was milled into the asphalt emulsion using a colloid mill. The emulsion must meet Caltrans' requirements for quality. If a tack coat is used, it consists of a 3:1 diluted SS or CSS grade emulsion, applied at a rate selected between 0.08-0.15 gal/yd². The City of Columbus uses either a QS or CQS emulsion. VDOT uses CQS-1h emulsion.

Caltrans uses rock dust or sand aggregates with gradations of Type I, II and III. These are also slurry seal type designations. The Type I gradation has a MAS of No. 4. The Type II and III gradations have a MAS of 3/8 inch. Particles larger than No. 50 must be 100% crushed. These gradations are similar to those found in the ISSA mix design standard.[2]

The City of Columbus uses 100% crushed gravel, slag or approved limestone in slurry seal treatments, with a Sand Equivalent greater than 45. The aggregate gradations are for Type I, II and III, all with a MAS of 3/8 inch. Aggregates are given a small amount of moisture before mixing. Aggregates must have a proven durability record that will hold up under the existing pavement's traffic levels. VDOT only uses non-polished crushed stone with gradations of Type A, B and C. All gradations have a MAS of 3/8 inch.

Caltrans allows for set-control additives to be used. The City of Columbus allows for mineral fillers such as Portland cement and limestone dust to be used. The filler is only to be used to provide sufficient mixture workability. VDOT allows for either non-air-entrained Type I Portland cement or hydrated lime to be used. Water may also be used.

Mix Design and Verification

Caltrans uses the ISSA mix design methods and verification tests. The mix design must include the percentage of emulsion by dry weight of aggregate. The allowable emulsion percentage ranges vary between slurry seal types. For Type I, the range is 15-20%. For Type II, the range is 12-18% and for Type III the range is 10-15%. Once the mix design is complete, the Contractor must submit a report and mix design to the agency. The report and mix design must include the specific materials to

be used and include the test results for the minimum and maximum amount of filler needed, the minimum and maximum amount of water, residual asphalt content and the use of a set control agent, if needed. The laboratory report must also compare these results to the specification values to determine if the results are within the tolerances. When translated to a Job-Mix Formula (JMF) for construction, the materials proportions should allow for the treatment to be cured within one hour post-construction. If any materials change, a new mix design and laboratory report must be submitted at least 10 days pre-construction.

The City of Columbus also uses the ISSA mix design method and verification tests, as outlined in ISSA TB 111—Outline Guide Design Procedure for Slurry Seal. [25] The potential Contractor must submit a trial mix design to Columbus for approval before being awarded the project, along with 11 lb of aggregate, 1 gallon of emulsion, 0.5 kg of mineral filler, three Consistency test results, two Wet-Track Abrasion test results, and two Loaded-Wheel Tester test results (all conducted on the complete mix design) for review. The design asphalt content must be within the following ranges: 10-16% for Type I mix, 7.5-13.5% for Type II mix, and 6.5-12% for Type III mix.

VDOT uses a department-created test method for slurry seal mix designs and requires the Contractor to submit a trial mix design for each slurry type that will be used for approval, along with results of the VTM-60—Compatibility Test of Slurry Seal Mixtures—(Asphalt Lab) and one Wet-Track Abrasion test result for each mix type to be used. [26] The Wet-Track Abrasion result must be less than 75 grams/ft². This test is used to determine the optimum asphalt content and limit the acceptable

asphalt content range. The range must be between: 8.0–10.5% for Type A mix, 8.0–10.5% for Type B mix, and 7.0–9.5% for Type C.

Caltrans uses Consistency, Wet-Stripping, Compatibility, Cohesion and Wet-Track Abrasion for mix verification. City of Columbus only checks Gradation to verify the mix design.[27] The specification has test requirements for Mixing Time, Set Time, Water Resistance, Coating and Wet Track Abrasion, although the City of Columbus is not capable of performing these tests.[27] VDOT reviews the Contractor's Wet-Track Abrasion test result to verify the mix design. The Gradation is tested based on the approved aggregates producer's modified acceptance production control plan.

When submitting the mix design, the Contractor must also supply VDOT with 6 quarts of emulsion and 50 kg of aggregate for asphalt content testing via the Ignition Method or the Nuclear Gauge Method (VTM-102—Determination of Asphalt Content from Asphalt Paving Mixtures by the Ignition Method – (Asphalt Lab) and VTM-93—Nuclear Asphalt Content Gauge Determination For H.M.A. and Slurry Seal Mixtures – (Asphalt Lab), respectively).[28,29] Samples of the completed mix are taken from the mixing unit and also tested for asphalt content. At the start of production, each of these samples are to represent no more than 25,000 yd² of slurry seal mix. Once the production becomes consistent, the sampling and testing frequency is reduced to once per 50,000 yd².

Equipment, Calibration and Construction Requirements

Equipment and Calibration

Caltrans uses either a truck-mounted or continuous mixing unit and a spreader box to construct slurry seal treatments. If using truck-mounted spreaders, at least two

must always be present on every jobsite. Both must be in working order. Each mixer-spreader unit is calibrated at least five business days before construction. The calibration is conducted using the process outlined in Caltrans' Material Plant Quality Program document.[18] If Caltrans authorizes a continuous mixer-spreader, its calibration is valid for six months provided that the same truck and materials are used, and no repairs are made to the proportioning systems. The adjustable cut-off gate settings of each continuous mixer-spreader on the project must be calibrated to achieve the correct delivery rate of materials for each revolution of the aggregate feeder.

The City of Columbus uses continuous-flow mixing machines, spreading equipment, cleaning equipment, and auxiliary equipment such as hand squeegees to construct slurry seal treatments. The Contractor must have a certificate that verifies that all equipment has been calibrated within the previous two months. As with Caltrans, two 10-ton mixing machines must always be present on each jobsite for continuous operation.

VDOT uses a mobile mixing unit and spreader to construct slurry seal treatments. The calibration data must be for the current calendar year for each mixing unit used. Calibration is to be conducted using the same materials as those to be used in the project. There is not currently a requirement for the minimum number of units that must be present on the jobsite.

Temperature and Seasonal Limits

Caltrans does not allow construction until both the air and surface temperatures are above 50°F and rising. Neither temperature is allowed to be below 50°F and falling. The forecasted air temperature must reach a high of at least 65°F

within 24 hours of placement. Slurry seals are not to be placed if precipitation or temperatures below 36°F are expected within 24 hours of the treatment being placed.

The City of Columbus allows construction when either the pavement or air temperatures are 45°F and rising. However, neither temperature can be 50°F and falling. The slurry seal treatment is not to be applied if excessive humidity will prolong curing to an unreasonable degree.

VDOT allows construction when the surface temperature is above 50°F and rising. The treatment can be placed if the surface temperature is 40°F and rising during the morning hours and provided that the anticipated high air temperature will be at least 60°F. The air temperature must not be expected to drop below 32°F in the next 24 hours. If the pavement temperature is above 90°F, the surface must be fogged with water at a rate of 0.05 gal/yd² immediately ahead of the spreader to prevent early curing.

Surface Preparation

Caltrans' surface preparation practices include covering exposed facilities, removing loose particles using any non-destructive method, such as flushing or sweeping, and applying a 3:1 diluted emulsion tack coat, if required, at a selected target rate between 0.08-0.15 gal/yd². The City of Columbus' surface preparation practices include sweeping, removing weeds, and executing a final cleaning ahead of the mixer using any standard cleaning method, except water flushing. A diluted emulsion tack coat applied at a rate between 0.05-0.10 gal/yd² may be required if the surface is concrete or brick, absorptive asphalt or if the surface is polished and slick. VDOT's surface preparation practices include cleaning the surface of all loose material using a mechanical sweeper or compressed air.

Construction Inspection Process

Caltrans requires that the mixture consistency during proportioning be monitored. It must be workable, uniform and homogeneous, with no separation of the emulsion and aggregate present after setting. The individual responsible (i.e., Caltrans or Contractor representative) for monitoring the consistency is not stated. The Engineer determines the exact spread rate for slurry seal, and the actual rate must be spread uniformly, within 10% of the determined spread rate. The target slurry seal spread rates must be within: 8-12 lb/yd² for Type I, 10-15 lb/yd² for Type II and 20-25 lb/yd² for Type III. Spotting, re-handling, or shifting the slurry mixture is not allowed. In areas inaccessible to spreading equipment, authorized methods are used to apply mixture in these areas. If placing with hand tools, the area should be first lightly dampened. The exact rate must be authorized by the Engineer. The finished surface must be smooth. The slurry seal must be protected from damage until it has cured so it will not adhere to or be picked up by vehicle tires. Caltrans does not require test strips to be constructed for slurry seal treatments.

The City of Columbus requires that the JMF established from mix design be translated to job control quantities per ISSA TB 107—A Method for Unit Field Control of Slurry Seal Quantities.[30] Spread rates are determined per ISSA TB 112—Method to Estimate Slurry Seal Spread Rates and to Measure Pavement Macrotecture, which bases application rates on the dry aggregate's unit weight.[31] These spread rates must be within: 8-12 lb/yd² for Type I, 15-17 lb/yd² for Type II and 15-22 lb/yd² for Type III. The slurry seal mixture must always be of proper consistency. The tolerance ranges for deviations from the ideal spread rates are not available.

VDOT inspects the slurry mixture to ensure that it is of a consistency that allows it to “roll” in the spreader box in a continuous mass. Segregating in the spreader box, so that flowing of liquid is evident, is not acceptable and any mix that exhibits this is not to be applied. The liquid portion of a slurry mixture must not flow from either the spreader box or the applied slurry and may be grounds for rejection of the work. A mixing aid additive may be used when necessary to accommodate slow placements or in high temperature conditions. Oversized aggregates cause a cease in construction until approved corrective measures have been taken to remove these materials from the mixture.

Application Adjustments

Caltrans does not have mix adjustments stated in the specifications. The City of Columbus also does not have mix adjustments. Columbus allows for the Contractor to make mix adjustments, although the actual limits and the agency approval process are not available.[27] VDOT recommends that the Contractor place a test strip prior to beginning the work, to verify that the target application rate is met and is sufficient. As was stated in the previous section, a mixing aid additive may be added if slow placement rates or elevated temperatures require it .

Opening to Traffic

Caltrans requires that the slurry seal must allow traffic within one hour post-construction. The one-hour requirement is based upon the Contractor’s mix design. The City of Columbus’ specification allows treated areas to cure until the Engineer permits opening to traffic. Columbus’ inspector who is responsible for determining when the pavement is to be opened to traffic.[27] VDOT treatment must be cured until the it cannot be damaged by traffic. If earlier openings are necessary, the

Contractor may lightly sand the surface using the same aggregates used in the treatment to mitigate any damage. Once curing is complete, this aggregate is to be removed.

Treatment Monitoring

Caltrans states that after the treatment is opened to traffic, it must not show signs of bleeding, ravelling, separation, or other distresses for 15 days after construction, at which point it is accepted. The City of Columbus currently uses delayed-acceptance practices, wherein acceptance occurs 30 days after construction. At this time, the Engineer will inspect the project, looking for flushing and loss of material. Corrective work is required if either defect is present, and must be completed within seven working days, or by an agreed date at the Contractor's expense. The 30-day requirement may be removed from current specifications and be replaced by a one-year material and workmanship warranty.[27] VDOT requires the Contractor to maintain the treatment until final acceptance. VDOT also monitors the treatment performance via network-level pavement condition surveys.[32]

Quality Control

Caltrans' QC process includes collecting moisture data for the aggregate every two hours each day, if the Contractor is unable to maintain the moisture content to within a maximum daily variation of $\pm 0.5\%$. This is monitored for each aggregate source using an approved vehicle scale. Individual checks of the aggregate feeder's delivery rate must not vary more than two percent from the average of three three-ton runs. Individual checks of the emulsion pump's delivery rate to the pugmill mixer must not vary more than 2% from the average of 3 runs of at least 500 gal each.

The City of Columbus' QC includes verifying the mix consistency via the cone consistency test. The result must be controlled to 2.5-3.5 cm. The test is conducted per ISSA TB 106—Slurry Seal Consistency Template.[33] The Contractor must keep a complete load-by-load record of the material quantities used during placement.

VDOT's QC includes continuously checking the mixture's consistency and monitoring aggregate abrasion loss. This testing is to be conducted by a VDOT-certified Slurry Surfacing Technician, a certification that is given through VDOT's Materials Certification Schools for Surface Treatment and Slurry Surfacing.

Acceptance

Caltrans' Acceptance includes accepting aggregates based on the Gradation and Sand Equivalent test results. An aggregate Gradation and Sand Equivalent test represents 300 tons or 1 day's production, whichever is less. If the results do not conform to specification requirements, the Contractor may remove the installed treatment represented by the test results or request it remains in place with a payment deduction of \$1.75 per ton of slurry seal for each noncompliant test. Columbus' Acceptance includes surface preparation approval, material quality verification and final treatment acceptance.

VDOT's Acceptance includes taking samples from the mixing units, which represent a maximum of 25,000 yd² at start-up (reduced to one sample every 50,000 yd² during construction) to check that the asphalt content is within $\pm 1.5\%$ of that stated in the JMF. If two consecutive tests fail or if the asphalt content deviates by more than 2%, that mixing unit is to be removed and corrected. The mixture consistency is checked at least twice per day. If a test fails, the mix proportions must

be immediately adjusted and re-tested. If two or more consecutive tests fail, then construction stops. If Wet-Track Abrasion failure occurs, mix adjustments may be required, and the abrasion must be re-tested prior to continuing work. If two or more consecutive tests fail, work must cease until the cause is corrected. If, during the life of this project excessive loss of cover aggregate occurs, the Engineer may suspend the work until the cause can be corrected, and new mix can be applied. The finished slurry mixture must be uniform, and it must not flush under traffic. The Contractor must repair or replace the failed treatment as directed by the Engineer if failure occurs prior to final acceptance.

Micro Surfacing

The micro surfacing specifications for Caltrans, MnDOT, and VDOT are discussed. The information obtained comes from Caltrans' 2015 Standard Specifications and 2015 Revised Standard Specifications, MnDOT's Standard Specifications for Construction, 2016 Edition and the Schedule for Materials Control for 2016 Standard Specifications and VDOT's Special Provisions for 2016 Road and Bridge Specifications. [11,13,14,24]

Micro surfacing “consists of a mixture of polymer-modified asphalt emulsion, well-graded crushed mineral aggregate, fillers, additives and water that is proportioned, mixed and uniformly spread atop a prepared pavement surface.”[3] Each agency's definition is listed below.

- Caltrans: “consists of spreading a mixture of micro surfacing emulsion, water, additives, mineral filler, and aggregate on the pavement.”

- MnDOT: “a mixture of polymer modified asphalt emulsion, well-graded crushed mineral aggregate, mineral filler, water and other additives applied to a prepared surface.”
- VDOT: No specification or special provision definition. VDOT interchanges micro surfacing with “latex-modified emulsion treatment.”

Materials

Caltrans uses any emulsion that contains a “homogeneous mixture of asphalt, polymer, and emulsifier solution”, with 3% polymer solids by weight of residual asphalt. The base asphalt binder is polymer-modified. MnDOT uses CQS-1P or CQS-1hP emulsions. As with Caltrans, the emulsion must contain at least 3% natural latex polymers or approved manmade latex, or styrene-butadiene-styrene (SBS) polymer. The residual asphalt content must be 62%. VDOT uses a quick-set CSS-1h latex-modified cationic emulsion. As with MnDOT, the emulsion must contain at least 62% residual asphalt. Latex modifiers and emulsifiers must be milled into the asphalt emulsion by an approved manufacturer.

Caltrans uses either rock dust or sand. As with slurry seals, particles larger than No. 50 must be 100% crushed. The gradations are Type I, Type II and Type III. It is important to note that ISSA does not recognise a Type I micro surfacing in its micro surfacing design standard.[3] Type I has a MAS of No. 4 and Types II and III have a 3/8-inch MAS. If aggregates from various sources are blended, each source’s aggregates must comply with Caltrans’ specification requirements. The Gradation requirement does not apply.

MnDOT uses Class A—crushed igneous bedrock or Taconite Tailings for micro surfacing treatments. The Contractor may blend Class B—carbonite and

metamorphic rock aggregate with the other aggregates if the resultant blend that passes the 3/8 inch sieve and retained on the No. 16 sieve is at least 90% Class A—or Taconite aggregates by weight. The gradations are Types I, II or III with MAS values of No. 4, 3/8 inch and 3/8 inch respectively.

As with VDOT's slurry seal requirements, VDOT uses a non-polishing crushed stone in micro surfacing treatments. The gradations are Types A, B, C and Rut-Filling, all with a MAS of 3/8 inch, except Type A, which has a MAS of No. 4.

Caltrans uses Portland cement in all micro surfacing types, as well as additive that do not negatively impact the treatment. MnDOT also uses Type 1 Portland cement, as well as hydrated lime as a mineral filler if the mix design results warrant its use. VDOT also uses non-air-entrained Type I Portland cement or hydrated lime, as well as water. Mix aid additives may be used to control the setting of the micro surfacing treatment.

Mix Design and Verification

Caltrans uses the ISSA mix design method. The proportion ranges of asphalt and mineral filler are 5.5-10.5% and 0-3% respectively. Water and additives are also stated in the mix design if needed. The Contractor must meet the following Submittals requirements: materials testing, providing two 1-quart samples of emulsion and data, a copy of the tests performed on emulsion and the results, a 50 lb sample of aggregates and the test results for Gradation, L.A. Abrasion, Percent of Crushed Particles, Sand Equivalent, and Durability. All of these must be submitted 15 days prior to construction.

10 days before construction, a laboratory report of test results and the proposed mix design that was signed and approved by an authorized laboratory are to be submitted. The report must include materials test results and the materials proportions based on the dry weight of aggregate, including ranges. If the air temperature during construction is anticipated to be above 90°F, then recommendations for changing the proportions based on a Mix Time test on the heated at 100°F and mixed for 60 seconds are to be included. Water, additives and mineral filler may be changed. Finally, determining the effect of moisture on the unit weight of aggregate based on the results from ASTM C29M—Standard Test Method for Bulk Density (“Unit Weight”) and Voids in Aggregate must also be included.[34] Mix verification tests include Wet Cohesion at 30 minutes and at 60 minutes, Excess Asphalt, Wet Stripping, Wet-Track Abrasion Loss, Lateral Displacement, Specific Gravity after 1000 cycles of 57 kg, Classification Compatibility, and Mix Time at 25°C.

MnDOT also uses the ISSA mix design method. A mix design must be submitted within 10 business days before construction and must include the sources of the materials used, the target residual asphalt content (must be selected between 5.5-10.5%) and the mineral filler content (selected between 0.25-3.0%). Mix verification tests include Wet-Stripping test, Wet-Track Abrasion Loss, Saturated Abrasion Compatibility, and trial Mix Times at 77°F and 100°F. MnDOT is to review the Contractor’s submitted mix design and perform tests on Gradation and Sand Equivalent on the submitted aggregate samples. MnDOT only checks the aggregate Gradation during the mix design verification process and conducts a paper review of

the Contractor's mix design.[21] If any of the Contractor's material sources change, a new mix design must be submitted.

As with slurry seal treatments, VDOT uses its own mix design method for micro surfacing treatments, which also uses components of the Marshall Mix Design Method. The mix design must be submitted two weeks before work is to begin. It must be designed in an approved laboratory by the Contractor for Engineer's approval. The JMF must show the materials compatibility based on the Schulze-Breuer test or other approved method, Marshall Stability (minimum of 1,800 lb) as tested using VTM-95—Design of Latex Modified Emulsion Treatment (Micro surfacing), Marshall Flow (between 6-16 units) and the design asphalt content needed to obtain 4.7% air voids in the mix for surface courses and 6.5% air voids for rut-filling courses.[35] Ignition oven calibration are to be conducted and submitted with the JMF. It is apparent that VDOT is the only lead agency that has an air voids design requirement. This could be to help mitigate certain types of distresses and to use the micro surfacing as a more robust layer. Mix verification includes Compatibility, Marshall Stability and Flow and Asphalt Content.

Equipment, Calibration and Construction Requirements

Equipment and Calibration

Caltrans uses either truck-mounted or continuous mixing and spreading equipment, standard spreader boxes, special spreader boxes (for edges or wheel depressions) and hand tools. As with slurry seals, two truck-mounted mixers must be present on the jobsite, if using. Each mixer-spreader used is to be calibrated in the presence of the Engineer. The calibration is conducted per Caltrans' Material Plant Quality Program document.[18] If using a variable-rate emulsion pump, it must be

calibrated before use. The aggregate belt feeder's delivery rate must be checked and for any individual check, it must not deviate more than two percent from the average of the rates of three three-ton runs. The emulsion pump's delivery rate is checked, and an individual check run must not deviate more than 2% from the average of the rates of 3 300-gallon runs. If using a continuous mixer-spreader machine, its calibration is valid for six months provided that the same truck and materials are used, and no repairs were made to the proportioning systems.

MnDOT uses a mixing machine, a spreader box, a rut-filling box, and weighing equipment to construct micro surfacing treatments. All equipment is calibrated annually, after equipment repairs have been made. The mixing machine is to be calibrated prior to each use and must be re-calibrated if changes to the equipment or materials are made. The mixing machine is calibrated at three aggregate flow rates for each emulsion and mineral filler used.[21]

VDOT uses mixing equipment, a spreader box and a pneumatic-tire roller for micro surfacing construction. All equipment must be designed for micro surfacing construction and must be calibrated annually for each mixing unit using the same materials as those materials that are to be used on the project.

Temperature and Seasonal Limits

Caltrans requires both the air and surface temperatures to be 50°F and rising to begin construction. Construction must not occur if either temperature is below 50°F and falling. The expected high air temperature must be at least 65°F not be expected to drop below 36°F within the next 24 hours. MnDOT requires the air and surface temperatures must be at least 50°F and rising before construction can begin.

Construction is not to occur during a precipitation event, or if the temperature will drop below 32°F within 48 hours. Construction ends on September 15.

VDOT requires the surface temperature to be above 50°F, except in the morning hours when the surface temperature is at least 40°F and rising. The anticipated high air temperature should be 60°F or higher and the low temperature is not expected to drop below 32°F within 24 hours. If required, night paving may be conducted under these conditions.

Surface Preparation

Caltrans' surface preparation practices include covering exposed roadway features and cleaning the pavement surface using any non-destructive method, such as flushing or sweeping, prior to construction. Water may be applied ahead of the spreader box. The application is adjusted for pavement temperature, surface texture and dryness. Wheel path depressions may require repairs prior to construction. In this case, the depressions and irregularities must be filled with a micro surfacing material before spreading the actual micro surfacing treatment in full lane-widths using either a scratch course for depressions less than ½ inch deep or using a rut-filling box for depressions deeper than ½ inch. Scratch courses are to be applied flush with the existing surface, whereas rut-filling courses are to be applied such that a slight crown of material remains. No more than 1.5 inch of material can be placed in a single application. Each depression is compacted by traffic for at least 12 hours before full construction begins.

MnDOT's surface preparation practices include cleaning the surface immediately before placing the micro surfacing, covering exposed roadway features and applying a fog seal, if required. The fog seal consists of a diluted CSS-1 or CSS-

1h emulsion is applied at a rate between 0.05-0.10 gal/yd². Only the area that is to receive the micro surfacing mix on a given day of construction may be fogged, and the fog sealed areas must not be opened to traffic. VDOT's surface preparation practices include cleaning the surface and applying a 3:1 water-diluted CSS-1h emulsion tack coat at a rate of 0.05 gal/yd². In hot conditions, the cured tack coat may be lightly sprayed with water to aid in bonding.

Construction Inspection Process

Caltrans inspects the spread rate to ensure that it is within 10% of the Engineer's determined target rate. The finished micro surfacing is inspected and must be free of irregularities such as scratches or tear marks. MnDOT begins inspection by first holding a pre-paving meeting with the Engineer before construction to discuss the JMF, equipment condition and calibration, test strips, a detailed work schedule, and traffic control plan.

Prior to treatment construction, a one-lane-wide 1,000-foot test strip is constructed by each machine. The test strip is constructed at least one hour after sunset or before sunrise. The test strip is not to be constructed until the emulsion temperature in the mixture falls below 122°F. A new test strip is constructed if, at any point during construction, the materials and/or the proportions change, or non-uniformity in the application is encountered. The test strip is opened to traffic one hour after construction. The surface texture is examined for variability between machines. The Engineer will evaluate whether any damage occurs and will inspect the completed test strip again after 12 hours of traffic to determine if the micro surfacing is acceptable. The Contractor may begin full production after the Engineer accepts a test strip. If the Contractor can prove that the mix design and application has been

successfully completed on another project within the same construction season, the test strip requirement may be waived. MnDOT inspects the application rate once per day. If the construction process is not yielding a micro surfacing treatment that is in compliance with the specifications, work must stop, and the cause corrected before continuing.

VDOT first determines the appropriate application rates for each type of micro surfacing that is being used. The minimum rates are 16 lb/yd² for Type B mix and 20 lb/yd² for Type C mix. If surface courses are used, the minimum ranges are 16-20 lb/yd² for Type B mixes and 18-22 lb/yd² for Type C mixes. If the micro surfacing is not being used to fill ruts or as a levelling course, the application rates are 18-22 lb/yd² for Type B and 20-24 lb/yd² for Type C. Application rates are verified by the Engineer, via weight tickets, delivery summaries and estimated aggregate loss or unused aggregate for each stockpile. Oversized aggregates and foreign materials should be screened from the stockpiles delivery. Loose aggregates must be removed without damaging the surface. The Engineer may reject any work that results from poor workmanship, or exhibits loss of texture, ravelling, or instability.

Application Adjustments

Caltrans adjusts the mix if field conditions require it. Proportion adjustments must be authorised by Caltrans or the Engineer. MnDOT allows for adjustments to be made, but each adjustment requires a new test strip to be constructed. Any mix adjustments require approval from the MnDOT inspector. MnDOT allows the Contractor to determine the need for a break additive, without changing the application rate.[21] VDOT allows a mixing aid additive to be used to accommodate spreading due to slow placing or high temperatures. Water may be sprayed into the

spreader box to prevent build-up on the blades, but care must be taken to prevent excess quantities that may cause separation of the mix.

Opening to Traffic

Caltrans requires the treatment to be opened within two hours post-construction. The treatment must be protected from damage until it has set. Once opened, bleeding, ravelling, separation, or other distresses must not be present. MnDOT requires the treatment to be protected and unopened to traffic until the treatment has cured sufficiently. A properly constructed treatment can be opened to free-flowing traffic within one hour of construction. Any damage to the surface caused by traffic is to be repaired. The inspector will confirm that the treatment has cured within one hour after the construction of the test strip using three one-hour spot checks conducted by the Engineer. If a spot check fails, a new test strip is constructed. Spot check failures are grounds for deeming the work unacceptable and subject to penalties. After the three, one-hour spot checks pass, the testing frequency is reduced to once a day during construction.

VDOT does not allow the treatment to be opened to traffic until the treatment has cured to the extent that it will not be damaged. If an earlier opening is necessary, a layer of the same sand that was used in the micro surfacing treatment may be placed. This cover may need to be removed after full curing has been achieved.

Treatment Monitoring

Caltrans requires the Contractor to sweep the fresh treatment daily for five days post-construction. MnDOT requires the Contractor to repair any damages to the treatment immediately post-construction. VDOT monitors the performance and

condition of projects at the network level.[36] This includes slurry seal and micro surfacing projects.

Quality Control

Caltrans' QC process includes Contractor mix design testing as outlined in the Mix Design and Verification section. MnDOT's QC process includes sampling and testing materials and application rate verification. For the emulsion, the Contractor must provide a material Bills of Lading (BOL) for each batch of emulsion used. QC testing is performed by the Contractor's emulsion supplier. For the aggregate, the Contractor must sample and test according to the SMC. QC test results must be provided daily to the Engineer and a summary upon completion of work must also be given.

VDOT's QC testing includes Asphalt Content testing on samples (each represents no more than 500 tons of mixture) from each mixing unit. The Asphalt Content must be within $\pm 1.5\%$ of the JMF target. If two consecutive tests fail or if one test fails by more than 2%, the mixing unit must be removed from the jobsite until the cause can be corrected. The asphalt content will be determined by the Ignition Method (VTM-102—Determination of Asphalt Content from Asphalt Paving Mixtures by the Ignition Method – (Asphalt Lab)) or nuclear gauge (VTM-93—Nuclear Asphalt Content Gauge Determination for H.M.A. and Slurry Seal Mixtures – (Asphalt Lab)).[28,29] Stockpiles are sampled and tested for Gradation. Materials testing and sampling frequencies are established by the Engineer.

Acceptance

Caltrans' Acceptance practices include material testing and inspecting the finished treatment. Caltrans accepts aggregate based on compliance with the

aggregate Gradation and Sand Equivalent requirements. If the test results do not comply with specification requirements, the Contractor may remove the installed treatment represented by the test results or request it remain in place with a \$2.00 per ton per test payment deduction. The finished surface is accepted based on visual inspection for uniform surface texture and the number of acceptable marks in the surface. The finished surface is rejected if marks in the completed micro surfacing surface are over 1 inch wide or 6-inch-long, or if there is excessive ravelling bleeding, delaminating, rutting or wash-boarding.

MnDOT's Acceptance process includes sampling and testing according to the SMC.[14] MnDOT tests aggregate for Gradation, Moisture Content and Sand Equivalent. Emulsion tests are also conducted, but the tests to be used are not listed in the SMC. MnDOT also tests the application rate once per day during construction.

VDOT's Acceptance includes accepting aggregate based on the approved producer's acceptance production control plan. The completed mix is sampled and tested by VDOT for Marshall results and Asphalt Content. The Engineer may reject any treated areas if poor workmanship, loss of texture, ravelling or apparent instability are present.

Thin Lift Asphalt Overlay

The thin lift asphalt overlay specifications for Caltrans, FDOT, MDOT, and ODOT are outlined in this section. The information is obtained from Caltrans' 2015 Standard Specifications and 2015 Revised Standard Specifications, FDOT's, Standard Specifications for Road and Bridge Construction, MDOT's 2012 Standard Specifications for Construction and Special Provision for Warranty Work

Requirements for Hot Mix Asphalt Ultra-Thin Overlay, and ODOT's, Construction and Materials Specifications.[11,37,38,39,40]

Thin Lift Asphalt Overlays “consist of a fine-graded surface asphalt mix 1 inch or less in thickness that is mixed and placed on a prepared surface.”[4] Caltrans and FDOT do not have thin lift asphalt overlay specifications. Both agencies use a fine graded mix that complies with the hot-mix asphalt specifications. Each agency's definition is listed below:

- Caltrans: No definition available. Caltrans uses the Rubberized Gap-Graded Asphalt for thin lift asphalt overlays.
- FDOT: “A small nominal maximum aggregate size surface asphalt mix, 1-inch or less in thickness that is mixed, placed, and compacted atop a prepared surface.”
- MDOT: No definition available.
 - Named Ultra-Thin Overlays.
- ODOT: “Consists of constructing a surface course of aggregate and polymer modified asphalt binder mixed in a central plant and spread and compacted on a prepared surface.” A thickness is not indicated.
 - Named Fine-Graded Polymer Asphalt Concrete in specifications.

Materials

Caltrans uses different binder grades, which are found in the special provisions of individual projects. General grades are based on climate zones. These grades include PG58-22, PG64-16, PG64-10 and PG70-10. Caltrans also uses asphalt rubber binder. FDOT uses a polymer- or rubber-modified PG76-22 binder. MDOT bases the PG binder grade on the roadway's current two-way average daily traffic (ADT)

volume. For a two-way ADT of less than 380 vehicles per day, the grade is PG58-28. For an ADT of 380-3,400, the grade is PG64-28P and for an ADT of more than 3,400, the grade is PG70-28P. Up to 27% virgin aggregate replacement of reclaimed asphalt pavement (RAP) may be used, without needing to change the binder grade. For a larger RAP percentage, a new binder grade is selected using a blending chart.

ODOT uses either a PG76-22M or a PG64-22 binder that is modified with $5.0\pm 0.3\%$ by binder weight of styrene-butadiene-rubber (SBR) solids, blended to meet the requirements for a PG76-22 binder. For all agencies, any binder that is used must meet the specification quality criteria laid out in each agencies' respective binder sections.

Caltrans does not state actual aggregate types to be used in thin lift asphalt overlays. The MAS is $\frac{1}{2}$ inch. FDOT selects aggregate types that are dependent on the project's. For northern Florida projects, granite is used. For southern Florida projects, limestone is used. In contrast to other agencies, the gradations are based on Nominal Maximum Aggregate Size (NMAS) and are $\frac{3}{8}$ inch and No. 4 NMAS for granite and limestone, respectively.

MDOT also does not state actual aggregate types in the warranty provision specific to thin lift asphalt overlays. However, MDOT's HMA specification shows aggregate types of natural aggregate, iron blast furnace slag, reverberatory furnace slag (produced during the refinement process of copper ore), steel furnace slag, manufactured fine aggregate, or a uniformly graded blend. Regardless of the type used, the warranty provision requires an aggregate gradation with a MAS of $\frac{1}{2}$ inch. ODOT uses natural sand or sand manufactured from stone, gravel, or Air-Cooled Blast Furnace Slag (ACBFS) for fine aggregate, and Crushed Carbonate Stone (CCS)

or ACBFS for coarse aggregate. ODOT uses two mix types: Type A and Type B. Type A mixes have a 3/8 inch MAS and Type B mixes have a 1/2 inch MAS.

Caltrans uses either dry lime or lime slurry liquid anti-strip to prevent moisture damage. Warm-mix asphalt technologies may also be used. FDOT also uses hydrated lime or liquid anti-strip treatments. FDOT indicated that lime is not always used in dense-graded mixtures, instead often selecting liquid anti-strip additives.[41] MDOT allows for mineral filler, anti-foaming agents, and RAP to be used as additives. Each additive must meet the pertinent specification requirements. ODOT allows up to 10% RAP in Type B mixes. RAP is not permitted in Type A mixes. Mineral filler, liquid anti-strip or hydrated lime may also be used.

Mix Design and Verification

Caltrans uses the Superpave mix design. Verification tests include Gradation, Percent of Crushed Particles for Coarse and Fine Aggregate, L.A. Abrasion, and Sand Equivalent, Air Voids, Number of Gyration, Voids in the Mineral Aggregate, Dust Proportion, Hamburg Wheel-Track Rutting Resistance and Moisture Susceptibility. Moisture Susceptibility is tested samples of the plant-produced mix.

FDOT also uses the Superpave mix design method. Verification includes testing for moisture susceptibility per FDOT's version of AASHTO T283. One of FDOT's districts also uses the Asphalt Pavement Analyzer (APA) rutting test for mix verification.[41]

MDOT uses both the Marshall and Superpave mix design methods. Verification testing is conducted per the MDOT HMA Production Manual.[42] For all mix designs, the MDOT Bituminous Mix Design Unit will first conduct a paper

review of the Contractor's submitted mix design documentation for specification compliance and will evaluate the mix design by entering the data into MDOT's Mix Design software. Next, the Contractor must submit the aggregates and mixture samples and test results for mix verification testing.

ODOT allows for any mix design method that is outlined in the Asphalt Institute's MS-2: Asphalt Mix Design Methods to be used. Verification for Type B mixes includes requiring the Contractor to submit a preliminary JMF to the ODOT Office of Materials Management (OMM) at least two weeks before starting work for preliminary approval. Upon approval, the Contractor is to create and test a mix design and submit the test results, along with a five-pound uncompact sample that represents the JMF.

Final JMF approval is done by field verification. This is conducted by obtaining split samples from the Contractor QC or from independent sampling taken from the plant or the roadway. If the JMF for Type B mixes contains gravel coarse aggregate or 25% or more of natural sand, tests for Moisture Susceptibility, Washed Gradation, and Adherent Fines for Each Component are to be conducted to determine the need for an anti-strip additive. Other tests that may be required are gradation and Methylene Blue Absorption of Fine Aggregate ODOT Supplement 1052— Determination of Methylene Blue Adsorption Value of Mineral Aggregate Fillers and Fines) may also be conducted.[43]

Equipment, Calibration and Construction Requirements

Equipment and Calibration

Caltrans requires that pavers, rollers, and material transfer vehicles (MTVs). There is also a provision for using method compaction. FDOT uses paver and rollers

for thin lift asphalt overlay construction. MDOT uses cold-milling equipment, hauling equipment, pressure distributor (for tack coat application), pavers, rollers, spreaders, material transfer devices and light equipment to construct thin lift asphalt overlays. Calibration procedures are not indicated in the specifications. ODOT uses hauling equipment, pavers, MTVs, and rollers. ODOT also has requirements for the mixing plant included in the specifications. The plant is to be calibrated per Supplement 1101—Asphalt Concrete Mixing Plants.[44] The aggregate weighbridge and asphalt binder metering system are both to be calibrated, and must be accurate to within $\pm 1.0\%$ of the required values for each.

Temperature and Seasonal Limits

Caltrans requires a minimum air temperature of 55°F and surface temperature of 60°F if using an unmodified asphalt binder. Temperature limits for using modified binders are not available. Tarps are required if the ambient air temperature is below 70°F or the haul time to the jobsite exceeds 30 minutes. FDOT requires the air temperature in the shade to be 50°F before construction can begin. MDOT does not allow construction if there is excessive moisture on the existing surface. The surface temperature must be at least 50°F. Seasonal limits depend on the project's location. For Michigan's Upper Peninsula, the construction dates are from June 1 to October 15. For Michigan's Lower Peninsula, north of M-46, the construction dates are from May 15 to November 1. For Michigan's Lower Peninsula, south of M-46, the construction dates are from May 5 to November 15. ODOT requires a surface temperature of at least 60°F. The air temperature must not be below 60°F. Construction of thin lift asphalt overlays is not to take place after November 1.

Insulated haul truck beds are required if transporting the material in ambient temperatures of 50°F or less or if the haul time is to exceed 20 minutes.

Surface Preparation

Caltrans' surface preparation practice is a required cleaning of the surface via flushing and sweeping before paving. FDOT's surface preparation practices include cleaning the surface and applying a tack or prime coat and allowing it to cure before construction. The tack coat is placed according to Section 300—Prime and Tack Coats and between successive layers of all asphalt mixes at an application rate selected from Table 300-1—Tack Coat Application Rates in the FDOT specifications.[45]

MDOT's surface preparation practices include covering exposed structures, cleaning the surface, cold-milling and removing shoulders. The surface is to be cold-milled after MDOT approves the mix design. Once cold milling is complete, the surface is to be cleaned again. If shoulders are constructed of HMA, these must be cut to full depth and removed from the roadway prior to construction. Any patches that will inhibit the overlay's performance must be removed. An SS-1h emulsion tack coat is to be applied at a rate of 0.11-0.15 gal/yd². ODOT's surface preparation practices include cleaning the surface and performing repairs. The surfaces of exposed structures are cleaned and sprayed with a PG binder, hot-applied asphaltic joint adhesive, or SBR emulsion.

Construction Inspection Process

Caltrans' construction inspectors are to inspect the longitudinal joints, method compaction, and mat temperatures during construction. Longitudinal joints must match lane lines at the surface, with 6-inch alternating offsets from the lane lines in the lower layers. Saw cuts or grinding may be needed if placing material next to an existing pavement. Method compaction is used for Caltrans' thin lift asphalt overlays and consists of performing breakdown compaction with 3 coverages with a vibratory roller at a speed determined by dividing the vibrations per minute by 1,000. For thicknesses of less than 0.96 inches, vibration is not allowed. Intermediate compaction consists of three coverages using a steel-wheel roller operating at 5 mph or less. Finish compaction is completed with an additional coverage with a steel-wheel roller. Rolling is to begin at the lower edge and progress toward the crown. Fewer coverages may be needed for thicknesses of less than 1.8 inches.

Mat temperatures are inspected to determine when each phase of compaction can begin. The temperatures are dependent on the binder type. For modified binders, breakdown compaction must have begun before the mat temperature drops below 285°F. Breakdown and intermediate compaction must be completed before the mat temperature drops below 250°F and final compaction must be completed before the mat temperature drops below 200°F. After rolling, sand is spread on the new surface at a rate of 1-2 lb/yd².

FDOT requires inspectors to monitor the mix temperature, spread rate, and the cross-slope. The required mix temperatures are defined in FDOT's specifications and are measured at the plant and on the project. The temperatures on the project are measured on the first five loads, then once per five loads. The actual spread rate must

be within 5% of the target spread rate. An average of five to ten truckloads of mix are used to determine the actual spread rate. FDOT verifies the spread rate once per lane, per lift, per day, using the truck ticket quantities and placed lane area. As with Caltrans, vibratory compaction is not allowed for layers of one inch or less in thickness. The surface must be uniform in texture and compaction and free of pulled, torn or ravelled areas. No segregation, bleeding, flushing, sand streaks or spots, or ripples should be present in the mat. The cross-slope is measured once per 100 ft per lane, and potentially reduced to once per 200 feet, at the Engineer's approval. The cross slope is verified by the Engineer with ten or more cross slope measurements per lane per mile in tangent sections and control points in transition sections. At super-elevated sections, three measurements are taken.

MDOT requires that inspectors monitor the mixture application rate and mat temperature. The mixture application rate is 83 lb/yd². If for any reason, the mat temperature immediately behind the screed falls below 200°F, construction stops and a transverse joint is placed to indicate the place of cessation. If the temperature falls below 190°F before initial compaction, that area is to be removed and replaced. As with Caltrans, MDOT requires that the longitudinal joints conform to planned lane lines. A tack coat is applied to the edge of a mat before placing the next adjacent layer of asphalt mix if that mat's temperature falls below 170°F. Each layer must be compacted as directed.

ODOT requires that inspectors monitor the spread rate, check for surface defects, measure the mat temperature, and inspect the rolling pattern. A test strip is required prior to construction. On the first day or night of paving, the Contractor constructs a 1,000-foot test strip to demonstrate that the equipment is not segregating

the mix and that the transverse temperature differential the mat surface is 35°F or less. If the equipment or JMF displays physical segregation, does not meet the temperature differential requirement, or both, the equipment or JMF must be removed, replaced and confirmed with a new test strip.

The mixture must be spread at the rate determined by the Engineer and is checked with calculations using the load tickets for each material and the required mat thickness. The calculated spread rate must not be greater than two times the roller capacity. The rate must be maintained to within $\pm 5\%$ of the calculated rate. The mixture is spread and finished using a process that allows compaction to immediately follow paving. The Engineer will verify mix temperatures at the jobsite. The paver operation, screed and extension, and/or the mix design must provide a mat that is free of inconsistencies, shadowing, streaking, tearing, pulling, or other deficiencies prior to compaction. If any of these occur, the deficiency is corrected.

Corrective action is to be taken if any defects such as flushing are present. It must be removed and replaced. Spreading and mixing must be coordinated to maintain a steady-state paving operation. Erratic spreader operations should be avoided, and line and grade control must be maintained. Sticking indicates early cooling, which must be corrected, potentially requiring the haul trucks to have insulated beds. The roller coverage required should be completed in a short but sufficient time frame at the design compaction temperature that is stated in a JMF approval letter. Rolling should begin at the edges of pavement, parallel to the centerline, and at a slow uniform speed, moving towards the crown with each coverage. Breakdown compaction should be conducted with a three-wheel roller. The temperature immediately before rolling must be 290°F or greater for hot mix asphalt

and 250°F for warm mix asphalt. Rolling should continue until full coverage is complete and all roller marks are covered.

Application Adjustments

Caltrans only adjusts the mix during JMF verification. FDOT allows the Contractor to request a target value revision to a mix design, provided that the Contractor submits all requests for revisions to mix designs, along with supporting documentation. A follow-up sample is subsequently taken to determine whether the revision did not cause any issues with the mix. If the sample fails specification requirements, the production of the asphalt mixture must stop until the problem is adequately resolved. The specification outlines the allowable ranges of adjustments that the Contractor can make for binder content and stockpile proportions. The Contractor must notify FDOT and get approval to make mix design target revisions. First approval is verbal (to keep operation moving) and is followed up with written request. MDOT's mix adjustments are not available. ODOT allows the Contractor to adjust the aggregate Gradation during the first three days of production, provided the adjustment remains in the specification limits.

Opening to Traffic

Caltrans does not have readily available opening to traffic criteria. FDOT allows the treatment to be opened to traffic when it cools to 160°F, but if traffic creates visible marks on the surface, the mix needs further cooling. MDOT also does not have readily available opening to traffic criteria. ODOT does not allow the treatment to be opened to traffic until it has cooled to the point where bleeding will not occur.

Treatment Monitoring

Caltrans and FDOT do not currently have post-construction monitoring specification practices. FDOT requires an annual warranty inspection and a three-year materials and workmanship warranty for all thin lift asphalt overlays.[41] Currently, less than 2% of projects required warranty repair action.[41] MDOT uses a two-year warranty for all work dated from the Acceptance date. ODOT also does not currently have post-construction monitoring practices.

Quality Control

Caltrans' QC includes testing the asphalt rubber binder, aggregate and completed mix. Testing on the asphalt rubber binder includes testing the asphalt modifier for Viscosity, Flash Point and Molecular Analysis for Asphaltenes and Aromatics. The CRM is tested for Gradation, Wire and Fabric Content, Specific Gravity and Natural Rubber Content. Testing on the blended binder includes testing for Cone Penetration, Resilience, Softening Point (all tested once per lot) and Viscosity (tested 15 minutes before being used in a lot).

Aggregate tests include Gradation, Sand Equivalent, and Moisture Content, the last of which is tested only at continuous mixing plants. Further tests include Crushed Particles, L.A. Abrasion, Flat and Elongated Particles and Fine Aggregate Angularity. Tests on the complete mix include Asphalt Content, HMA Moisture Content, Air Void Content, Voids in Mineral Aggregates (VMA), Dust Proportion, Hamburg Wheel Track and Moisture Susceptibility.

FDOT's QC process includes testing the pavement density, mix temperature, pavement smoothness, pavement cross-slope, mix spread rate, and pavement texture. The Contractor is responsible for having full-time quality control personnel for plant

production and paving. Other QC practices include obtaining random samples and testing within one working day from the time the samples were obtained. FDOT requires the Contractor to conduct Process Control testing, in addition to QC testing. Process Control is separate from Quality Control, in that Process Control is concerned with monitoring the construction operations used to create a product, whereas Quality Control monitors the quality of the materials used to create the product and the product being created. The Contractor must control all paving operations and processes to meet FDOT's specifications. Process Control is tested at the plant and on the jobsite. Process Control is not used as a part of Acceptance.

FDOT uses lots for QC testing. Lot sizes vary. Lots are not acceptable if an individual air void, average density or two consecutive gradation or asphalt content results do not meet the FDOT specification requirements. QC failures for lots warrant a cease in production. Tack coat QC requires corrections if the application rate varies by more than 0.01 gal/yd² or varies beyond the in the tack coat section of the specifications. The application rate is randomly checked by the Engineer to confirm the Contractor's measurement (taken twice a day).

MDOT's QC process includes developing a Quality Control Plan (QCP) and mix QC testing. The QCP is project-specific and includes all personnel and the responsibilities of each individual, documentation and QC testing. QC tests include Asphalt Content taken from core and mixture samples.

ODOT's QC process includes requiring the Contractor to create a QCP for each paving season and testing the completed mixture for specification compliance. The QCP must have details regarding personnel and each individual's responsibilities, annual training requirements, sampling and testing records for the plant or project for

the duration of the contract or 5 years, whichever is longer, equipment calibration and documentation procedures, Quick Calibration methods, random plant sampling procedures, RAP and RAS procedures, materials handling procedures and other provisions intended to produce a consistent and quality mix production operation. The asphalt mix testing varies by mix type.

For Type A mixtures, the QC tests are Gradation and Asphalt Content. If an asphalt content varies by more than $\pm 0.5\%$ from the JMF, another sample is tested, and if that result also varies by $\pm 0.5\%$, production must stop. If the difference between three consecutive asphalt content results is greater than 0.6, the ODOT Monitoring team is notified and production may be stopped. If the difference between three gradation results for the No. 4 sieve is greater than 10.0%, again, the Monitoring team is to be notified. For Type B mixes, the QC tests are Asphalt Content, Gradation, Air Voids and Maximum Specific Gravity. The Contractor may test a Sublot sample as an alternative, provided the Sublot sample was tested within one half-day of that Sublot's production.

Acceptance

Caltrans' Acceptance process includes testing aggregate for Gradation, Percent Crushed Particles, L.A. Abrasion, Sand Equivalent Flat and Elongated Particles and Fine Aggregate Angularity. Acceptance tests conducted on samples of the complete mix include Asphalt Content, HMA Moisture Content, Air Voids at N_{des} , VMA on both laboratory- and plant-produced HMA, Dust Proportion, Hamburg Wheel Track and Moisture Susceptibility. Acceptance sampling and testing frequencies are indicated in the Caltrans Construction Manual.[46]

FDOT's Acceptance includes mixture acceptance and smoothness acceptance. Mixture is accepted at the plant and on the roadway. The mix at the plant is accepted based on Gradation, Asphalt Content, and Air Voids on random split samples that represent each lot. The mix on the roadway is accepted, also on a lot-by-lot basis, using core density measurements (may not be used if the thin lift asphalt overlay is less than one inch in thickness). Lot Acceptance is based on FDOT-verified QC test results. Samples are taken using the process outlined in FM 1-T168—Florida Method of Test for Sampling Bituminous Paving Mixtures and must be large enough to be split into three separate samples.[47] Acceptance lot sizes are either 2,000 tons, divided into four 500-ton sublots or 4,000 tons, divided into four 1,000-ton sublots. Each subplot will be sampled randomly for Acceptance testing.

Pavement smoothness is accepted based on straightedge testing conducted using FM 5-509—Florida Method of Test for Measurement of Pavement Smoothness With the 15-Foot Rolling and Manual Straight-Edge.[48]. The final structural layer is straight-edged immediately behind the final roller or after construction.

MDOT's Acceptance includes accepting the asphalt binder, inspecting in-place material, sampling and testing the mix and ensuring that the Contractor follows the QCP. The asphalt binder will be accepted per MDOT's procedures. The finished surface is within 36 hours of construction. Visual inspection acceptance applies to mix amounts of 500 tons or less according to the Materials Quality Assurance Procedures Manual.[49] Small tonnage Acceptance may also be used and involves Acceptance testing for total mix tonnages of 5,000 tons or less. Full Acceptance sampling and testing is conducted for tonnages of more than 5,000 tons. For all three Acceptance alternatives, actual tests are not available. It is important to note that

while MDOT's warranty provision includes QA requirements, these requirements are often not used, as the thin lift asphalt overlay work is warrantied against damages for two years.

ODOT's Acceptance includes random testing conducted by ODOT, which may verify the QC test results. If the Acceptance testing verifies the Contractor's QC, the average daily QC results (for Type A mixes) or the average daily Sublot results (for Type B mixes) is used for Acceptance. For both mix types, the Acceptance tests are Asphalt Content and the Percent of Material Passing the No. 4 Sieve.

For Type A plant sampling, the Contractor's technician will randomly select the truck to sample, excluding the first three trucks. Samples are split by quartering and should be 22-27 lb. If a sample is mishandled, Unconditional Acceptance is used for that sample. Unconditional Acceptance occurs when the Contractor is removed from ODOT's Verification Acceptance. The Contractor's Prequalification Rating (C-95) will reflect the change to Unconditional Acceptance for future projects, which may result in that Contractor's disqualification for bidding.

For Type B plant sampling, samples are taken from the trucks at the plant. ODOT may require Lots of 3,000 tons and Sublots of 750 tons to be sampled if there are problems with workmanship, unless production is limited to less than 3,000 tons. That quantity is a partial Lot. If the Lot is 1,500 tons or less, 2 Sublot samples are tested. ODOT's Monitoring Team or the Engineer selects sampling locations. Acceptance for Type B mixes is based on the results for Asphalt Content, Percent of Material Passing the ½ inch sieve, Percent of Material Passing the No. 4 Sieve and the Percent of Material Passing the No. 8 Sieve, all conducted on 5,000-ton Lots and 1,250-ton Sublots.

If the Contractor's test results (for either mix type) are not verified by Acceptance testing, the cause is to be corrected. If there is a $\pm 0.5\%$ deviation between Asphalt Content results or a $\pm 7.0\%$ No. 4 sieve test deviation, production stops. This will lead to requiring the Contractor to raise the QCP to an acceptable level as determined by ODOT before production can continue. Under this level of Acceptance, all of the Contractor's materials will be accepted for ODOT projects.

Chapter 4 Identified Best Practices

Introduction

Identified best practices are identified here discussed in this chapter. These practices were identified based upon the advice given by the reviews of the expert panel and agency interview outcomes. As with Chapter 3, the progression will be from chip seals to slurry seals, then micro surfacing and will conclude with thin lift asphalt overlays. Each section will include both best practices and areas in the specifications that could be improved. In the best practices section, a concise summary of some common agency practices is also included. These common practices are important because, while not necessarily identified in this project as “best” practices, the fact that there are commonalities between agencies can indicate the importance of the practices to preservation treatment performance.

Chip Seal

Specification Best Practices

Best practices include:

- Proper project selection,
- Adequate pre-sealing and patching activities,
- Annual personnel training,
- Performing equipment maintenance and calibration activities,
- Mandating low-abrasion aggregates,
- Enforcing wintertime construction shut-down periods, and
- Using certified materials.

In general, there were several common practices used by the agencies to construct chip seal treatments. There were some differences, but nothing of significance. A summary of common practices among the agencies include:

- Caltrans and TxDOT allow for both emulsions and asphalt binders for chip seal treatments.
- All four agencies allow CRS-2P emulsion to be used
 - Two require it alone, and two allow for its use, in addition to other binder materials.
- All four agencies use at least one 3/8 inch gradation or aggregate size.
- Caltrans and TxDOT both have pre-coated aggregate use, which may aid in chip retention.
 - Used with a paving-grade asphalt binder to further increase retention.
- MnDOT, Spokane, TxDOT all use the Modified McLeod mix design method.
 - Each agency's modification may be different.
- All four agencies had similar air and surface temperature minimum limitations.
- Caltrans and Spokane County have maximum surface temperature limitation.
 - May aid in curing, as excessively high temperatures may prolong cure times.
- All four agencies' specifications recommend tack coat activities.
 - May or may not actually be used in practice.
- MnDOT and Spokane County both require test strip to check application rates.
 - Should be done every project.

- All four agencies had temperatures to which the asphalt material was to be heated for application.
- MnDOT, Spokane County and TxDOT require a minimum number of roller passes.
- All four agencies continuously monitor for non-uniformity in the application rates of both the aggregate and asphalt binder.
- All four agencies require non-uniformity to be corrected.
 - MnDOT and TxDOT may require a test strip to be constructed.
- Caltrans and TxDOT allow for a reduction in the wheel path asphalt binder application rate.
- All four agencies test aggregates and asphalt binders as a part of both QC and Acceptance.
 - Similar tests include L.A. Abrasion, Gradation and Sand Equivalent for aggregate.
 - TxDOT uses materials tests for QC only.

Areas for Improvement

Areas that could be improved include:

- Increasing the experience and training of inspection personnel.
 - Significant turn-over of inspection personnel and reduced emphasis on implementing inspection practices contributes to the issue.
- Creating stronger QC and Acceptance specifications.
- Increasing equipment calibration frequency and mandating that calibration be conducted.
 - Should be checked prior to the construction of every project.
 - The equipment manufacturers' calibration procedures shall be followed.

- Staggering the haul trucks across the newly-constructed chip seal treatment when loading the chip spreader, if possible.
- Selecting the proper project.
 - Severely distressed pavements are not ideal candidates for chip seals.

Slurry Seal

Specification Best Practices

Identified slurry seal best practices include:

- Using only Type II mixes,
- Awarding projects to competent Contractors, and
- Using separate documents for sampling and controlling slurry seals

In general, slurry seal practices used in each agency's specifications were similar, with the main difference occurring in the materials, mix design and QA sections. There was not a common QA practice conducted by any of the agencies.

This may be due to how each agency uses slurry seals and how often.

- All three agencies use CQS/QS emulsion and at least one 3/8-inch MAS aggregate gradation.
- All three agencies use Sand Equivalent as an aggregate quality test.
- The City of Columbus and VDOT allow Portland cement to be used as a mineral filler and base the required emulsion materials proportions on residual asphalt content, rather than emulsion content.
 - May aid in reducing asphalt content variability.
- Caltrans and the City of Columbus use the ISSA mix design method.

- Caltrans and the City of Columbus both require that two mixer-spreaders are to be on-site for continuous operation or in the event of a breakdown in one of the machines.
 - Caltrans' requirement applies only to truck-mounted mixers.
- All three agencies have similar minimum air and surface temperatures do not allow construction if freezing temperatures are predicted in the next 24 hours.
- Caltrans and the City of Columbus both recommend tack coats.
- All three agencies monitor the mixture consistency during construction.
- VDOT and City of Columbus allow the mix proportions to be adjusted.
- Caltrans and VDOT check the equipment operation as a part of the QC process.

Areas for Improvement

Some improvements include the following:

- Include specific equipment calibration practices in the specifications.
 - Should calibrate equipment before construction of every project.
- Continuously update specification details and requirements to reflect the current changes in slurry seal design and construction practices,
- Require a check of the equipment calibration, in the presence of the agency Engineer, on every project.
 - If the agency does not have its own specification calibration requirements, the agency should require the Contractor to follow the equipment manufacturers' calibration.

- Test strips should be required to be conducted prior to the construction of every project.

Micro Surfacing

Specification Best Practices

Identified micro surfacing best practices include:

- Enforcing winter shutdowns in wet-freeze climate zones,
- Monitoring asphalt content during placement, and
- Ensuring that the Contractor always has a certified technician on site,
- Screening oversized particles during the proportioning phase
 - May not be feasible from a dust-control perspective; Contractor should work closely with aggregate producers to ensure that oversized particles are screened out.

In general, there was a greater difference in common practices between agency micro surfacing specifications, as compared to the agency specifications for chip seals and slurry seals. The greatest difference was in the Quality Assurance requirements of each agency. There were not any common practices identified, apart from all three agencies requiring some form of materials testing as a part of QC and/or Acceptance.

Common specification practices include:

- All three agencies require the use of an emulsion that is modified with latex.
- All three agencies allow Portland cement may be used as a mineral filler.
- MnDOT and VDOT also indicate hydrated lime can be used.
- All agencies use ISSA mix design method, except VDOT, which uses its own method.

- All three agencies indicate similar minimum air and surface temperatures.
- All three agencies indicate that the treatment is not to be placed if freezing temperatures are predicted in the next 24 hours.
- MnDOT and VDOT both require fog seals.

Areas for Improvement

Improvements can be made to micro surfacing specifications by:

- Incorporating more personnel training and gaining more experienced construction personnel,
- Improving and implementing QA programs,
- Checking the daily yield or treatment thickness to ensure that the correct amount of material is being placed,
- Improving the review and approval process used for allowing mix design changes,
- Controlling the amount of moisture added to the mix,
- Allowing a softer base asphalt to be used for emulsions,
- Revising the current specifications to address dynamic changes in micro surfacing practices,
 - Focus primarily on inspection practices.
- Using a mix design method that adheres to any current accepted methods, and
- If using an annual equipment calibration requirement, test strips must be performed at the beginning of every project.
 - Ensures that the calibration is sufficient.
- If it is practical, equipment calibration could be checked prior to the construction of every project.

Thin Lift Asphalt Overlay

Specification Best Practices

Best practices include

- Requiring warranties on thin lift asphalt overlay treatments,
- Requiring full-time inspection and verification testing.
- “Verify and Document” everything,
- Using a paver segregation specification, and
- Requiring the Contractor to operate an accredited mix design laboratory.

In comparison to the other preservation treatments, there were more common agency specification practices for thin lift asphalt overlay treatments. This could be due to agency use of industry hot-mix asphalt mix design and construction standards, as well as the experience each agency possesses in the construction of hot-mix asphalt layers. Again, the main difference is in the Quality Assurance specifications used by each agency. Common practices are included below:

- FDOT and ODOT indicate polymer-modified PG76-22 asphalt binder.
- Caltrans and FDOT indicate the use of liquid anti-strip.
- MDOT and ODOT indicates the use of RAP and mineral filler.
- All four agencies use the Superpave mix design method.
- Caltrans and FDOT both test for moisture susceptibility in accordance with AASHTO T283.
- MDOT and ODOT both indicate that the Contractor must submit aggregate and binder samples to the agencies for mix verification.

- Three of the agencies require a Material Transfer Device or Vehicle to be used.
 - Aid in preventing mix segregation.
- All four agencies require similar minimum air and surface temperatures before construction can begin.
- MDOT and ODOT both have seasonal limits for construction.
 - Both agencies are in a wet-freeze climate, so enforcing wintertime shut downs is key to successful thin lift asphalt overlay treatments.
- FDOT and MDOT indicates applying a tack coat as part of surface preparation.
- FDOT and ODOT indicate that the mixture spread rate is monitored to ensure that it remains within $\pm 5\%$ of target rate.
- All four agencies use the mat temperatures to begin and end compaction activities.
 - Key to achieving optimum density.
- FDOT and MDOT require warranties for thin lift overlay treatments.
- Three agencies use Gradation, Asphalt Content and Air Voids as QC and/or Acceptance tests.
- FDOT and ODOT both use Lots for QC and Acceptance testing.

Areas for Improvement

Improvements can be made by:

- Implementing incentive/disincentives for smoothness,
- Increasing field density requirements,
 - Aid in prolonging the treatment life.

- Checking equipment calibration prior to every project.

Chapter 5 Case Study Documentation

Introduction

This chapter will present the case studies that were collected during the course of the project. As was stated in Chapter 2, two case studies were collected for each treatment, except for micro surfacing. The primary documents that were desired were the agency specifications—especially any special provisions, mix design, inspection and construction records, and any performance records. The case studies are from Caltrans, the City of Columbus, FDOT, MDOT, Spokane County and VDOT. Caltrans' documentation was collected during a site visit that was conducted during the construction of an asphalt rubber chip seal project. The City of Columbus provided the entirety of a slurry seal preservation program. FDOT provided documentation for two thin lift asphalt overlay projects. MDOT also provided similar documentation for two thin lift asphalt overlay projects. Spokane County provided documents for a chip seal project, and finally, VDOT provided documentation for a slurry seal and micro surfacing job.

It is important to note that some of the case studies provide more detail when compared to others. This is due to the availability and accessibility of the requested documents. Some of the agencies did not have readily available records for the given projects but were able to provide sufficient detail to outline the project's construction practices.

California Chip Seal

Description

An asphalt rubber chip seal was applied on a two-lane highway with narrow shoulders (approximately 3 ft) on US 395 between Mile Post 119-128.7, northeast of Susanville, CA. Construction began on July 7, 2017, and continued to July 8, 2017, when the documents were collected. The aggregate, asphalt rubber binder, and hot mix plant used to produce the pre-coated chips were all located in Alturas, California, approximately 30 minutes north of the project.

The existing pavement was surfaced with a chip seal that had been applied in 2009 (8 years prior). Surface preparation included some repairs and very limited crack filling. The pavement appeared to be in relatively good condition with any structural deficiencies repaired by dig outs (areas of pavement that have been removed and replaced, particularly in wheel paths).

Documents

The primary specification that was used was the Caltrans 2015 Revised Standard Specifications, under Division V—Surfacing and Pavements, Section 37-2.05—Asphalt Binder Seal Coats. A special provision was added to the project that required a maximum L.A. Abrasion loss of 25%, to mitigate wintertime damage from chains, studded tires and plows. The construction records that were collected are presented in picture format. Figure 5.1 displays a photograph of the inspector's application rate calculations.

13. Recycled screenings
PM 120.15 - 7.5-17
M. Ferrer

Area	Width	Length	Area	Total
120.15 - 120.50	18.49	16.5	3390 yd ²	61.7
120.5 - 121.0	2640 X	16.25	4767 yd ²	85.8
121.0 - 121.5	2640 X	16.25	4767 yd ²	85.8
121.5 - 122.0	2640 X	16.4	4811 yd ²	86.6
122.0 - 122.5	2640 X	33	9680 yd ²	174.2
122.5 - 123.0	2640 X	33	9680 yd ²	174.2
123.0 - 123.5	2640 X	32.75	9607 yd ²	172.9
123.5 - 124.0	2640 X	32.5	9533 yd ²	171.6
124.0 - 124.5	2640 X	32.5	9533 yd ²	171.6
124.5 - 124.6	528 X	32.5	1907 yd ²	34.3
				1044 sq ft

Figure 5.1. Photo. The senior field inspector's calculation for application rate verification.

The asphalt binder was a PG64-16M binder, modified with 21% CRM by weight. The aggregate type was not available, but consisted of a 3/8 inch, single-sized aggregate that was pre-coated with 0.5-1% of asphalt binder. The sand seal specification required use of aggregate type. The type of sand and its gradation were not determined.

Caltrans is the designer of record for chip seal projects in this district—District 2. The designer provides the Contractor only with the aggregate and asphalt binder application rates. All other materials requirements are outlined in the specifications. The target asphalt binder application rate was 0.58 gal/yd² and the target aggregate

spread rate was 35 ± 1 lb/yd². The emulsion application rate for the sand seal was 0.12 gal/yd².

During production, the aggregate was sampled and tested for Gradation and Cleanness Value. During start-up and throughout production, binder is sampled and sent to an independent laboratory for Acceptance testing, primarily Softening Point and Viscosity at 375°F. On-site binder tests included viscosity, sieve analysis, and flash point.

One asphalt storage container, two binder distributors equipped with an emission capture apparatus, one aggregate spreader—with a second one ready in case of break downs, thirteen haul trucks, two pneumatic-tire rollers, one front-steel-drum roller with two pneumatic rear tires, seven sweepers, an emulsion distributor and a blotter truck were all present at the jobsite. Figures 5.2 and 5.3 show some of the more unique pieces of equipment. Figure 5.2 shows one of the distributor trucks with an emission apparatus. These are necessary when using asphalt binders modified with CRM at elevated temperatures. The project's binder temperature range was 385-415°F. Figure 5.3 shows the single-drum roller used on the project. While there is not a detail in the Caltrans specifications regarding equipment calibration, the Senior Field Inspector indicated that the equipment is expected to arrive on the jobsite calibrated. The calibration was indirectly verified daily with inspection of meters on the equipment and raw material plus total production quantity reconciliation. The Inspector further indicated that calibration is dependent upon existing conditions, the weather and material type. Other equipment employed requiring calibration were the asphalt rubber plant and hot mix plant located at the hot plant site in Alturas. Both had

to be calibrated per the Caltrans MPQP requirements (109) and verified by Caltrans Independent Assurance (IA) prior to use.



Figure 5.2. Photo. Asphalt binder distributor with emissions capture apparatus.



Figure 5.3. Photo. Single-drum steel roller.

As the project was constructed in the summer, the minimum temperature requirement was met, with an ambient temperature of 52°F and a surface temperature of 56°F when construction began. The project's surface preparation included limited

dig out repairs and very limited crack filling. The pavement appeared to be in relatively good condition, with any structural deficiencies repaired by the dig outs. No other surface preparation practices were determined.

The project's inspection process followed several required practices, such as monitoring the application rates and asphalt rubber binder temperature ranges. The driving lanes and shoulders were treated separately with the driving lane always treated first. Following specification requirements, construction joints were marked using builder paper. Two distributors were on site, one driving in front of the other. This allowed for the front-most truck to begin application once the back-most truck was empty, resulting in a near-continuous operation.

The application monitoring resulted in a uniform treatment. Figure 5.4 is a close-up of the chip seal surface after rolling. The entire construction process was continually monitored by both Caltrans and the Contractor. Haul trucks were continuously rotating and unloading the chips into the spreader hopper, keeping it full at all times. Rolling was quick, being conducted with two pneumatic rollers and the single-drum steel roller. The rollers engaged in an overlap pattern and performed two passes. Finish rolling was conducted by the steel-drum roller, consisting of four passes.



Figure 5.4. Photo. Final chip seal.

The sweeping operation included all seven sweepers continuously sweeping. This project had a flush coat—sand seal—applied, consisting of an SS-1 emulsion applied at a rate of 0.12 gal/yd^2 , followed by a coat of sand. **Error! Reference source not found.**5 shows the sand distribution process. The inspector monitored the application rates with daily hand calculations to verify that the values shown on the distributor and spreader were equal with the hand calculations and also within specification tolerances. The calculations also verified that the equipment calibration was accurate. **Error! Reference source not found.** illustrated an example of this calculation process. Throughout the duration of the project asphalt binder application rates ranged from $0.58 \text{ gal/yd}^2 \pm 0.05$ and aggregate spread rates were from $34.6\text{-}37 \text{ lb/yd}^2$. Both values were within the specification tolerances of $0.55\text{-}0.65 \text{ gal/yd}^2$ and $28\text{-}40 \text{ lb/yd}^2$ for the binder and aggregate, respectively.



Figure 5.5. Photo. Distributor applying sand.

The pre-coated aggregate experienced a change in asphalt content. During construction, the pugmill at the mixing plant broke down and needed to be replaced, during which time, the asphalt content was increased from 0.5% to 1% by the resident engineer. Once replaced, the asphalt content was reduced to 0.5%. As this project was constructed on a two-lane road, the treatment was swept for four consecutive days and traffic was controlled via pilot car. Post-construction monitoring for this project consisted of monitoring the treatment for 15 consecutive days after final sweeping, repairing any failures. Repairs had not been made on the areas that were treated prior to the project visit.

The Contractor's QC required testing the asphalt rubber binder only. The asphalt rubber binder was produced at the mixing plant used to produce the pre-coated aggregate, located 30 minutes away, in Alturas, California. The mixing plant is CT 109-certified. The Quality Assurance Field Inspector on-site witnessed the sampling of the virgin and blended binder as shown in **Error! Reference source not found.6.**

The inspector also monitored the temperatures of the virgin and asphalt rubber for specification compliance. Certificates of compliance were provided and collected during this process.



Figure 5.6. Photo. Binder sampling.

Acceptance activities included inspection, sampling, and testing of the aggregates. The aggregate was sampled and tested for quality at start-up, per Caltrans' specifications. A sample of pre-coated aggregate was also taken daily (Figure 5.7) These samples were tested for Gradation and Cleanness Value.



Figure 5.7. Photo. Pre-coated aggregate sampling

Quality Practices

Several inspection practices were observed on this project and they were clearly selected for the specific project traffic, climate, and construction conditions. The first practice was in project selection, as the relatively good pavement condition and dig-out repairs of structurally-deficient areas provide for high performance success. Examples include specifying: a very tough aggregate in an environment with tire chain/studded tires and snow plow exposure; asphalt rubber binder; and a steel drum finish roller. The use of a steel drum roller appeared to be beneficial and not destructive, likely because of the low L.A. Abrasion loss requirement for the specified aggregates. Plant and construction equipment calibration requirements were adhered to leading to positive construction. The distributors were properly calibrated, applied a uniform spread and did not leave streaks or puddles of binder on the surface. The

chip spreading operation followed within seconds of applying the binder and provided complete and uniform coverage of the hot asphalt rubber binder.

Continuous daily on-site inspection, sampling and testing of the materials all ensured that a quality product would be placed. The inspection further ensured that good workmanship practices were followed and that any corrective measures that were needed would be implemented in a timely manner. Requiring the distributor to start and stop application on builder paper ensured proper transverse joints were created. Sweepers were able to keep loose chips down and there was proper signage. Pilot car operations ensured adequate flow and maintained traffic at a speed of 15 mph or less.

Table 5.1 presents a summary of identified Caltrans inspection practices that led to quality chip seal projects. As can be seen, many of the identified practices are contained within the specifications. One can reasonably assume that this may be due to some of these practices originally being “test” practices, but due to the positive effect that was displayed in the initial and subsequent projects, were incorporated into Caltrans’ specifications. As will be shown in subsequent sections, project selection is a key factor in determining the overall success of a preservation treatment. However, the actual parameters that go into selecting the proper project is beyond the scope of this study.

Table 5.1. Summary of Caltrans Inspection Practices for Quality Projects.

Practice	In Specifications?	How Practice Affects Quality
Project selection.	No	Early distresses not an issue.
Low L.A. Abrasion Loss value for aggregates.	Special Provision.	Prevents wintertime damage for increased treatment life.
Inspection based upon site-specific conditions.	No	Adjusts inspection tasks and goals to accommodate variations across projects.
Surface preparation	Yes	Although dig-outs not specified, were needed as part of surface preparation to repair structurally deficient areas to prevent early chip seal distresses
Use of asphalt rubber binder and pre-coated aggregates.	Yes	Enhances aggregates retention.
Proper equipment calibration.	Yes	Proper application is achieved.
Daily and continuous inspection.	Yes	Maintains consistency and specification compliance
Effective communication.	No	Allows both entities to create a good project.

Spokane County Chip Seal

Description

This case study is based around visits to multiple chip seal projects that Spokane County has constructed in the previous decade. Twelve post-construction projects and one project that was under construction were visited. The case study documentation was determined via an on-site interview.[19] One post-construction site was a project constructed on Hayford Road in Spokane County, 9 miles northwest of Spokane. The roadway is a main arterial with an ADT of 16,000 vpd and 20% truck traffic. The project was constructed in 2015.

Documents

The Hayford Rd. project was constructed using the requirements outlined in the Washington Department of Transportation's Standard Specifications for Road, Bridge, and Municipal Construction 2016, Division V—Surface Treatments and Pavements, Section 5-02—Bituminous Surface Treatment.

The project's mix design included a CRS-2P emulsion and a 3/8 inch single size basalt aggregate. The treatment was given a CSS-1h emulsion fog seal post-construction. As was stated in Chapter 4, Spokane County performs crack sealing treatments one year prior to construction. Patches of 3/8 inch HMA are also applied at this time. Spokane County owns the pressure distributors, aggregate spreaders, pneumatic-tire rollers, static steel drum roller, and end dump trucks, calibrates and maintains the equipment, and constructs all chip seals. During construction, the emulsion is sprayed four inches past the pavement's edge and the joints are overlapped by four to six inches.

Quality Construction Practices

Table 5.2 outlines the observed practices. As can be seen, none of these practices are in the specifications used by Spokane County. This is critical, in that it shows that other practices are conducted outside those that are written in the specifications to achieve a quality product.

Table 5.2. Summary of Quality Spokane County Practices.

Practice	In Specifications?	How Practice Affects Project Quality
Rubberized crack seal and patches one year before construction	No	Ensures adequate curing of crack seal treatment, which will prevent swelling in chip seal.
Proper equipment calibration and maintenance	No	Ensures that application rates will be uniform across all projects
Frequent personnel training	No	Ensures that, even if there is high turn-over, all chip seal crew members are competent and aware of the workflow and processes needed for quality.

City of Columbus Slurry Seal

Description

This case study presents a city-wide preventive surface treatment program. It involved placing slurry seal mix in 18 areas around Columbus, Ohio on 209 street segments. The total treated surface area was 560,000 yd². Being residential streets, the traffic is low volume and the routes are two-lanes. The project was constructed between August and November 2016 and was selected as a case study because the construction had few problems. Figure 5.8 below is one of the plan sheets for the project showing a group of street segments designated for slurry seal treatment. Note that the segments to be treated have a segment number for purposes of documenting progress and quantities. Also note that not all streets in this residential area received treatment.

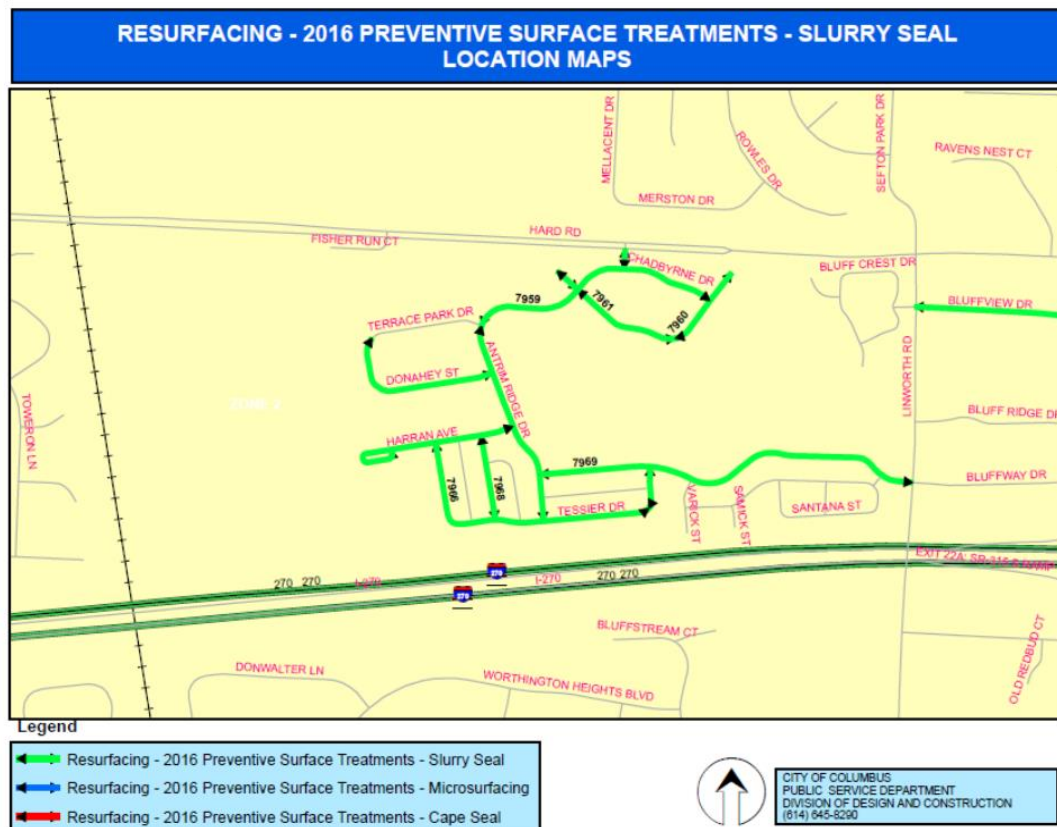


Figure 5.8. Photo. Map of street segments designated for slurry seal in City of Columbus.

Documents

The construction specifications used for this program are Item 400—Flexible Pavement, Item 417—Asphalt Emulsion Slurry Seal, and Supplement 1032—Asphalt Material Certification Requirements. The JMF used on the project was prepared by the contractor and emulsion supplier and is dated September 2, 2016. The slurry mixture is a 3/8 inch limestone, 1.0% cement, 13.0% CSS-1h emulsion, 11% water, and 0.02% additive. The mix design shows the material proportions, aggregate and emulsion data, and mix design test results. All JMF values complied with the specification's values, except the L.A. Abrasion result. Table 5.3 shows some of the test results for the mix design.

Table 5.3. City of Columbus Slurry Seal JMF.

Slurry Mix Properties	Results at 13% Emulsion
Mix time @ 77F (25C), TB113	250 seconds
Mix time @ 100F (37.7C), TB113	44 seconds
Cohesion @ 30min, TB139	17 N kg-cm
Cohesion @ 60min, TB139	23 N kg-cm
Water Resistance Test, 30 min	Pass
WTAT 1 hour, TB100	3.3 grams/ft ²
Cone Consistency Flow	3 cm
Set Time Blotter Test	Pass
Coating Test	99%
Excess Asphalt/Sand Adhesion, TB109	24.7 grams/ft ²
Gradation (Percent Passing)	
Passing 3/8 inch	100%
Passing No. 4	99%
Passing No. 8	79%
Passing No. 16	54%
Passing No. 30	36%
Passing No. 50	25%
Passing No. 100	20%
Passing No. 200	14.7%

An aggregate load ticket for September 21 was provided, as well as an example emulsion shipping ticket for September 21, a yield report, and the inspection records for the entire project. Other items included in the project's scope were crack sealing and patching, ADA curb repairs and placing permanent markings. The relevant work was conducted from September 21 to October 17. Each day, 17,000-18,000 yd² of mix were placed using several mixer-spreader machines. The specification requires a minimum of two slurry trucks to provide a nearly continuous operation, which was provided here.

Six inspectors are listed on different days. The primary documentation on the inspection reports were quantities placed on each roadway segment. Very few inspection reports note quantities of aggregates or emulsion delivered to the project. The Contractor documented one yield report on September 21, the first day of slurry

placement, which covered 18,501 yd² at an emulsion content of 13.33 and aggregate spread rate of 16.03 lb/yd².

Quality Construction Practices

Table 5.4 presents a summary of identified City of Columbus inspection practices that lead to a quality slurry seal placement project. As can be seen, only one practice was actually written in the specifications, with the other two being considered quality practices regardless of inclusion.

Table 5.4. Summary of Quality City of Columbus Practices.

Practice	In Specifications?	How Practice Affects Quality
Project size	No	Consistency can be achieved with increased project size.
Inspection	No	The city had an inspector on-site for every day of slurry seal treatment placement. As was discussed, continuous inspection is required to monitor the quality during construction.
Provide a nearly continuous operation, minimum of two slurry trucks.	Yes	Continuous operation provides consistency to placement, as there does not need to be a cease in production in the event of breakdowns or other issues.

Virginia Slurry Seal Project

Description

This project involved slurry seal construction on ten roads using Type B and Type C slurry seal mixes. All of the roads were two-lane and in rural areas. Type B mix was placed on King George county roads 1108 and 1101, Richmond County route 1010, and Lancaster County route 354. Type C slurry seal was placed on Westmoreland County route 621, Lancaster County routes 637, 709 and 675, Northumberland route 621, and Spotsylvania County routes 656 and 1368. Construction occurred between March 2014 to May 2014.

Documents

The primary specification that was used was the SP312-000100-00—Special Provision for Emulsified Asphalt Slurry Seal. One JMF was created on February 26, 2014. It was approved by VDOT. The approved JMF design summary includes the aggregate source and gradation, emulsion type, design emulsion rate and the mix design test results. The target residual asphalt content is $8.5 \pm 1.5\%$.

The Type B slurry seal mixture consists of granite aggregate with a 3/8 inch MAS, 1.0% hydrated lime, cement mineral filler as needed, and CQS-1H emulsion. All of these materials are written in the special provision, so the use of these materials is in compliance with the specifications. A summary of the JMF gradation is shown in Table 5.5 below. VDOT did not provide the JMF for the Type C mix.

Table 5.5. VDOT Slurry Seal Gradation

Sieve Size	Specification Type B	Mix Gradation Percent Passing
3/8 inch	100	100
No. 4	70-95	94
No. 8	45-70	65
No. 16	32-54	45
No. 30	23-38	34
No. 50	16-29	26
No. 100	9-20	17
No. 200	5-12	9.1

VDOT provided two types of construction records for the case study project, including asphalt mixture laboratory tests on Form TL-50 and application rate checks. VDOT provided five mixture test reports for the Type B mixture ranging from sample dates of March 21 to May 4. All of the reports showed that each sample represented exactly 20,000 yd². The specification for mix sampling and testing requires that samples represent a maximum 25,000 yd² at the start of production and can be increased to one sample per 50,000 yd² once the mixture has become consistent in quality.

The residual asphalt content was between 7.12% to 7.98% for the first three samples and increased to 9.34% and 9.83% for the last two samples, all within the 8.5±1.5% tolerance range. The percent of material passing the No. 200 sieve ranged from 13.0% to 14.6% which were on the high side of the target range of 5 to 15%. VDOT provided an aggregate application rate report on March 31 for the Type B slurry seal mixture. The aggregate spread rate for the report was 15.37 lb/yd² which is lower than the specification's 16 lb/yd² target.

Nine mixture test reports for the Type C slurry with sample dates of April 8 to May 15 were also provided. Each listed the quantity of mix the sample represents. Six

of the reports lists quantities from 70,000 to 170,000 yd². Some only list the residual asphalt content, which, for all nine reports, ranged from 6.44% to 7.58%. The tolerance range was 5.7-8.7%. VDOT provided ten aggregate application rate reports from April 8 to May 19. The aggregate spread rate for the reports ranged from 19.44 to 21.88 lb/yd² with a specification target of 20 lb/yd². Projects records did not include data on placement temperature, equipment calibration, and time to open to traffic.

Quality Construction Practices

Table 5.6 presents a summary of the practices that VDOT carried out, which led to constructing quality slurry seal treatments. Note here that two of these practices are within the special provision regarding slurry seals, whereas the other two are practices that are conducted, but are not necessarily a requirement. This is critical in understanding that, while specification practices are very important for consistency across projects, these are not the only practices that can lead to quality projects.

Table 5.6 Summary of Quality VDOT Practices

Practice	In Specifications?	How Practice Affects Quality
Project size.	No	Combining multiple routes into one allows for one mix to be used, which will lead to consistency of the material being placed. May also be beneficial from a budgetary standpoint.
Require a certified technician on site.	Yes	Certified technicians know how to monitor consistency and know which corrective action to take, if needed.
Frequent sampling and testing for asphalt content.	Yes	Residual asphalt content is a major part of consistency and performance.
Checking application rate.	No	Further monitors consistency, leads to uniform treatment.

Virginia Micro Surfacing Project

Description

Three routes were given a micro surfacing treatment. All of the routes are rural, two-lane roads. The routes are Caroline County route VA-207, Richmond and Northumberland Counties route US-360, and Lancaster County route VA-200. Construction took place from March 2014 to May 2014. Approximately 2,100 tons (or 200,000 yd²) of material was placed.

Documents

The construction specification relevant to this project is: SP312-000110-00—Special Provision for Latex Modified Emulsion Treatment (Micro Surfacing). The micro surfacing type was Type C and was prepared by the Contractor's emulsion

supplier on March 10, 2013. Another JMF using the same design was created on February 21, 2014. The mix design included the aggregate source and gradation, emulsion type, test results on the mixture at three asphalt contents, design asphalt content, and the mixture properties. The design asphalt content rate is based on 4.7% air voids in the compacted mix and is reported as residual asphalt by total weight of mix. Residual asphalt is expressed by dry weight of aggregate. The report also includes Schulze-Breuer Compatibility for Water Absorption, and Abrasion Loss. The residual asphalt content range is $6.9 \pm 1.5\%$. The micro surfacing mixture consisted of No. 4 NMAS granite aggregate, 1.0% cement mineral filler, CQS-1HLM emulsion and a field control additive. A summary of the JMF is shown in **Error! Reference source not found.7**.

Table 5.7. Type C JMF for the Micro Surfacing Project from VDOT.

Micro Surfacing Mix Properties	Results at 6.5% Residual Asphalt	Specification Type C
Average Marshall Stability, VTM-95	3,163 lb	N/A
Average Marshall Flow, VTM-95	0.14 inch	N/A
Average Voids in Total Mix	5.3%	N/A
Average VMA	18.3%	N/A
Asphalt Absorption	1.89%	N/A
Water Absorption, Schulze-Breuer	7.0%	N/A
Abrasion Loss, Schulze-Breuer	3.2%	N/A
Ignition Oven Correction Factor	0.042	N/A
Gradation (Percent Passing)		
Passing 3/8 inch	100%	100
Passing No. 4	85%	70-95
Passing No. 8	55%	45-70
Passing No. 16	39%	32-54
Passing No. 30	30%	23-38
Passing No. 50	24%	16-29
Passing No. 100	16%	9-20
Passing No. 200	8.9%	5-12

VDOT submitted emulsion tank reports, laboratory tests and application rate verification forms. The emulsion supplier provided 29 certified asphalt emulsion test reports for March 14 to May 12. Test results are from the Sieve Test, Particle Charge, and Asphalt Percentage, Penetration, and Softening Point (last three tested on residual asphalt). All tests complied with the special provision's requirements.

Six mix test reports were submitted for March 20 to May 2. Among other items, the report listed the quantity of mix the sample represents, typically 500 tons, as required by the special provision. The reports only list the aggregate gradation and residual asphalt content. The residual asphalt content ranged from 5.84 to 7.22% (JMF range was 5.4 to 8.4%). The P-200 ranged from 11.6 to 14.1% which were at or above the target range of 5 to 12%. Three samples were delivered to the lab the day they were sampled, and three samples were delivered one to seven days after sampling. Eleven aggregate application rate reports were submitted for March 20 to May 9. The spread rate ranged from 19.77 lb/yd² to 27.08 lb/yd², with a theoretical spread rate of 24 lb/yd², the maximum value allowed in the special provision. The actual special provision application range for Type C mix is 20-24 lb/yd², so some of the reports noted values that were out of tolerance.

Quality Construction Practices

8 presents a summary of identified VDOT inspection practices that lead to a quality micro surfacing placement project. As can be seen, only one practice was not included in the specifications. Larger project sizes ensure that consistency can be met, and a uniform mix can be placed. Both factors lead to long-term performance success.

Table 5.8. Summary of Quality VDOT Practices.

Practice	In Specifications?	How Practice Affects Project Quality
Project size	No	The project combined three route segments to achieve 200,000 yd ² of placement.
Collection of emulsion tanker shipment tickets	Yes	The tickets provided a good record of emulsion quantity and quality.
Routine checks of residual asphalt content every 500 tons of mixture placed	Yes	Residual asphalt content is key to treatment consistency and performance. Routine measures of residual from micro surfacing is important.
Routine checks of the treatment application rate	Yes	This QA practice monitors the consistency of the micro surfacing equipment spread rate.

Florida Thin Lift Asphalt Overlay

Description

This thin lift asphalt overlay construction project was conducted on a two-mile two-lane section of US-17 (also Florida Route 5) near the Georgia border with an annual average daily traffic (AADT) of 5,000 vpd. A total of 2,350 tons of FC-9.5 asphalt rubber binder mix was placed. The project was constructed in July 2009.

Documents

The section of FDOT's standard specifications that were used are Section 105—Quality Control Plan, Section 300—Prime and Tack Coats, Section 320—Hot Mix Asphalts – Plant Methods and Equipment, Section 327—Milling of Existing Asphalt Pavement, Section 330—Hot Mix Asphalt—General Construction Requirement, Section 334—Superpave Asphalt Concrete and Section 337—Asphalt Concrete Friction Courses.

Two JMFs were used: SP 08-6327A and SP 6327B (revised version). Both were prepared by an independent laboratory for the Contractor. The surface course was a friction course (FC), 3/8 inch NMAF fine gradation. Both mix designs followed Superpave's mix design procedures with a 75-yr design traffic level. The revision changed the asphalt binder content from 5.5 to 5.8%. Liquid anti-strip was added to the mix at 0.5%. It is not clear what the resulting moisture susceptibility test results were or if the results are compliant with specifications.

9 presents the mix design tests and results for both mixes.

Table 5.9. Thin Lift Asphalt Overlay JMFs.

Mix Properties	SP 08-6327A	SP 08-6327B
Asphalt Binder Content, Pb	5.5%	5.8%
Effective Asphalt Binder Content, Pbe	4.7%	4.8%
Air Voids, Va	4.0%	4.0%
VMA	15.2	15.5
Liquid Anti-Strip	0.5%	0.5%
Mixing Temperature	Target +/- 30°F	Target +/- 30°F
Compaction Temperature	Target +/- 30°F	Target +/- 30°F
Gradation (Percent Passing)		
Passing 1/2 inch	100%	100%
Passing 3/8 inch	99%	99%
Passing No. 4	74%	74%
Passing No. 8	49%	49%
Passing No. 16	38%	38%
Passing No. 30	30%	30%
Passing No. 50	25%	25%
Passing No. 100	12%	12%
Passing No. 200	5.6%	5.6%

The two JMF reports provided information regarding traffic level and design gyrations, materials sources, aggregate gradations and bulk specific gravity for each

type used, the optimum asphalt binder content, mixing and compaction temperatures, mix tests at four binder content values, ignition oven calibration and the warm-mix additive used, if using. All of these items are required per FDOT's specifications.

Three production lots were used, and documentation was provided for all three. The lots were subdivided into 500-ton sublots for testing. The first lot, Lot-2, was 2,000-tons in size. Approximately half of Lot-2 failed meet the density requirement. This section was removed and replaced. Lot-3 was 1,200 tons in size. The JMF was changed at the end of Lot-3. Lot-4 was 94 tons in size. As Lot-4 was too small to subdivide, the entire lot was tested. FDOT uses Percent Within Limits (PWL) pay factors for the percent of material passing the No. 8 Sieve (P_8), the percent of material passing the No. 200 sieve (P_{200}), binder content (P_b) air voids (V_a), and core density. FDOT also requires QA testing for smoothness, but this documentation was not submitted.

Construction for Lot-2 was conducted on July 13-14. The tack coat was placed first, at a temperature of 160°F and an average application rate of 0.06 gal/yd², based on the total application length. These values meet FDOT's specification requirements. During the thin lift asphalt overlay placement, the mix temperature upon leaving the plant was between 300-315°F on the first day and 310-325°F on the second. These values also meet the specification requirements. Mixture test results indicated the P_8 gradation results were between 50.8 to 55.3%. The specification target is a maximum of 49.0%, so all of those results failed to meet the requirement.

The Contractor's calculated spread rates were 111 lb/yd² on the first day and 120 lb/yd² on the second. The target was 110 lb/yd², which meets the specification requirements. FDOT also calculated the spread rates and obtained resulting values of

114.9 lb/yd² and 113.6 lb/yd². Field density values ranged from 88.0 to 90.5% of the maximum specific gravity (G_{mm}). The target value was 92% of G_{mm} with a minimum of 89.5% G_{mm} for at least two sublots. These values were not met by the tested cores, which was cause for removing the failed areas and replacing those areas. FDOT tested samples from Lot-2's second subplot. The tests were for Gradation, P_b , G_{mm} , and bulk specific gravity (G_{mb}), core density, temperature, binder Viscosity, tack coat temperature and application rate, and the cross slope. All of these verification tests verified that the Contractor's QC results were accurate and within the specification tolerances.

Lot-3 was constructed on July 14, 15 and 22. The JMF was revised, causing the lot to be deemed a partial lot comprised of two 500-ton sublots and a smaller subplot of 260 tons. The tack coat temperature was 150°F and applied at a rate of 0.07 gal/yd². The temperature of the mix was 300-305°F on the first two days of construction and 310-325°F on the final day. The Contractor's spread rates on the second day ranged from 113 to 127 lb/yd². The target rate was 110 lb/yd². FDOT's calculated spread rate was 112.5 lb/yd² on that same day. The final day of construction saw the spread rate being measured several times, with most values being above 120 lb/yd². FDOT tested samples from the second subplot for field density. Sublot 1 was also tested, although those tests are not available at this time. As with Lot-2, these test results verified the Contractor's accuracy and specification compliance.

Lot-4 was constructed on July 23 using the revised JMF. The lot ended at 94 tons, making it a partial lot. The tack coat was applied at a temperature of 160°F and applied at a rate of 0.04 gal/yd². The mix temperature was 310-325°F and the

Contractor's calculated spread rate was 142 lb/yd², with the same 110 lb/yd² target as the other two lots. All FDOT verification testing confirmed the Contractor's accuracy and compliance.

In contrast to many of the other case studies, performance records were readily available for this project. These records include pavement condition surveys that were conducted from 1976 to 2017. The main distresses that were rated were cracking (all kinds), ride (roughness) and rutting. Figure 59 displays the ratings for the roadway section during this time, from 1990 to 2017. Just prior to the construction of this project, the pavement's cracking rating was only 4.5 out of 10 and the ride rating dropped to 6.6 out of 10. It is not clear what the ratings indicate in terms of being good, fair or poor. Rutting stayed fairly consistent, with only some consolidation-related rutting during the first few years after construction.

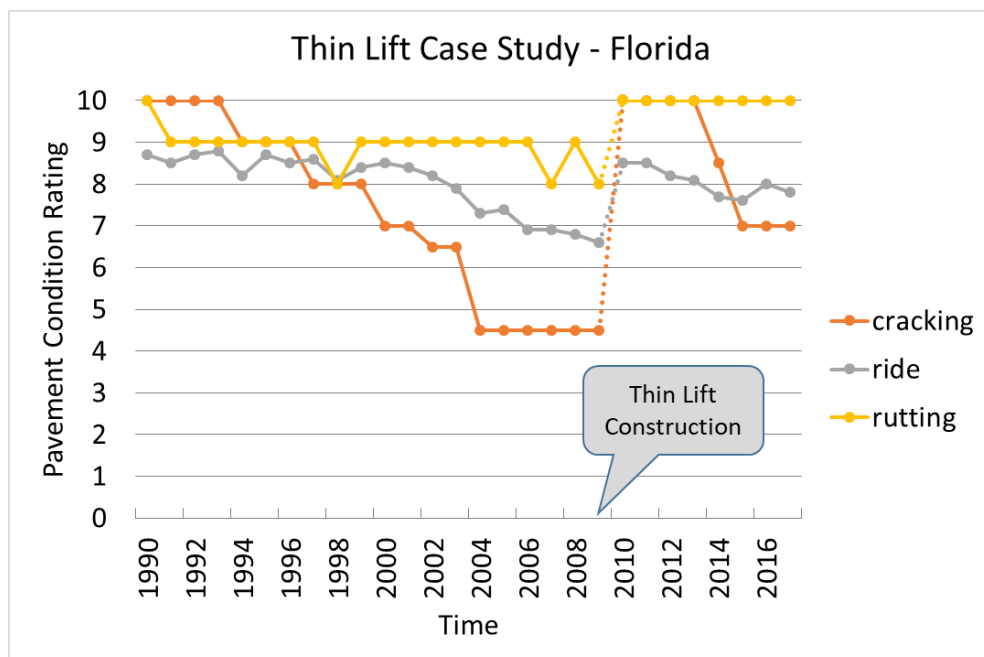


Figure 5.9. Graph. Pavement condition rating as a function of time.

Thin lift asphalt overlay treatment performance is a direct indicator of the condition of the underlying pavement. Any distresses—especially cracking—will be noticeable in the treatment soon after construction, hence the need for proper project and treatment strategy selection. Rutting was low in the existing pavement and remained minor after construction, maintaining a 10 rating after seven years. As expected, high cracking in the existing pavement caused the cracking rating to fall to 7 of 10 after 3 years, primarily in the form of reflective cracking. Ride increased to 8.5 after the treatment, not 10, as thin lift asphalt overlays are often not thick enough to offset the lowered ride quality of the existing pavement. Currently, the performance of the thin lift asphalt overlay is good, especially considering the pavement on which it was placed.

Quality Construction Practices

The single most important practice that was identified was FDOT’s practice of “Verify and Document.” This practice allows both FDOT and the Contractor to keep accurate records for sampling and testing the materials and mix, to carefully monitor the inspection practices that FDOT requires, and allows the entities to quickly determine where an issue is arising so that it can be corrected.

Michigan Thin Lift Asphalt Overlay Projects**Description**

This case study contains documentation from two projects: one on M-123 in the Superior Region of Michigan and one on M-48, also in the Superior Region. The M-123 project was a thin lift asphalt overlay section that was placed in Superior region of Michigan near the town of Trout Lake. It was placed in 2004 and involved

placing 9,092 tons of Low-Volume Hot-Mix Asphalt on approximately 12 miles of M-123. The application rate required by the warranty provision is 83 lb/yd². The total covered area is 206,538 yd². This was a warranty project so there were not any incentives or penalties for Ride Quality or Quality Assurance Results.

The M-48 project was another thin lift asphalt overlay that was near the towns of Raber, Pickford and Detour in 2013. A total of 11,084 tons of mix was placed on approximately 16.1 miles of M-48 at the warranty provision's required rate of 83 lb/yd². This was also warranty project so again, there were not any incentives/penalties for Ride Quality or Quality Assurance Results. Both roads had asphalt concrete pavements and traffic was controlled throughout the projects' durations.

Documents

The primary specifications that were used were Section 501—Plant-Produced Hot Mix Asphalt from MDOT's standard specifications and the warranty provisions 12SP504(C)—Special Provision for Warranty Work Requirements of Ultra-Thin Asphalt Overlay and 12SP500(B)—Special Provision for Pavement Performance Warranty. The JMF used on both projects was prepared by one Contractor. The mix design requirements are presented in Table 5.10. The asphalt binder grade information is not currently available for either project. The first thin lift asphalt overlay was completed on July 29, 2004 and the second was completed on August 22, 2013. Both construction dates were within MDOT's seasonal limit requirements.

Table 5.10. Mix Design Requirements from Michigan.

Mix Properties	Values
Percent Air Voids	4.5%
VMA	15.5%
Fines-to-Binder Ratio (Dust Proportion, %)	1.4% Max
Gradation (Percent Passing)	
Passing 1/2 inch	100%
Passing 3/8 inch	99-100%
Passing No. 4	75-95%
Passing No. 8	55-75%
Passing No. 30	25-45%
Passing No. 200	3-8%

Quality Construction Practices

Table 5.11 presents two important practices that lead to the quality of these thin lift asphalt overlay projects. Both projects were nominated for—and in the case of the M-123 project, won—an award for the quality of the project, due in no small part to these practices, in addition to others.

Table 5.11. Summary of Quality MDOT Practices.

Practice	In Specifications?	How Practice Affects Quality
Warranty Project	Yes	Guarantees good workmanship and adequate performance.
AADT-based binder grade requirements	Yes	Ensures adequate project-specific grade for both traffic and climate.

Chapter 6 Evaluating the Impacts of Implementing Best Practices in Preservation Treatment Construction

While this research presents a rather thorough review and discussion of how to properly construct pavement preservation treatments based on current specifications, there is little information concerned with how these treatments impact the road user. These impacts could be the improved comfort of the user, reduced carbon emissions, improved skid resistance, delay in the need for a more time-intensive and costly rehabilitation or reconstruction alternative, or a combination. In this chapter, the focus will be on how a few of these impacts—namely, carbon emissions—can be measured. An experimental outline will be created that can be used to compare the difference in carbon emissions during construction between treatments that are constructed using practices that are not identified as being “best” practices versus those constructed using a select few of the best practices that were identified in this study. The reference state for using the “best” practices is to use these practices in lieu of conventional practices that have not resulted in well-performing treatments.

Carbon emissions are a part of the carbon life cycle. The carbon life cycle is a biological process that describes the various phases and forms that carbon takes as it moves through the environment. The carbon begins as an element in the earth and is used to create a product. The product is used and once it is unusable, the carbon within is then returned into the earth through one of several processes. This process is displayed in Figure 6.1.

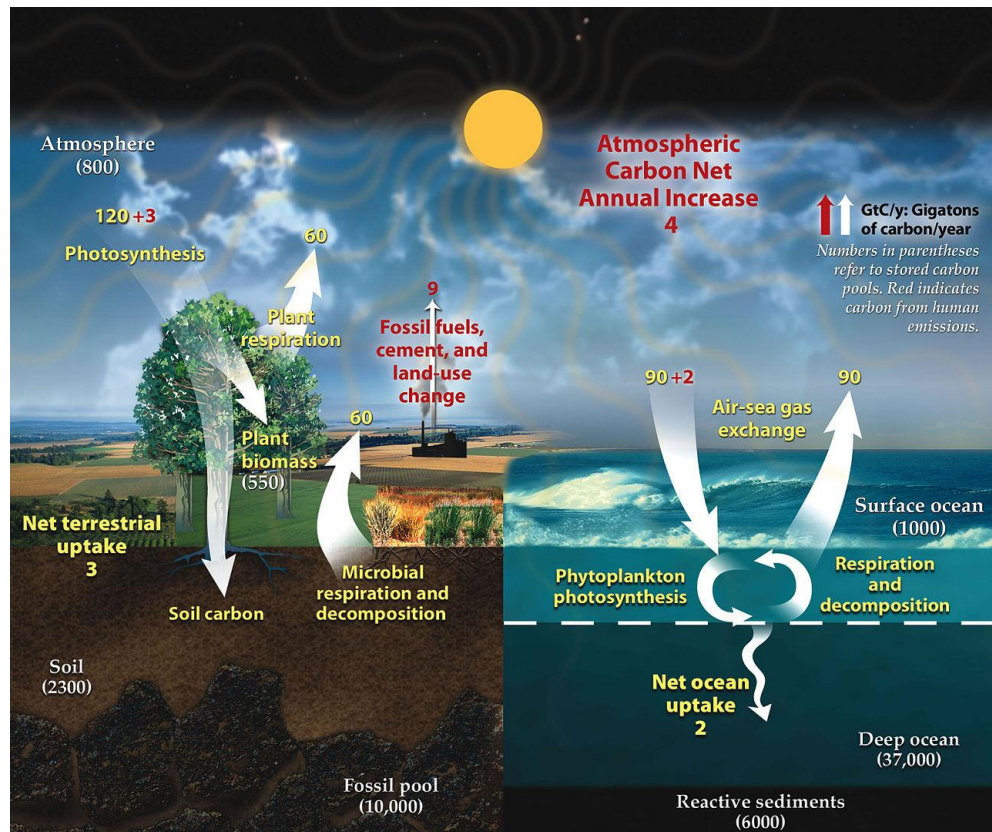


Figure 6.1. Infographic. Carbon life cycle (Source: The NASA Earth Observatory, 2018).

For manufactured products, the carbon exists both in the product as well as in the creation, operation and disposal of that product. For example, in the manufacture of a car, the car itself is manufactured from steel—a carbon-based product. The manufacturing process of that car requires machinery, much of which still relies upon fuel-burning engines, thus emitting carbon into the atmosphere. Another key area where carbon emissions come into play is throughout the life cycle of the car. Assuming the car is run using a standard fuel engine, there are carbon emissions associated with operating the vehicle. The final stage of the car's life where carbon emissions are an issue is in the disposal of the car. Crushing and shipping operations

also rely on petroleum products to run, thus emitting more carbon into the atmosphere.

In the natural carbon process, airborne carbon is returned to the earth during the photosynthetic process conducted by plants. Some of this carbon also enters the ocean and is returned to the earth. If there is enough flora in the environment to “scrub” the atmosphere of all of the airborne carbon, then the process is homeostatic. However, as the earth’s climate begins to change, it is apparent that there is an imbalance in the cycle. More governments and companies are taking the initiative to regulate and reduce carbon emissions in an attempt to return this cycle to its natural state.

There are several methods that can be used to determine exactly where emissions can be reduced and how. One method is a carbon life cycle assessment of a product and identifying key stages during the life of the product where the carbon emissions associated with that product can be reduced. The carbon emissions of the production, operation and disposal of the product are all estimated and given a quantifying value. Returning to the car example, some areas where carbon emissions can be reduced include the manufacturing process. Using “cleaner” machinery can reduce the emissions associated with production, as well as using different materials (non-petroleum-based plastic components, e.g.). Creating a hybrid or electric vehicle in lieu of a fully petroleum-based car reduces the emissions associated with the operation of the vehicle. Recycling the car’s parts can aid in reducing the emissions associated with its disposal.

There are three main carbon life cycle stages to be considered in this analysis. Stage 1 is the construction phase. Stage 2 is post-construction. Stage 3 is end-of-life

of the treatment. Each stage has associated benefits and costs. Table 6.1 and Table 6.2 shows the theoretical costs and benefits to consider in these stages for both the conventional and “best practices” treatment. The tables also indicate which variable is more likely to be measured: monetary or carbon emissions, or both.

Table 6.1. Carbon life cycle stages for conventional chip seal.

Stage	Cost	Benefits
1—Construction	Increased time of construction, leading to increased emissions. If using asphalt binder, increased emissions from binder	Lower financial burden. If using emulsion, reduced emissions.
2—Post-Construction	Increased road roughness, leading to increased emissions.	Improved skid resistance (may not reduce or increase emissions).
3—End-of-life	Reduced life, thus requiring frequent construction.	Time to garnish agency funds.

Table 6.2. Carbon life cycle stages for “best” practices chip seal.

Stage	Cost	Benefits
1—Construction	Reduced emissions due to lower construction time. If using emulsion, reduced emissions. If using asphalt rubber binder, increased emissions and cost.	Higher cost of construction. Lower emissions from emulsion. Indirect, from recycling old tires, thus reducing emissions.
2—Post-Construction	Potential for prolonged curing, causing indirect emissions (controlled traffic idling, increasing emissions) in short term.	Reduced road roughness, thus reducing emissions in short and long term.
3—End-of-life	Reconstruction of treatment, increasing costs.	Potentially prolonged life, leading to delay in reconstructions.

The primary approach that will be considered in this outline is an economic approach. The recommended economic analysis method to use is the cost-benefit analysis method. A cost-benefit analysis compares the costs and benefits associated

with using an alternative, or different sets of alternatives.[50] The main process used to achieve this goal includes the following:

- 1) Define the main objective of the study—to quantify carbon costs;
- 2) List alternatives—“best” practices versus “conventional” practices;
- 3) Select measurements and measure the costs and benefits associated with each—International Roughness Index (IRI), fuel economy, emissions;
- 4) Predict eventual outcome over time period—predict that the carbon cost will be less for the “best” practices test section as compared to the “conventional” over the treatments’ life span;
- 5) Calculate present value of each alternative;
- 6) Select appropriate alternative.

Other factors that need to be considered in cost-benefit analysis are discounting and uncertainty. Discounting applies a certain factor to the predicted future costs and benefits that are calculated in the cost-benefit analysis. This is done to account for the changing value of money with time. Uncertainty is a measure of the inherent variability in the analysis and accounts for the effects of altering any of the assumptions or parameters of the analysis. It can be measured in any number of ways. As preservation treatments tend to have a useful life of 3-7 years, discounting may not be a concern in this analysis, whereas uncertainty may be. It is left to the discretion of the future researcher whether or not to use discounting for this analysis. It is recommended that uncertainty be measured, regardless of whether discounting is considered.

The primary costs that are being considered in this analysis are the actual monetary costs associated with constructing both treatments (conventional vs. “best”)

and the carbon emission costs associated with construction (from equipment, as well as bituminous material and potentially even controlled traffic) in the short term, as well as the long-term costs associated with carbon emissions from vehicles throughout both treatments' life cycles. The primary benefits of both treatments include the reduced monetary cost of selecting one treatment over the other and the reduced carbon emissions associated with one treatment over the other in the short term. The long-term benefit to investigate is the potential for reduced carbon emissions over the life cycle of the treatment. Another benefit will be a reduction in road roughness, especially if using a smaller aggregate size than is mandated in the state specifications.

The hypothesis of this study is that the treatments that are constructed using three best practices will reduce carbon emissions long-term, as compared to the conventional treatment. Another hypothesis is that the use of emulsion in one of the test sections will reduce the carbon cost associated with construction in the short term as compared to all three alternatives. This last point may be more difficult to prove or disprove, as carbon emissions during construction are difficult to measure. However, there are several studies that have successfully measured carbon emissions during pavement construction.[51]

The treatments will be constructed as test sections. The sections should be of the same length and width, located along the same roadway corridor and placed as close to the same time as possible. An alternative to this plan would be to construct a series of test sections, each one having only one best practice implemented (for one section, change aggregate sizes. For the adjacent treatment, change application rates, etc.) For the purposes of this outline, the test sections will be constructed on an

NDOT road using the same construction Contractor throughout. The treatment used in this example is the chip seal.

Chip seals are the recommended treatment to be constructed in this experimental study due to its usually lower cost and time requirement of construction and equipment availability. The recommended “best” practices that should be tested are changing aggregate sizes, as smaller aggregates reduce road roughness; vary the material application rate; to change the bituminous material; and selecting a more severely-distressed road to demonstrate the effect of proper project selection.

The first variable may allow for the ease of quantifying long-term carbon costs, whereas the last variable may allow for the ease of quantifying carbon emissions during construction. The middle variable may or may not influence carbon emissions in either the short term or long term. The final variable will demonstrate the effect of project selection as a best practice (although still beyond the scope here), as this section may exhibit earlier degradation, increased road roughness and increased carbon emissions. This, of course necessitates multiple test sections. The recommended minimum test section length is 1,000 feet. It is also recommended that, prior to the construction of each test section, the equipment be re-calibrated, to reduce the effect of equipment variability, and a test strip should be constructed to ensure that this calibration is correct. As was discussed in Chapters 3 and 4, test strips are a best practice and should be constructed if any of the materials change, as is the case here.

“Best” practices, in this context, are those practices that many agencies are using to create high-quality, successful preservation treatments. These are not industry best practices, but rather practices that, once the agency requires the use, changed the

quality and performance of preservation treatments as compared to the previous, “conventional” methods of constructing surface treatments.

When conducting a cost-benefit analysis, some assumptions must be made that allow the researcher to define and analyze the main variables, while reducing the risk of adding others. Some key assumptions include the following:

- NDOT will always construct a preservation treatment when either a pavement condition survey or a set time frame has elapsed to maximize the treatment’s effectiveness;
- The climate will be appropriate for placing the treatment;
- Both sections will be constructed based on NDOT specifications, with the second test strip allowing for the details to be altered to include the best practices identified in this study;
- During the long-term analysis period, a standardized vehicle will be used and operated in such a way as to reflect expected driving behaviors (i.e., driving at the posted speed limit, not changing lanes on the treatment, maintaining as constant a rate of speed as practical);
- Both test sections will be constructed on a road that is relatively flat, to eliminate the influence of grade on fuel economy;
- The test sections will be constructed on a road that exhibits free-flowing traffic conditions most of the time.

Two methods of measuring carbon emissions that can be used in this experiment are to fix a carbon emission detection apparatus to the test vehicle. Another option is to measure the carbon emissions indirectly via the change in the vehicle’s fuel economy across both treatments. For the purposes of this study, the

carbon emissions should be indirectly measured via fuel economy. Some key studies have examined a relationship between fuel economy and road texture.[52] As the texture of the road becomes rougher, fuel consumption for all vehicles increases, and in theory, so will carbon emissions. By using smaller aggregate sizes or varying application rates, roughness should reduce, while not negatively impacting skid resistance.

After one year, the treatments will be driven by the standard vehicle. Of the two methods suggested for measuring carbon emissions, it is recommended to use the fuel economy estimation method. The vehicle's fuel economy will be estimated before and after driving across each treatment. From the fuel economy, the carbon emissions can be estimated using appropriately researched methods (one example can be found from the California Air Resources Board [53]). This will be repeated once a year throughout the life span of the treatment.

Once the carbon emissions are calculated for each time period, the costs of carbon on the environment can be given monetary value. These costs, combined with the initial cost of each test section and the associated monetary benefits of each section, will be compared and evaluated using appropriate methods. Finally, the hypotheses that were set forth previously will be accepted or rejected based on statistical analysis and the conclusion will be drafted.

Chapter 7 Conclusions

In general, the lead agencies' specification practices are similar to the best practices that were listed in the state-of-the-practice documents from the ISSA, CCSA, NCHRP and others. For all treatments, all of the lead agencies followed proper surface preparation practices. For chip seals, these practices included monitoring the application rates and binder temperatures, constructing test strips, ensuring proper equipment calibration is maintained, and aggregate requirements. Slurry seal practices include using the proportions recommended by the ISSA, following ISSA's mix design method and tests and ensuring favourable climate conditions are met. Micro surfacing practices include also following the ISSA mix design method and tests, using latex-modified emulsions and ensuring proper climate conditions are met. Thin lift asphalt overlay practices include creating mix designs using the accepted industry methods (Superpave, e.g.) and implementing QC requirements.

The main deficit for all agencies appeared to be in actual Quality Assurance specifications, particularly for chip seal, slurry seal and micro surfacing treatments. There appeared to be some areas, such as materials testing, where all agencies could benefit from adding more Quality Assurance requirements. Since the lead agencies used hot-mix asphalt QA specifications as a basis for conducting QC and Acceptance testing on thin lift asphalt overlay treatments, the QA specifications for thin lift asphalt overlay treatments are much more robust and have adequate provisions for many of the areas of concern, as compared to chip seals, slurry seals and micro surfacing treatments.

Finally, two items that appear to be absolutely critical to preservation treatment success is to perform equipment calibrations and test strips prior to every project. In general, most agencies could benefit from including more robust and detailed specification procedures to address both areas. The first step that can be taken in this direction is to require that equipment calibration be conducted prior to every project and verifying that the application rates are sufficient post-calibration using a test strip of sufficient length. Each agency can then begin to add more detailed, state-specific requirements for the test strip length and conditions of construction, and calibration practices.

Test strips will ensure that

- The proper project was selected,
- Proper surface preparation practices were followed,
- The equipment is appropriate for the treatment construction,
- An adequate mix design was created,
- Equipment calibration was correctly performed,
- Proper application rates are achieved, and
- Proper inspection practices are followed.

Areas for Further Research

In addition to the experimental study that was created in Chapter 5, it is recommended that more research be dedicated to determining the effect of project selection on the performance of the various preservation treatments. Project selection is critical to ensuring that a selected treatment is appropriate for the pavement. Other areas for further research include test strip and equipment calibration best practices,

long-term performance studies and investigating the potential for creating a sample QA specification for use by any state or local agency.

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