# Southeast Transportation Consortium

## Final Report 515

## Asphalt Surface Treatment Practice In Southeastern United States


by

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# Table of Contents

# SUMMARY

It costs less to maintain roads in good condition than in poor condition. Pavement preservation is a set of activities to extend pavement life, improve safety, and meet road user expectations. Surface treatments are pavement preservation treatments applied to the whole surface of the road. This synthesis summarizes surface treatments' state of practice in the United States, especially southeastern states. Eleven pavement preservation techniques were addressed: fog seal, rejuvenator seal, chip seal, sandwich seal, scrub seal, slurry seal, microsurfacing, cape seal, thin overlays, ultrathin bonded wearing course and crack sealing/filling. Recent work on surface treatments has been reviewed and summarized. To research surface treatments' state of practice, a survey was designed and distributed to Southeastern Association of State Highway and Transportation Officials (SASHTO) agencies. Nineteen participants from Florida, Georgia, Louisiana, Virginia, West Virginia, North Carolina, and Arkansas participated in the survey. The electronic survey consisted of three questionnaires asking administrative, technical, and research-related questions. Results showed that thin overlays, crack repairs, microsurfacing, chip seal, and fog seal are the most common preventative maintenance practices. In this report, each chapter is dedicated to one surface treatment technique. Chapters start with a description of the technique, its applications, features, material and equipment requirements, and construction procedures. This is followed by a summary of recent work and implementation status, as obtained from the survey.

CHAPTER ONE

# INTRODUCTION

## PAVEMENT SURFACE TREATMENT

Pavement preservation is an approach to enhance pavement performance using a set of practices that extend the life of the pavement and improve safety and ride quality. According to World Bank's Pavement Deterioration Model, the cost of bringing back a pavement to good condition if it is left to deteriorate may be four times as the cost of maintaining it in good condition (Shahin, 2005). The results of a UDOT (Utah Department of Transportation) research study showed that it costs less to maintain roads in good condition than in poor condition (Zavitski, et al.). According to the National Cooperative Highway Research Program (NCHRP) Synthesis 223, every dollar spent on preventative maintenance at the correct time in a pavement's life cycle saves $3-4 in future rehabilitation costs (Geoffroy, 1996). Later work by Galehouse, Moulthrop, & Hicks, (2003) showed that future rehabilitation cost savings are $6–10 for every $1 spent on preventative maintenance, as demonstrated in Figure 1-1.

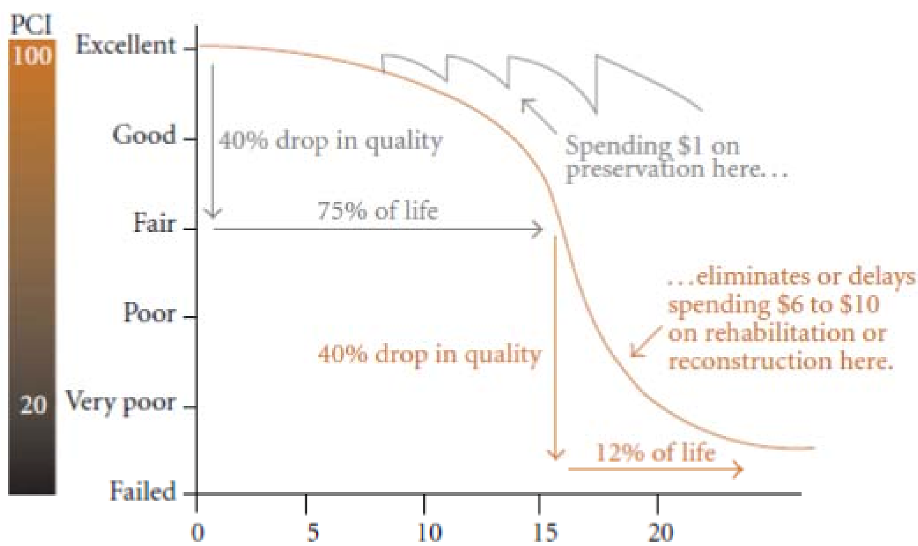



**Figure 1-1 Effect of Preventive Maintenance at Life Cycle Cost of the Pavement (Galehouse, Moulthrop, & Hicks, 2003)**

Some surface treatments are effective for maintaining pavements in good condition. They are applied to the entire surface of the pavement and are usually used for pavements with no major structural deterioration. The relatively low cost and simplicity of these techniques, besides their effectiveness in extending the life of the pavement and improving performance, has attracted many agencies to use them. Chip seal, slurry seal, microsurfacing, surface rejuvenation, fog seal, scrub seal, and thin overlays are among popular surface treatments.

## SCOPE OF WORK

This report is aimed to research asphalt surface treatments' state of practice in the United States, particularly SASHTO (Southeastern Association of State Highway and Transportation Officials). The synthesis is designed to provide a reliable reference for those who are involved in surface treatment projects. Surface treatment techniques were described and recent research projects on this field were summarized. Best practices and implementation status were also addressed through a survey sent to SASHTO agencies.

## METHODOLOGY

The general methodology of this research was two tiered; first, conduct a comprehensive literature review on asphalt surface treatments. Second, send a survey to state and local agencies. The results from the survey were analyzed and presented in this report.

### Survey Questionnaires

To investigate actual surface treatment practices in southwestern states, three electronic questionnaires were prepared (Appendix A). The questionnaires were sent to southeastern state agencies as well as the local highway agencies involved in surface treatment projects.

The survey consisted of three electronic questionnaires as follows:

Questionnaire 1, Administrative
Questionnaire 2, Technical
Questionnaire 3, Research Status

Questionnaire 1 asked general questions regarding implementation status of surface treatment techniques, level of proficiency, specifications, and other administrative issues. The participant was first asked to determine what surface treatments were being implemented or have been completed before by that agency. Based on the answer of this question, survey participants were directed to the pages related to chosen techniques. The number of projects for each technique, proficiency of the agency, specifications, quality control, performance, life extension, cost, purpose, and obstacles are questions asked in Questionnaire 1.

Questionnaire 2 was more technical and designed for people who have detailed technical information of surface treatments state of practice. For each technique, general information related to the condition of pavement before applying surface treatment was asked. The next section of the questionnaire was related to the specification of material used in surface treatment. “Design and Construction” issues and “Cost and Performance” were discussed in the last two sections of the questionnaire.

Questionnaire 3 investigated surface treatment related research projects conducted by the agency. Completed, ongoing, and planned research projects were asked to be listed and uploaded if possible.

After filling out the first questionnaires, the participant was directed to the next sections of the survey. Those sections could be answered by the same participant or be sent to other people at the agency with appropriate knowledge for each questionnaire. Electronic questionnaires were developed using Qualtrics® survey development software. A paper copy is presented in Appendix A.

## GENERAL SURVEY RESULTS

Nineteen participants completed at least one questionnaire. Participants were from Florida, Louisiana, Georgia, North Carolina, Virginia, West Virginia, and Arkansas. All participants completed Questionnaire 1. However, of those, only eight completed Questionnaire 2 and 3. Table 1-1 lists the survey participants, their title and the agencies they represented. Figure 1-2 shows distribution of participants within SASHTO states. Mentioned numbers reflect participants who have filled out questionnaires completely and submitted their own information. Other participants answered parts of the questionnaires and did not provide their name and affiliation. Their responses were also used in statistical analyses.

Figure 1-3 shows the information obtained from the survey. crack sealing/filling is the most commonly used pavement preservation practice. Technically, crack sealing/filling is not applied on the whole surface of the pavement, so it is not considered as surface treatment. However, it was covered in this report as it is commonly used as a prerequisite to many surface treatment applications. Among surface treatments, thin overlays, microsurfacing, and chip seal are the most widely used. Fog seal, ultra-thin bonded wearing course, rejuvenating, and cape seal are used less. Other techniques are used only by one or two agencies.

**Table 1-1 Information of Survey Participants**

| TAG | Agency | Title | Address |
|---|---|---|---|
| **GA1** | GDOT | Technical Services Engineer | 15 Kennedy Drive<br>Forest Park, GA 30297 |
| **GA2** | GDOT | LTAP Director | 3993 Aviation Circle<br>Atlanta, GA 30336 |
| **WV** | WVDOT/DOH | Pavement Engineer | 190 Dry Branch Drive<br>Charleston, WV 25306 |
| **VA** | VCTIR - VCOT | Research Implementation Coordinator | 530 Edgemont Rd<br>Charlottesville, VA |
| **LA** | Louisiana LTRC | LTRC Material Research Administrator | 4101 Gourrier Ave<br>Baton Rouge, La 70808 |
| **NC** | NCDOT | Pavement Preservation Engineer | 4809 Beryl Road<br>Raleigh, NC 27606 |
| **AR** | AHTD | Staff Research Engineer | 10324 Interstate 30<br>Little Rock, AR 72209 |
| **FL-Oka** | Okaloosa County | Road and Parks Division Manager | 1759 S. Ferdon Blvd<br>Crestview, FL 32536 |
| **FL-Oka** | Okaloosa County BCC | Operations Manager | 1759-A South Ferdon Blvd<br>Crestview, Fl. 32539 |
| **FL-Nas** | Nassau County<br>Engineering Services | Engineer | 96161 Nassau Place<br>Yulee, FL 32097 |
| **FL-Orl** | City of Orlando | Division Manager - Streets and Storm water Services | 1010 Woods Ave<br>Orlando, FL 32805 |
| **FL-Lee** | Lee County DOT | Deputy Director | 1500 Monroe St Ft.<br>Myers, FL 33991 |
| **FL-Kis** | City of Kissimmee, Florida | Construction Coordinator | 101 N. Church Street Suite 301<br>Kissimmee Fl. 34741 |
| **FL-Bru** | Brunson | Inspection and construction supervisor | 685 west Montrose street<br>Clermont, Fl |
| **FL-For** | FDOT | District Pavement Design Specialist | 3400 West Commercial Blvd<br>Fort Lauderdale, FL 33309 |
| **FL-Tal** | FDOT | Pavement Management Engineer | 605 Suwannee Street, MS 32<br>Tallahassee, FL 32399-0450 |
| **FL-Gai** | FDOT | State Bituminous Materials Engineer | 5007 NE 39th Avenue<br>Gainesville, Florida 32609 |
| **FL-TrP** | FDOT Turnpike Enterprise | Turnpike Materials Engineer | PO Box 613069<br>Ocoee, Fl. 34761 |
| **FL-Del** | FDOT | District Pavement Design Engineer | 719 S. Woodland Blvd.,<br>Deland, Fl |

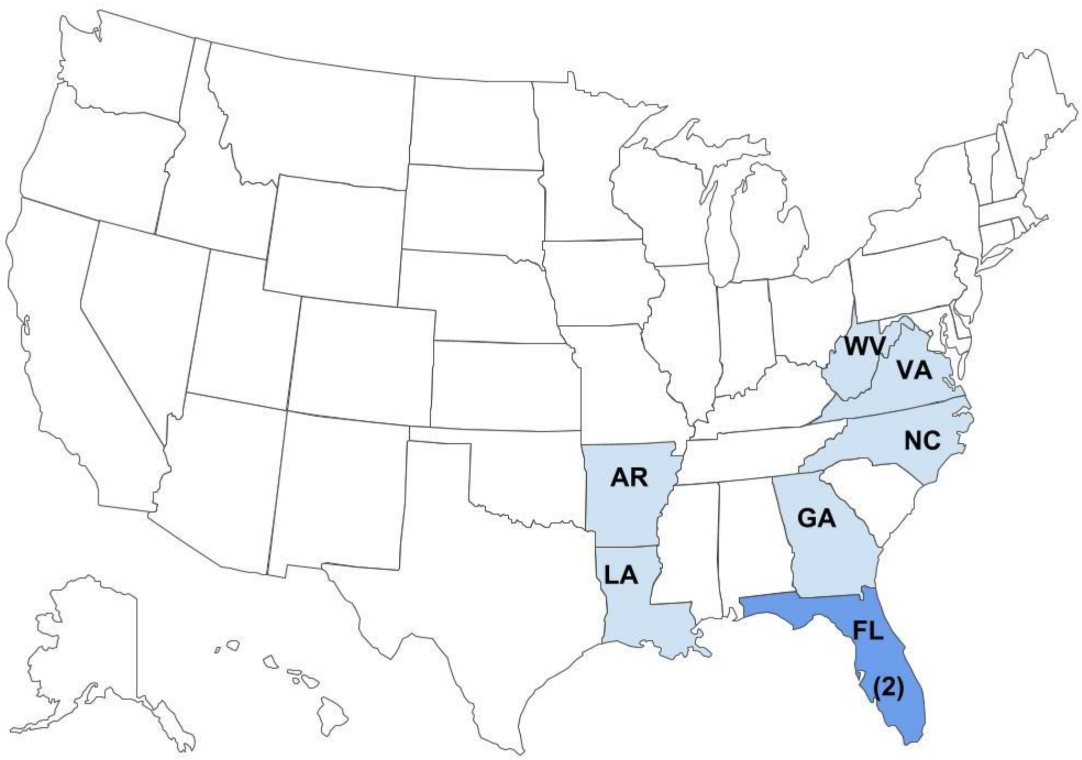



**Figure 1-2  Distribution of participants**

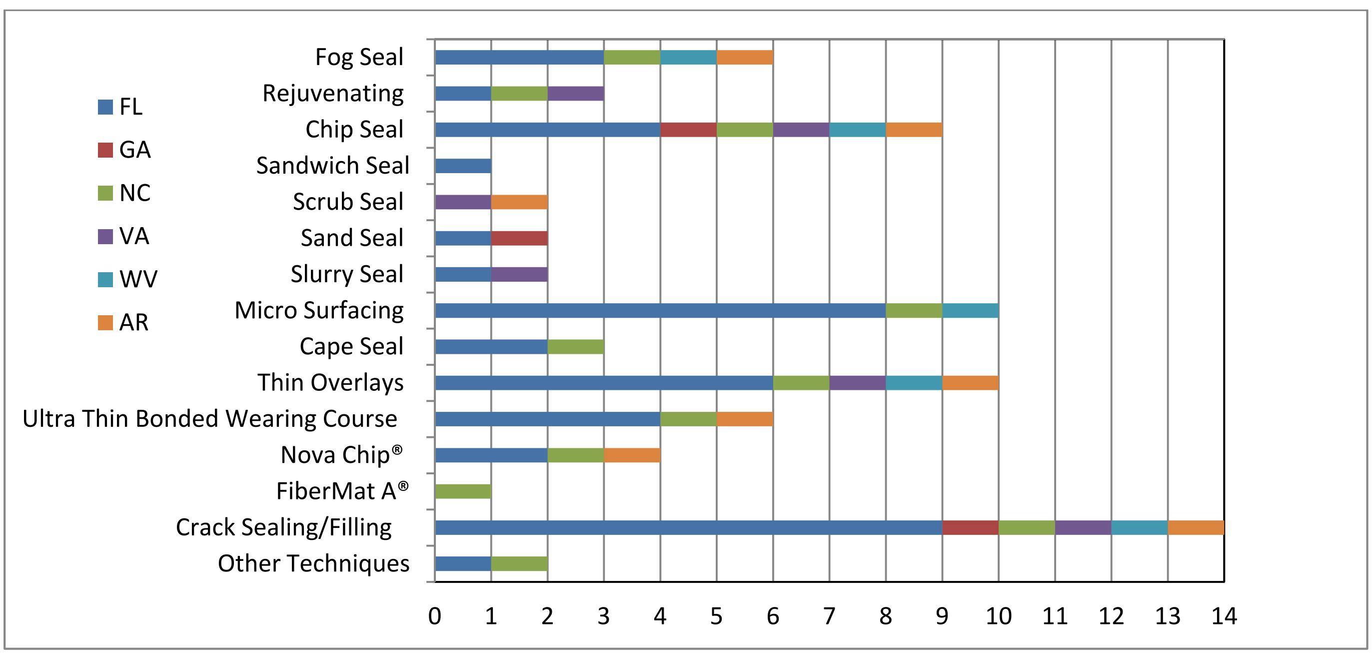



**Figure 1-3 Number of Agencies that Implement Surface Treatment Techniques**

CHAPTER TWO

# FOG SEALS

## TECHNIQUE DESCRIPTION

### Introduction

Fog seal is a lightly sprayed application of diluted asphalt emulsion to an asphalt pavement surface. The main function of fog seals is to renew old asphalt pavements that have aged, becoming dry and brittle. Applied emulsion can also seal small cracks and fill small voids, consequently reducing permeability of the pavement surface. Fog seals extend the life of the pavement and postpone major rehabilitations. Fog seals are also used in chip seal applications to hold chips in their place and to prevent them from flying and damaging vehicles. This application of fog seal is also called flush coats. Fog seal does not correct severe distresses such as rutting, aggregate loss, or major cracking. Figure 2-1 shows a typical fog seal application.

### Material

A relatively low viscosity diluted asphalt emulsion is used for fog seals. To coat and waterproof pavement surface, fog seal material should fill pavement voids. The emulsion should have a low viscosity and be slow-setting in order to penetrate enough into the surface before it breaks (Fog Seal Guidelines, 2003). SS-1, RS-a, SS-1h, CSS-1h, CRS-1are emulsion grades used for this technique (Asphalt Institute, 2009). A typical emulsion already has up to 43% water content. However, to be used in a fog seal, the emulsion should be diluted further. Dilution makes asphalt less viscous and allows it to penetrate deeper into the surface. A 1:1 ratio of water and emulsion is usually suitable. (Fog Seal Guidelines, 2003). However, up to 5:1 water to emulsion proportion is used in some cases (Asphalt Institute, 2009). Figure 2-2 shows variations of viscosity with percentage of dilution for CSS-1H emulsion.

A water compatibility test might be performed for the water used in dilution. A small amount of water and emulsion should be mixed for 2 to 3 minutes with a stirrer. Then the mixture is poured through a pre-wetted 150 μm sieve. To assure that water is compatible and does not clog in spray jets, weight of retained material on the sieve should not exceed 1% of total material weight. If the water is incompatible, it can be treated by adding 0.5 to 1.0% of an emulsifier solution (Fog Seal Guidelines, 2003)

Positively charged (cationic) or negatively charged (anionic) asphalt emulsion can be used for fog seal. Cationic emulsions can replace the water on the surface of old asphalt or aggregate. These emulsions are broken due to loss of water and chemical action, forming a layer of new binder on the surface of aggregate. They are advantageous for roads in wet weather. Anionic emulsions, however, do not have any interaction with aggregates and break just due to absorption in voids and evaporation (Fog Seal Guidelines, 2003).

**Figure 2-1 Application of Fog Seal on US-36 (Caltrans, 2009)**

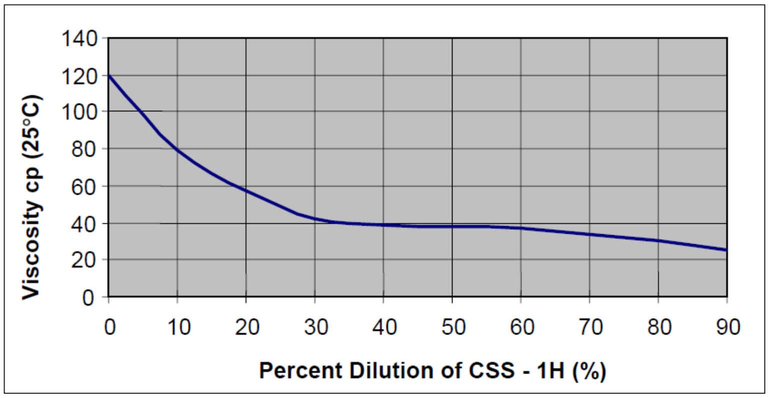



**Figure 2.2 Viscosity Variations with Dilution (Caltrans, 2009)**

### Design and Construction

Exact application rate of diluted asphalt depends on the texture and dryness of the surface and cracking level. However, the typical range for an application rate of (1:1) diluted emulsion is 0.03 to 0.22 gal/yd$^2$ (0.15 to 1.0 l/m$^2$) (Hicks & Holleran, 2002). To estimate the application rate for a specific project, a test section may be useful. One liter of diluted emulsion is poured evenly on the surface of 1 m$^2$ of pavement surface to represent 1 l/m$^2$ application rate. If the emulsion is not absorbed after 2-3 minutes, the test should be repeated for smaller amounts of emulsion to obtain a suitable application rate. Common application problems and their solutions can be seen in Table 2-1.

Fog seals should be applied when the air temperature is not below 50°F (10°C), and pavement surface temperature is not below 59°F (15°C). Also if it rains before the emulsion breaks, it will be washed out and create a slippery surface, so there should be no or little probability of rain when a fog seal application is planned. The surface of the pavement should be clean and dry before fog seal is applied. Over-application of emulsion may lead to a slippery surface and should be avoided. Traffic should be stopped for 1 to 3 hours after fog seal application to let the emulsion be absorbed into the surface. Table 2-2 shows typical fog seal problems and how they are caused.

## REVIEW OF RECENT WORK

### Effects of Fog Seal on Surface Friction

A study by the Joint Transportation Research Program (Indiana Department of Transportation and Purdue University) investigated the effect of fog seal on road surface friction (Li, S., Noureldin, S., Jiang, Y., & Sun, Y., 2012). According to this research, friction measurement decreased dramatically after the application of fog seal. Two road sections at US-36 and U-231 were tested. Friction measurements before and after application of fog seal are presented in Table 2-3. The average friction number fell from 61 and 58, respectively, to 28 and 23 after application of fog seal. It shows that fog seal significantly reduces friction of the surface of the road. The reduction of deviation of friction measurements, however, shows that fog sealing lead to a more uniform pavement surface. This study also shows that it normally takes the pavement surface friction about 18 months after a fog seal application to return to the original level of friction.

### Effectiveness of Fog Seal

The effectiveness of fog seal was also recently assessed by measuring stiffness of pavement binder and performing t-test analysis for untreated and treated binders (Prapaitrakul, Freeman, & Glover, 2010). Sample cores were taken from different sections of pavements and each was sliced into 3/4 in. thick specimens, sampling the top 1/4 in. and two lower 1/4 in. of pavement. Then asphalt binder was extracted and the Dynamic Shear Rheometer (DSR) test was performed on it. The obtained ductility values from treated and untreated samples were then compared using paired t-test analyses. The analyses were categorized by treatment type, depth, and a combination of these two parameters. Figure 2-3 presents the procedure of sample preparation and statistical analysis.

This assessment was done for some of the common emulsions used in fog seal. Table 2-4 summarizes the results for different emulsions, solvents, and application rates. Advantages and disadvantages of each material are addressed.

Also, results of paired t-test statistical analysis showed a significant improvement of ductility of binder was achieved only using EB44 coal-tar type material. The upper quarter inch of pavement is most affected by fog seal. There was almost no penetration below the pavement surface.

**Table 2-1 Common Problems and Related Solutions (Caltrans, 2009)**

| PROBLEM | SOLUTION |
|---|---|
| Spattering of the Emulsion | Reduce the rate of dilution.<br>Ensure the spray bar height is set correctly.<br>Ensure the spray pressure is not set too high. |
| Streaking of the Emulsion | Ensure the emulsion is not too cold.<br>Ensure the emulsion viscosity is not too high.<br>Ensure the nozzles are at the same angle.<br>Ensure the spray bar is not too high or too low.<br>Ensure the spray bar pressure is not too high.<br>Ensure all nozzles are not plugged. |
| Bleeding or Flushing of the Emulsion | Ensure the emulsion application rate is not too high.<br>Check application and dilution rate and recalibrate sprayer, if necessary. |
| Surface Coefficient of Friction is too Low per CT 342 | Apply coating of clean dry sand.<br>Sweep sand with rotary broom to absorb excess binder.<br>Perform CT 342.<br>Repeat process until coefficient of friction is at least 0.30. |

**Table 2-2 Troubleshooting Fog Seal Problems (Caltrans, 2009)**

| PROBLEM / CAUSE | Slick Surface | Not Breaking | Washes Off | Tacky Picks Up | Will Not Dilute | Breaks Too Fast | Dilution Wrong |
|---|---|---|---|---|---|---|---|
| Road Wet | • | • | • | | | | |
| Road Too Dry | | | | • | | • | |
| Road Dusty | | | | • | | • | |
| Hard Water | | | | | Anionic | | |
| Alkaline Water | | | | | Cationic | | |
| Acidic Water | | | | | Anionic | | |
| Application Too High | • | • | • | • | | | • |
| Application Too Low | | | | | | • | • |
| Wrong Emulsion | | • | • | • | • | • | |
| Rain | • | • | • | | | | |
| Cold Weather | • | • | | | | | |
| Hot Weather | | | | • | | • | |

**Table 2-3 Friction Measurements Before and After Fog Seal (Li, S., Noureldin, S., Jiang, Y., & Sun, Y., 2012)**

| | **Before** | | **After** | |
|---|---|---|---|---|
| | Average | Standard Dev. | Average | Standard Dev. |
| **US- 36 EB** | 61 | 10.8 | 28 | 4.0 |
| **US-231, NB** | 58 | 9.9 | 23 | 3.5 |

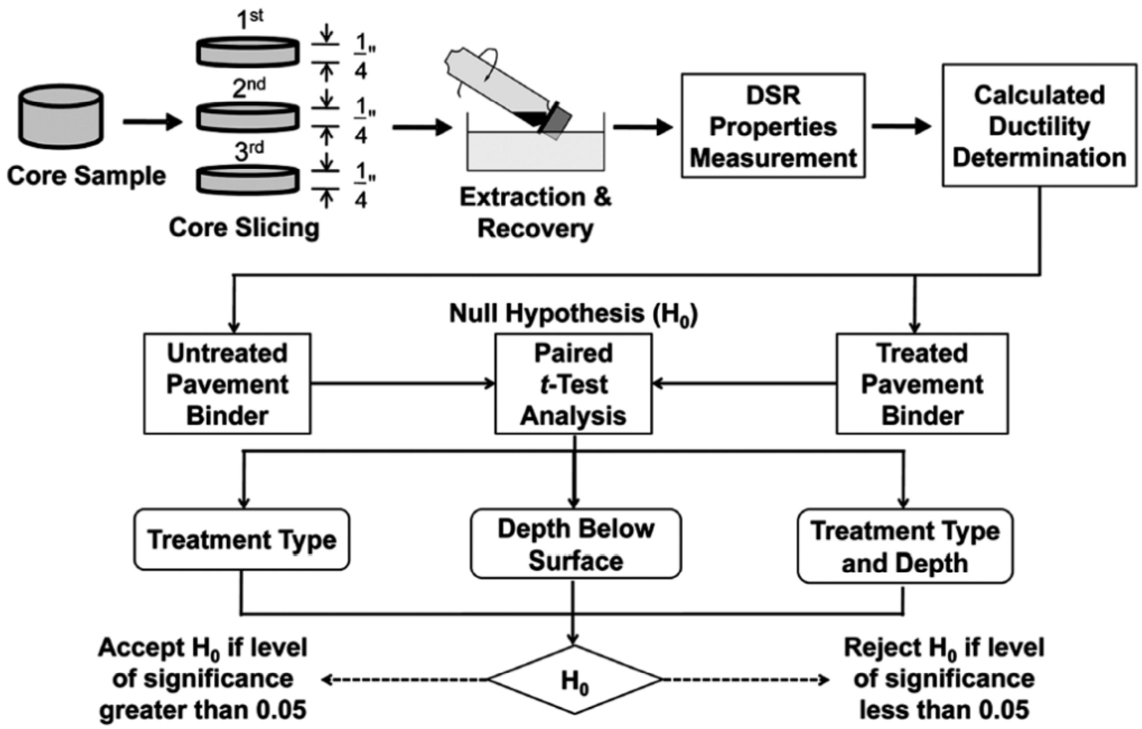



**Figure 2-3 Sample Preparation and Statistical Analysis Procedure (Prapaitrakul, Freeman, & Glover, 2010)**

## SASHTO STATE OF PRACTICE (SURVEY RESULTS)

According to the results of the survey, fog seal is carried out in the states of North Carolina, West Virginia, Arkansas, and three Florida counties. Comparing other techniques, it can be concluded that fog seal is considered a common practice in SASHTO regions. Okaloosa County, with 20 ongoing and 50 completed fog seal projects, applied this technique more than any other agency.

Results of the first questionnaire showed that 50% of agencies using fog seal considered themselves familiar with fog seal, and another 50% rated their knowledge only adequate. While no agencies claimed proficiency in fog sealing, no agencies reported inadequate knowledge either.

Figure 2-4 shows the pavement condition where agencies decided to perform fog seal. This practice is normally done when the pavement is in good or excellent condition with minimum distresses. Performing fog seal in a fair pavement condition seems to be rare.

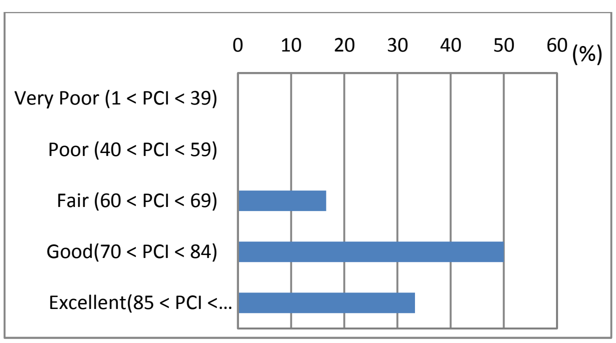



**Figure 2-4 Pavement Condition Before Fog Sealing**

No well-established and widely implemented specification for fog seal was found to exist. Volusia and Nassau Counties used their own specifications and other participants reported using manufacturer recommendations or specifications required in each contract. Agencies rated specifications they use as somewhat effective or effective. No agency rated implemented specification as very effective.

Seventy-five percent of agencies reported that they did not have any established quality control (QC) or quality assurance (QA) program. The only agency that had a QA/QC program, only tested the emulsion to ensure it met the specifications.

The performance of fog seal was rated as fair to very good. No agency was totally satisfied with the performance of this technique. The life extension due to fog seal was reported erratically by agencies between 1 and 5 years of life extension and some other agencies could not estimate the life extension.

**Table 2-4 Specification and Performance of Asphalt Emulsions Used in Fog Seal (Prapaitrakul, Freeman, & Glover, 2010)**

| Treatment material | Example grades | Solvent | Application rate* Gal/SY | Residue viscosity* | Field Performance | | Remarks |
|---|---|---|---|---|---|---|---|
| | | | | | Advantages | Advantages | |
| Slow Setting Emulsion | CCS-1 , SS-1 | Water | 0.09–0.1 | 2200[a] | -Low cost<br>-Easily Applied | -No pavement penetration detected<br>-No water sealing effect detected | -Slow-set emulsions typically are better for coating dust or fine aggregate; the faster setting the emulsion, the cleaner the surface should be<br>-Gel Permeation Chromatography (GPC)<br>-Chromatogram similar to unmodified asphalt |
| Medium Setting Emulsion | MS-2 , CMS-2 | Water | 0.15 | 2000[b] | -Low cost<br>-Easily Applied | -No pavement penetration detected<br>-No water sealing effect detected | -Most commonly used product for both seal coats and HMAC<br>-Slow-set emulsions typically are better for coating dust or fine aggregate; the faster setting the emulsion, the cleaner the surface should be<br>-GPC Chromatogram similar to unmodified asphalt |
| Hard Residual Emulsion | COS-50, SS-1H , CSS1H | Water | 0.14 | 30000[c] | -May possibly be more durable<br>-Unlikely to bleed or flush | - No pavement penetration detected<br>-No water sealing effect detected<br>- In some cases, it may provide a less skid resistant surface | -For COS-50, only used experimentally<br>-Slow-set emulsions typically are better for coating dust or fine aggregate; the faster setting the emulsion, the cleaner the surface should be<br>-GPC Chromatogram similar to unmodified asphalt |
| Polymer Modified Emulsion | Pass(CMS-1P) , SS-1P, CSS-1P | Water | 0.1 - 0.16 | 1100[d] | -Break Rapidly after application | -No pavement penetration detected<br>-No water sealing effect detected<br>-Cost may be higher | -Used often, especially on HMAC<br>-Most common rejuvenator used<br>-Slow-set emulsions typically are better for coating dust or fine aggregate; the faster setting the emulsion the cleaner the surface should be<br>-GPC Chromatogram similar to polymer modified asphalt |
| Coal- Tar Sealer | PDC-EB44 | Naphtha/ Antracene | 0.04 - 0.1 | <1000[e] | -Hard, fuel-resistant surface<br>-retains black color for longer period | -No pavement penetration detected<br>-No water sealing effect<br>-Environmental concern with runoff/solvent | -Used extensively on airports<br>-GPC Chromatogram similar to light organic material |

*Approximate values from field and laboratory data.

[a] Viscosity measured from CSS-1.

[b] Viscosity measured from MS-2.

[c] Viscosity measured from COS-50.

[d] Viscosity measured from PASS.

[e] Viscosity measured from PDC (pavement dressing conditioner

All agencies apply fog seal to delay deterioration of the pavement and reduce water infiltration. However, most of them reported that they also fog seal for better appearance and aesthetics purposes.

The cost of fog seal was estimated at \$0.35-\$0.5 per square yard by agencies. Also, \$0.6-\$1.0 per square yard was reported, but this data did not seem to be reliable.

The major obstacles for fog sealing were reported to be lack of effective specifications and skilled local contractors, as well as social, legal, and political considerations. Effectiveness of the technique was also doubted by practitioners as it is in the literature.

Two agencies provided technical information for fog seal. CSS-1h asphalt emulsion was used by both of them. Grip Tight and CRS-2p were reported to be used for fog seals. The quantity of emulsion was reported at 0.08 and 0.22 gal/yd$^2$. Practitioners usually cease using fog seals at the time when the temperature is expected to fall or when humidity is high.

Sudden rain showers can affect application of fog seals. Moreover, actual curing time is usually reported to be longer than anticipated. Traffic is often left to cross uncured seal. Emulsions stick to tires and leave marks on driveways, which is not aesthetically desirable.

Just one research project related to fog seal was reported: "Fog Seal Effectiveness for Bituminous Surface." (Kim, 2010-Present). This project investigated effectiveness of fog seal to improve performance of chip seals based on laboratory and field tests. This research is still in progress.

CHAPTER THREE

# REJUVENATION

## TECHNIQUE DESCRIPTION

A fog seal using rejuvenator is called a rejuvenating or rejuvenator seal. Oxidation of asphalt over time makes it brittle and reduces pavement performance (Halstead, 1963). Asphalt consists of a solid fraction, asphaltenes, and liquid maltenes. As the asphalt ages, the maltenes oxidize and so its ratio to asphaltenes reduces. As a result, asphalt becomes brittle and dry. Rejuvenators are material such as recycling agents and special chemicals that can improve aged asphalt properties. Aging caused by air, moisture, and time is reversed as a result of rejuvenating. Maltenes in aged and oxidized binder are restored. Rejuvenation also prevents the intrusion of air and water and postpones deterioration of the pavement. Rejuvenating is usually done for severely oxidized pavement surfaces.

## REVIEW OF RECENT WORK

Fog seal treatment without rejuvenation was found to be ineffective by some researchers. For instance, according to research conducted by FHWA and Texas A&M University (Prapaitrakul, Freeman, & Golver, 2007), simple fog seal did not improve viscosity, or permeability of the pavements. Testing cores obtained from fog sealed and untreated pavement sections also showed that oxidation aging was not relieved by simple fog seal treatment. It was claimed that fog sealing causes no significant improvement of pavement durability. Rejuvenator fog seals, however, were shown to be effective in various studies. Recent work on rejuvenator seal performance is addressed in following paragraphs.

A study conducted by Tricor Refining, LLC (Brownridge, 2010) supported pavement life extension due to rejuvenation in the top ¼ in. to 3/8 in. of pavement surface by testing thousands of core samples. Effectiveness of a rejuvenator seal was also evaluated by Jusang Lee et al. (2012) in Indiana through friction, permeability, Dynamic Shear Rheometer (DSR), and Contact Angle (CA) tests. Rejuvenators decreased dynamic shear modulus and increased the water drop contact and phase angles. However, no significant improvement in permeability was observed. The influence depth of the treatment was found to be only 0.5 in. Friction numbers, on the other hand, reduced considerably (app. 56%) but still met INDOT minimum requirement.

Effects of rejuvenator seal material (RSM) on aged binders and asphalt mixtures were investigated by J. Lin et al. (2012). Rolling Thin-Film Oven Test (RTFO) and ultra-violet light were implemented to simulate asphalt aging. Performance of the aged binder, rejuvenated by two types of RSM was evaluated by component analysis as well as creep recovery, fatigue, viscosity, and temperature sweep tests. Both rejuvenators successfully reduced viscosity, complex modulus, and phase angel of aged asphalt. Asphalt mixtures were subjected to frequency sweep tests, wheel tracking tests, static creep tests, indirect tensile strength tests, raveling tests, and skid resistance tests. It was found that rejuvenation decreases rutting resistance of hot mix asphalt. RSM also increased creep strain and decreased tensile strength of the mix. Rejuvenators were found effective in decreasing raveling, but, at the same time, decreasing skid resistance.

Rheological techniques were also employed to study rejuvenator effectiveness (Romera et al., 2006). Thermal transition due to collapse of the compact structure constituted by asphaltene was determined by Dynamic Mechanical Thermal Analysis. As a result of aging, the transition shifts to higher temperatures. Rejuvenation was found to reverse this change. The highest temperature the binder can stand without permanent deformation is defined as rutting factor, $G^*/\sin \delta$. Rejuvenators were effective in postponing permanent deformation. Moreover, it was observed that its required to raise the temperatures to higher than 392°F (200°C) to mix the hardened binder as an appropriate fluid-like material. However, rejuvenators decreased mentioned temperature.

Using waste oils as rejuvenators can enhance sustainable development by reducing cost of road system maintenance and environment pollution caused by waste oil disposal. As such, evaluating different types of waste oil as rejuvenators is becoming popular. Dedene, Mills-Beale, and You (2011) studied waste engine oil as a rejuvenating agent. Rutting factor, G*/Sin(δ) was measured for aged binders mixed with waste engine oil as well as virgin and aged binders. Waste oil successfully decreased the viscosity of the aged binder and improved thermal cracking resistance. Also, adding waste oil was found to facilitate mixing, handling, and compaction of the asphalt mix.

Used motor oil was considered a rejuvenator for totally recycled (100% RAP) HMA (Oliveira, Silva, Jesus, Abreu, & Fernandes, 2013). A penetration grade test was implemented to determine the optimum amount of oil. The optimum amount was defined as the minimum percentage of oil that changes the penetration grade of the aged binder from 10/20 to 20/30. Rheological tests were employed to evaluate the performance of rejuvenated mix. Results approved the used oil effectiveness in rejuvenating totally recycled mixtures. As a result, 100% RAP, mixed with motor oil was claimed to be an effective sustainable paving solution.

Zargar et al. (2012) studied asphalt rejuvenating with waste cooking oil (WCO). According to the results of this research, 3–4% waste cooking oil content can successfully restore original 80/100 bitumen performance for asphalts aged to the grade 40/50. Rejuvenated bitumen was even affected by short-term aging less severely than the original binder. So WCO was found to be another new green and economical solution in pavement preservation.

## SASHTO STATE OF PRACTICE (SURVEY RESULTS)

Just one rejuvenating practice was reported. Familiarity with the technique was evaluated as adequate to good. The specifications from the manufacturer were often used as a guideline for this technique. These specifications were evaluated as effective. The technique is applied on pavement in good condition and the performance of the practice is evaluated as very good. Lack of more effective codes and specification, skilled local contractors, and material are the obstacles of pavement rejuvenating treatment. No detailed technical response was received for rejuvenating.

CHAPTER FOUR

# CHIP SEAL

## TECHNIQUE DESCRIPTION

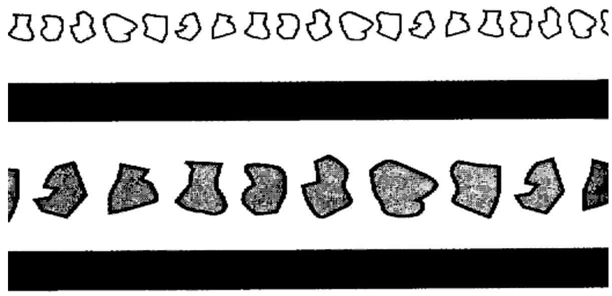
A chip seal (also referred to as "seal coat") is a sprayed application of asphalt emulsion that is followed by spreading a single layer of uniform size aggregate. This layer protects pavement from deterioration due to traffic and environmental conditions. The cover aggregate also improves skid resistance of the pavement surface.

Multiple chip seal consists of two or more courses of chip seal that are placed one on each other to provide more resistance to deterioration and improve the performance of the pavement. The nominal size of aggregate for top course should not exceed half the underlying course's aggregate size. Figure 4-1 shows a two-layer chip seal schematically.

### Material-Asphalt

Selection of asphalt grade for chip seal is based on parameters such as temperature of air and pavement surface, humidity, aggregate to be used, and condition of the current surface. The emulsion should be fluid enough to be easily sprayed and viscous enough to retain consistency to aggregates. Moreover, it should be cured rapidly. Some of common asphalts for chip seals are listed below (Asphalt Institute, 2009):

RS-1, RS-2, CRS-1, CRS-2, MS1, HFMS1, PG 46-34, PG 52-28, PG 64-22, PG 58-28, PG 70-22



(a)

(b)

**Figure 4-1 Schematic Multiple Chip Seal A) Different Layers, B) Completed Chip Seal (Caltrans, 2009)**

### Material-Aggregate

Aggregates to be used for chip seals should be of uniform size. However it is not practical and economical to supply perfectly uniform material. The largest aggregate should not be larger than two times the size of the smallest one (Caltrans, 2003).

The best shape for aggregates is cubic. It should be somewhat angular and should not be flat. It is also important that aggregates should be clean and dry.

### Design

To design a chip seal, one should determine the application rate of asphalt and aggregate, maximum aggregate size, volume percentage of voids and bulk specific weight. State Departments of Transportation propose different procedures to design chip seals. However, Table 4-1 provides some typical amounts of asphalt and aggregate. Correction factors delivered in Table 4-2, which considers pavement texture, should be applied to Table 4-1 values.

**Table 4-1 Quantities of Asphalt and Aggregate for Single Layer Chip Seals (Asphalt Institute, 2009)**

| Nominal Aggregate Size | Size No. | Aggregate Quantity ($lb/yd^2$) | Emulsion Quantity ($gal/yd^2$) | Emulsion Grade |
|---|---|---|---|---|
| 3/4 to 3/8 in. | 6 | 40-50 | 0.4 – 0.5 | RS-2, CRS-2, CRS-2P, CRS-2L, HFRS-2 |
| 1/2 in. to No.4 | 7 | 25-30 | 0.3 – 0.45 | RS-2,CRS-2, CRS-2P,CRS-2L, HFRS-2 |
| 3/8 in. to No.8 | 8 | 20-25 | 0.2 – 0.35 | RS-2,CRS-2, CRS-2P,CRS-2L, HFRS-2 |
| No.4 to No.16 | 9 | 15-20 | 0.15 – 0.2 | RS-1,CRS-1, MS-1, HFRS-2 |
| Sand | AASHTO M-6 | 10-15 | 0.1 – 0.15 | RS-1, CRS-1, MS-1, HFRS-2 |

**Table 4-2 Surface Condition Correction Factors for Chip Seals (Caltrans, 2003)**

| EXISTING PAVEMENT | CORRECTION ($l/m^2$) |
|---|---|
| Black, flushed asphalt | -0.01 to -0.06 (Depending on severity) |
| Smooth, non-porous or smooth | 0.00 |
| Slightly porous and oxidized or matte | +0.03 |
| Slightly pocked, porous, and oxidized | +0.06 |
| Badly pocked, porous, and oxidized | +0.09 |

### Equipment

Main equipment used in chip seal projects are asphalt distributors, aggregate spreaders, rollers, and cleaning equipment.

An asphalt distributor is a truck or a truck-mounted tank that carries the emulsion and distributes it. Distributors have a spray bar at the back of the tank that consists of several nozzles. Each nozzle has a specific spraying angle and covers a predetermined width. It is important to adjust the height of the bar properly to make asphalt application uniform and spray all points of the pavement surface at least two nozzles.

An aggregate spreader is the equipment that applies a uniform cover of aggregate at a specified rate. Rollers seat aggregates on pavement surface and applied emulsion, compact chip seal and push it to the old surface. Cleaning of the surface prior to application of asphalt is absolutely necessary and is done using cleaning equipment.

## REVIEW OF RECENT WORK

Effects of construction and environmental condition on performance of chip seals are widely addressed in the literature. Some of the most recent work on this issue is reflected in this synthesis.

Construction related factors affecting performance of chip seals were recently studied in Turkey (Gürer, Karasahin, Çetin, & Aktas, 2012). Factors investigated include adhesion capability and dust content of the aggregate, the temperature of bitumen at distribution tank, surface and ambient temperature, and time between bitumen spraying and aggregate distribution, and then between aggregate spreading and rolling. Effects of the mentioned factors were studied by one year of monitoring and conducting non-destructive tests on five test road sections. Macrotexture loss was considered as a cause of chip seal deterioration. Results showed that use of larger aggregates with a modified binder on roads provides better performance for single-layer chip seals on unbound granular base courses for heavy traffic roads. Initial texture depth was also evaluated to have a significant effect on long term performance of chip seals. It was recommended that this value should not be less than 9 mm. Aggregate average least dimension as well as traffic volume should be considered in designing rolling passes.

Rolling at temperatures higher than 124° F (51℃) was observed to cause excessive aggregate embedment and bitumen flushing. Therefore, rolling should be delayed until surface temperature falls blow this value.

It is recommended that chip seal application should be done when ambient temperature is between 86° F (30℃) and 110° F (43.5° C). Otherwise, long term performance of chip seal will be affected.

The authors of the paper mentioned above have also developed a model to predict macrotexture of chip seals. (Aktas, Karasahin, & Tigdemir, 2013). This model can be employed to predict chip seal life based on minimum macrotexture criteria.

Loss of aggregates is considered one of the major constructability issues related to chip seals. Factors such as improper timing of distributing emulsion or aggregate and insufficient amount of binder and premature traffic passing can cause loss of aggregate. All of the reasons in fact lead to inadequate development of the adhesive bond between emulsion and the cover aggregate. A predictive model to quantify the amount of water lost as a function of time and changing weather was developed to estimate water loss and its effect on the evolution of the mechanical properties of the binder (Banerjee, Smit, & Prozzi, 2012). This estimate is necessary to determine the waiting period before the aggregates can be placed in a chip seal construction. The water loss was studied in two stages: first, at the time the emulsion cools down, and then evaporation due to the vapor pressure. System water content and emulsion temperature specific evaporation coefficient are factors influencing water loss at the stage of cooling down. Results of this study showed that the mentioned coefficient only depends on the nature of the emulsion and is not affected by the temperature of the system. The rate of moisture loss was observed to drop with the square of residual water in the emulsion. Temperature, relative humidity and wind speed were distinguished as factors affecting the rate of water loss under ambient conditions.

The model proposed in this study is useful for determining the time interval after emulsion is sprayed and before aggregate is spread. Proper timing can ensure an adequate bond between emulsion and aggregate and prevent loss of aggregate in chip seals.

The North Carolina Department of Transportation (NCDOT) and North Carolina State University (NCSU) conducted a comprehensive research program on asphalt surface treatments, especially chip seals. Quantifying the benefits of improved rolling of chip seals, development of a new chip seal mix design method, extending the use of chip seals to high volume roads by using polymer-modified emulsions, and field calibration and implementation of the performance-based chip seals mix design method are some of the topics covered or currently being investigated in the NC program.

Kim and Lee (2008) introduced an improvement in the chip seal rolling pattern, based on aggregate retention performance and embedment depth. Roller type, number of coverages, coverage distribution on the sub layers of a multiple chip seal, and the rolling pattern were investigated as rolling parameters affecting the performance. Based on test results, it was concluded that:

- The aggregate loss percentages obtained from the MMLS3 test were smaller than those of other tests. It showed that those conventional aggregate retention tests are conservative in determining aggregate retention performance.
- Rolling is recommended to begin with the pneumatic tire roller and finish with the combination roller, which provides a smoother finished texture.
- Taking into account aggregate retention test results and practical considerations, optimal number of coverage\s was found to be three for both straight and split seal constructions.

- One rolling coverage of the layer immediately below the top layer improves the aggregate retention performance of the top layer for multiple chip seals. So rolling of the bottom layer is necessary for split chip but not seals for the triple.
- The optimal delayed rolling time between aggregate spreading and the rolling changes according to the water content of the aggregate.

Richard Kim and Javon Adams (2012) proposed a new performance-related mix design method for chip seal. In this method, optimal Aggregate Application Rate (AAR) was determined using modified board test and optimal Emulsion Application Rate (EAR) was determined using laser profiler. The initial embedment depth of the aggregate particles was assumed as 50% of the total depth. This assumption was confirmed by the aggregate loss and bleeding data obtained by third scale Model Mobile Loading Simulator (MMLS3). Granite 78M and lightweight aggregate with CRS-2L emulsion was used to produce chip seal specimens for this validation test. For each of the two aggregate types, three gradations with different performance uniformity coefficients (PUCs) were tested. PUC represents the uniformity of the aggregate gradation.

Laboratory scale chip spreader (ChipSS) was employed to fabricate chip seal specimens. It was concluded from this study that:

- Using 12 in. by 20 in. board for board test leads to better consistency of AAR, comparing larger boards. However, three tests are required to obtain an AAR representing the aggregate.
- The NCSU-developed laser profiler and its associated algorithms can accurately capture the distance, area, and volume of the AST system subjected to laser testing.
- PUC has a good agreement with chip seal aggregate loss performance.

Based on a comparison between the optimal rates from the mix design with those currently used by some divisions, it was shown that the mix design AARs were about 40% less than the field AARs. Also, mix design EARs were found 14 to 28% less than the field EARs in some cases. Aggregate moisture and traffic whip-off have not been considered in the mix design process, but they occur in actual field conditions. This might be a reason for observed higher field AARs than the mix design AAR. Also, absorption of the emulsion into aggregate and into the existing pavement surface was guessed to be responsible for higher EARs field values in comparison with the design.

Richard Kim's team is continuing their work on Performance-Based Chip Seals Mix Design (NCDOT Research Project 2013-03). They are conducting a field and laboratory experimental program to calibrate implementation of this new design method. The researchers are also evaluating implementation of chip seals on high volume roads. To achieve that, modified emulsions are being tested, guidelines for maximum traffic volume are being developed, and construction procedures are to be optimized.

A study conducted in Mississippi by Jordan (2010) was aimed at determining the effects of chip seal and scrub seal on aged asphalt pavements for the potential use in performance based specifications for Mississippi Department of Transportation (MDOT). Rejuvenation effect of chip seal treatment on underlying old asphalt pavement was investigated through Frosted Marble Test and Viscosity for extracted binder. Figure 4-2 shows the section of old pavement affected by treatment. Various emulsions (CRS-2, CRS-2P, CRS-2P, PASS-CR, CHFRS-2P, Road Armor, and CFS-2HP) were tested in this study and effects of them were evaluated and compared.

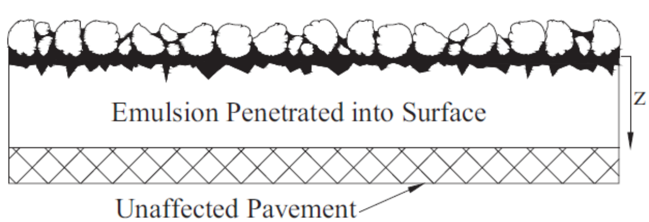



**Figure 4-2 Old Pavement Rejuvenated by Chip Seal Treatment (Jordan, 2010)**

**Best Practices**

Chip seal best practices are addressed in NCHRP synthesis 342 (Gransberg & James, 2005). Best practices were researched through a comprehensive literature review and distributing a survey to 42 state DOTs, 12 U.S. cities and counties, 10 Canadian provinces, 1 Canadian territory, 2 Canadian cities, 4 Australian provinces, 2 New Zealand provinces, 2 public agencies in the United Kingdom, and 1 public agency from South Africa. The summary of best practices recommended in this synthesis were as follows:

Best practices in pavement selection, design, and material selection are as follows:

1. View chip seals as a preventive maintenance tool to be applied on a regular cycle to reinforce the pavement preservation benefits of the technology.
2. Use chip seals on roads with low underlying surface.
3. Use chip seals that can be successful on high-volume roads if the agency's policy is to install it on roads before pavement distress becomes severe or the structural integrity of the underlying pavement is breached.
4. Characterize the underlying road's texture and surface hardness, and use that as a basis for developing the subsequent chip seal design.
5. Try using the "racked-in seal" as the corrective measure for bleeding instead of the North American practice of spreading fine aggregate (sometimes called "chat") on the bleeding surface.
6. Conduct electrostatic testing of the chip seal aggregate source before chip design to ensure that the binder(s) selected for the project is compatible with the potential sources of aggregate.
7. Use life-cycle cost analysis to determine the benefit of importing either synthetic aggregate or high-quality natural aggregates to areas where the availability of high quality aggregate is limited.
8. Specify a uniformly graded, high-quality aggregate.
9. Consider using lightweight synthetic aggregate in areas where post-construction vehicle damage is a major concern.
10. Use polymer-modified binders to enhance chip seal performance.
11. Recognize that both hot asphalt cement and emulsified asphalt binders can be used successfully on high-volume roads. The selection of binders modified by polymers or crumb rubber seems to reinforce success.

Best practices in contract administration, warranties, and performance measures are as follows:

1. Award chip seal contracts in time to permit early season construction (Chapter Four).
2. Time the letting of the contract to allow sufficient time for the curing requirements of preconstruction pavement preparation activities.
3. Package chip seal contracts in jobs large enough to attract the most qualified contractors.
4. Use in-house maintenance personnel to install chip seals in areas where the greatest care must be taken to achieve a successful product.
5. Use warranties for chip seal projects only when the contractor is given the latitude to determine the final materials and methods used to achieve a successful chip seal.
6. Use sand patch method to measure chip seal macrotexture can serve as an objectively measured chip seal performance indicator.
7. Use the chip seal deterioration model expressed in the New Zealand P17 specification to furnish an objective definition of chip seal performance based on engineering measurements.
8. Supplement the two previously described practices with continued visual distress rating based on the Ohio DOT chip seal performance criteria.

Best practices in construction are as follows:

1. Apply all types of chip seals in the warmest, driest weather possible, for optimum performance.
2. Use an ambient air temperature at the time of application: a minimum of 50°F (10°C) when using emulsions, and 70°F (21°C) when using asphalt cements, with a maximum of 110°F (43°C).
3. Use emulsions in a temperature of a minimum of 70°F (21°C) and no more than 140°F (54°C) on the surface.

4. Complete patches at least 6 months before and crack seals at least 3 months before the application of chip seals.
5. Use variable nozzles to permit the application of a reduced rate of binder in the wheelpaths and help combat flooding in the wheelpaths, a defect that makes chip seals prone to bleeding. Conversely, the Australian use of pre-spraying is another method for adjusting the transverse surface texture of a pavement surface before applying a chip seal.
6. Fit a drag broom on those rollers doing the initial roller pass corrects minor aggregate spread deficiencies such as corrugation, uneven spread, or missed areas.
7. Apply the aggregate as quickly as possible to both emulsified and hot asphalt binders.
8. Use the Montana field-sweeping test to curtail the bias to spread excess aggregate created by a unit-price contract.
9. Have the most experienced inspector predrive each shot and paint binder rate adjustments on the pavement to facilitate field rate adjustments.
10. Apply a small amount of excess aggregate to reduce scuffing and rolling. The use of a racked-in seal may be a viable engineered solution for determining the precise amount of aggregate for these problematic areas.
11. Furnish and enforce rolling guidelines and specifications for roller coverage, rolling patterns, and minimum rolling time to achieve full lane coverage and a similar number of passes for all areas of the lane.
12. Use the required number of rollers is a function of desired distributor production and required rolling time for each shot width on the project.
13. Have rolling follow as closely as practical behind the chip spreader.
14. Maintain traffic control for as long as possible to give the fresh seal the maximum amount of curing time

Best practices in chip seal equipment and quality assurance and quality control are as follows:

1. Require chip seal contractors to use state-of-the-art equipment and to control the rolling operation to enhance chip seal success.
2. Use computerized distributors.
3. Require pre-project analysis of the ability of the chip seal equipment spread to keep up with the production rate of the distributor.
4. Use variable nozzles to reduce the amount of binder that is sprayed in the wheelpaths.
5. Use plastic bristles for rotary brooms minimize aggregate dislodgment during brooming.
6. Combine an aggressive quality control testing program with a close inspection that generates chip seal success.
7. Assign experienced personnel who understand the dynamics of chip seal construction as field quality control and quality assurance persons.
8. Calibrate regularly both the distributor and the chip spreader.
9. Evaluate aggregate–binder compatibility tests for local appropriateness and use in the field.
10. Field test both binders at the distributor and aggregate stockpiles to ensure that material has not degraded owing to handling during transportation

## SASHTO STATE OF PRACTICE (SURVEY RESULTS)

Nine participants, from all states participating in this survey, reported implementation of chip seal. Typically, agencies reported about 20 chip seal projects under construction and almost 100 completed chip seal constructions during the past 5 years. NCDOT also self performs 2000 to 3000 center-line miles of chip seals annually.

While 60% of the participants reported just adequate knowledge of the technique, 40% of the agencies evaluated themselves as being familiar with chip seal or proficient in it. Eighty percent of agencies use chip seal when the pavement is deteriorated to fair condition (60 < PCI < 69) and 60% also apply it on pavements in good condition (70 < PCI < 84).

GDOT and NCDOT use their own standard specifications:

GDOT Standard Specifications - Section 424 - 4/20/2010

NCDOT specifications section 660, 2012

Florida counties also usually use county specs.

In sum, most of agencies rated specifications they use as effective or very effective. However, the following gaps in specifications were identified:

- Specifications for Higher Traffic (more than 2000 ADT) and Higher Trucks (more than 200 TPD)"
- Need for expanding or modifying types of emulsions allowed.
- Suggestion for modifying to allow and/or specify the use of a scrub seal for a single course treatment or the first application of a multiple course treatment.

QC/QA programs seem to be well developed on the emulsion materials and gradation of material. Sixty percent of agencies have implemented these programs.

Except for one participant, agencies reported good to excellent performance for chip seal constructions. They also expected at least 5 years of pavement life extension due to chip seal construction. This estimate was up to 10 years for some agencies.

Chip seal construction cost, as reported by agencies, has a good consistency, ranging from 1.87 to 2.7 $\$/yd^2$.

Figures 4-3 and 4-4 show objectives of implementation of chip seal and practical obstacles. All agencies use chip seal to delay deterioration of the pavement and reduce water infiltration. Also, 80% of them considered surface friction improvement as an objective of chip seal construction. Social, legal, or political considerations are the most common difficulties agencies deal with in their chip seal projects. Lack of skilled personnel and contractors is also counted as a problem. Lack of appropriate material and equipment is also reported. Loose rocks and maintenance of traffic is also reported to cause citizens concern.

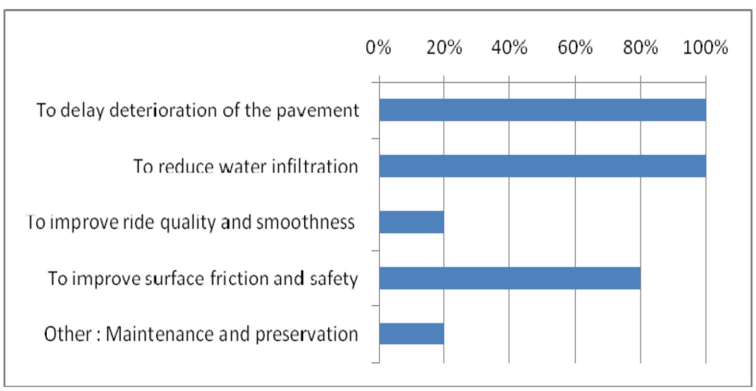



**Figure 4-3 Objectives of Chip Seal Constructions**

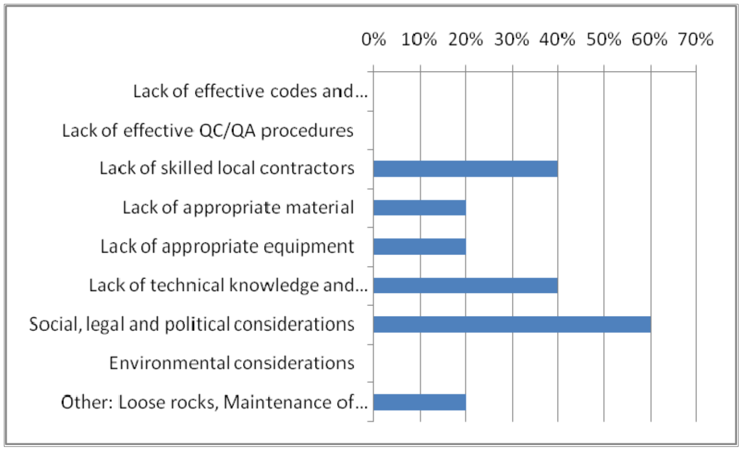



**Figure 4-4 Obstacles and Difficulties of Chip Seal Constructions**

GDOT reported that its typical chip seal wearing course consists of a triple application (No. 7, No. 89 & W10 Sand Seal) with a total application of approximately 0.64 gal/yd$^2$ CRS-2L emulsion. This is evaluated as good for up to 2000 ADT and 200 trucks per day. Beyond these limits, bleeding becomes more common.

According to the response from the West Virginia Department of Transportation (WVDOT) representative, WVDOT's use of chip seals had varied greatly over the years to improve their ability to properly apply them. There are regions in the state that have maintained this practice as a part of pavement preservation and the results are not debatable. The use of chip seal in those areas has significantly helped those regions maintain their portion of the system. Other areas strayed away from the practice and pavements have suffered as a result. WVDOT is taking strides to improve its ability to apply chip seal on a statewide basis.

According to the responses to the technical questionnaire, chip seal is applied on pavements with just minor distresses or moderate cracking and loss of aggregate.

CRS-2, CRS-2h, CRS-2p, and CRS-2L are asphalt emulsions used for chip seal constructions. They are generally cationic rapid setting emulsions. Polymer modified binders are also being widely used. The application rate of emulsion varied from 0.4 gal/yd$^2$ to 0.5 gal/ yd$^2$. Table 4-3 presents some of maximum and minimum of aggregate sizes used for chip seal. The quantity of spread aggregate ranged from 25 lb/ yd$^2$ to 30 lb/ yd$^2$.

**Table 4-3 Maximum and Minimum of Aggregate Sizes Used For Chip Seals**

| Agency | Aggregate Maximum Size | Aggregate Minimum Size |
|---|---|---|
| **GDOT** | 1/2" | 3/8" |
| **NCDOT** | 5/16" | 1 1/2 % passing 200 sieve |
| **KCI Technologies Inc** | FDOT 89 stone | 89 stone |

The following rolling patterns are reported for chip seals:

GDOT: "Two individual rollers. At least 1 must be a pneumatic tired roller. Each roller makes 3 passes."

NCDOT: "5 - 8 ton dual steel wheel roller 5 -8 ton 9 wheel articulating rubber tire roller (most preferred) steel wheel/rubber tire combination roller. Three complete passes with 2 or 3 rollers on each layer of aggregate"

Private sector in Florida: "Pneumatic Tire Rollers: The contractor shall use 8 to 12-ton self-propelled pneumatic tire rollers with oscillating wheels and low pressure, smooth tires. Maintain the inflation of the tires such that in no two tires the air pressure varies more than 5 psi. The rollers will be equipped with an operating water system and coco pads. A sufficient number of rollers and a sufficient number of passes shall be used to ensure cover aggregate is properly rolled."

NCDOT proposes following construction sequence:

"1) Set up traffic control.  2) Cut back edge of pavement as necessary.  3) Sweep entire area.  4) Apply first layer of emulsion and immediately place first layer of aggregate.  5) Multiple rollers make 3 complete coverages of area within 5 minutes of emulsion application.  6) Repeat steps 4 & 5 for second layer application.  7) Maintain low speed traffic on the new seal coat for a couple of hours."

A good practice to deal with construction joints in multiple chip seal constructions is that chip seal placed in second pass overlaps first lane completed few inches.

The appropriate season for chip seal construction varies state to state. However, generally the technique is executed when temperature is above $50^0$F and rising.

Texture of the road surface after application of chip seal is generally reported to be good. However, existence of loose gravel for up to two weeks is reported.

NCDOT has a comprehensive research program for chip seals. See chapter 4 – Review of Recent Work.

CHAPTER FIVE

# SANDWICH SEAL AND SCRUB SEAL

## SANDWICH SEAL

Sandwich seal is variation of chip seal, which is generally used to cure excessive asphalt on pavement surface. In this technique, a layer of large aggregate (15-20 mm) is applied on the pavement surface. Then asphalt is sprayed and a layer of smaller aggregate is spread. The excess asphalt at existing pavement acts as the binder for the first layer. The finished surface is expected to have a surface free of flashing asphalt with restored texture. Polymer modified RS-2, CRS-2, and HFRS-2 emulsions are usually used for this technique (Asphalt Institute, 2009). Figure 5-1 shows a schematic cross section of sandwich seal. This technique is described and approved as a solution for bleeding road section at NCHRP Synthesis 342 (Gransberg & James, Chip Seal Best Practices, 2005)

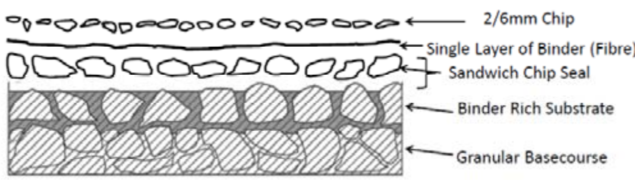



**Figure 5-1 Schematic Cross Section of Sandwich Seal**

## SCRUB SEAL

Scrub seal is another variation of chip seal that is most effective for oxidized and distressed pavements. The procedure is just like regular chip seal except that after application of liquid asphalt, a specified scrub broom that is towed behind the distributor forces the emulsion into the old pavement. This action seals minor cracks in pavement and provides a waterproof film. Figure 5-2 shows application of scrub seal. The PASS-CR is considered a common emulsion for the scrub seal. (Jordan, 2010)

**Figure 5-2 Application of Scrub Seal (Howard, 2009)**

## REVIEW OF RECENT WORK

Fiber reinforced sandwich seal was applied on a highway in Saskatchewan, Canada. The construction and performance was addressed by Marjerison, Anthony, J.M., & Gareau (2011). There were many graded seal patches with bleeding on the road section. Alternatives to solve the problem were single chip seal with reduced binder application rate, inverted double chip seal, and sandwich chip seal. Sandwich seal, reinforced by fiber membrane was selected. One other section was also tested for sandwich seal without fiber. Both the fiber-reinforced sandwich chip seal and the regular sandwich chip seal were successful to cure flushing and bleeding. A desirable micro texture was also created as a result of this practice. The treated sections performed well after one year. However, service life benefits should be monitored and studied later.

Howard (2009) studied application of chip seal and scrub seal on two highway sections in Mississippi. Evaluation was based on several criteria, including aggregate retention, skid resistance, cracking, bleeding and flushing, rutting, roughness, and structural integrity via a Falling Weight Deflectometer (FWD).

Statistical analysis showed that bleeding or flushing was less for scrub seal than chip seal for the highway sections which had flushing issue and were tested for both techniques. Also, the scrub seal sections have a better aggregate retention performance in comparison with chip seal sections. Aggregate loss was more severe in the lane center than in the wheel path. There were no significant differences observed in pop outs between chip and scrub seals. Generally, it was concluded in this study that scrub seal outperformed chip seals.

## SASHTO STATE OF PRACTICE (SURVEY RESULTS)

Application of sandwich seal was reported by just one agency in Florida. Also, Arkansas and Virginia Departments of Transportation reported implementation of scrub seal. No more information was provided by the participants. Generally, sandwich seals and scrub seals are not common surface treatment practices; they are usually considered a part of chip seal projects.

CHAPTER SIX

# SLURRY SEAL

## TECHNIQUE DESCRIPTION

Slurry seal is an application of a mixture of emulsified asphalt, fine aggregate, mineral filler, and water on the surface of the pavement. The thickness of the seal is usually equal to largest aggregate size. This technique is considered as both a preventive and corrective surface treatment. Excellent surface texture, fast application, correction of minor irregularities, cracks, and also small thickness (which leads to minimum curb height loss) are some of advantages of slurry seals.

Slurry seal is an effective way to seal minor cracks, waterproof the pavement surface, and improve skid resistance. It can also address hot mix asphalt oxidation, hardening, and weathering. However, slurry seal should not be performed when there are structural failures or severe cracking. Patching and crack sealing should be performed prior to application of slurry seal.

### Material

Aggregate used in slurry seals should be uniform, clean, angular, rough, durable, sound, and abrasion resistant. Compatibility of adhesive and cohesive properties with the emulsion should be taken into account as well. The following criteria should be met for slurry seals:

ASTM D 2419 Sand Equivalent Value not less than 45

ASTM C 131 Los Angeles Abrasion Loss (Grade C or D) not greater than 35

Aggregate used in slurry seals are classified into three grades based on their quality as presented in Table 6-1.

**Table 6-1 Slurry Seal Aggregate Gradations (Asphalt Institute, 2009)**

| Sieve Size | Percent Passing | | |
|---|---|---|---|
| | TYPE I | TYPE II | TYPE III |
| $^3/_8$ in. (9.5 mm) | 100 | 100 | 100 |
| # 4 (4.75 mm) | 100 | 90 - 100 | 70 – 90 |
| # 8 (2.36 mm) | 90 - 100 | 65 - 90 | 45 – 70 |
| #16(1.18 mm) | 65 - 90 | 45 – 70 | 28 – 50 |
| # 30 (600 um) | 40-65 | 30 – 50 | 19 – 34 |
| # 50 (330 um) | 25-42 | 18 - 30 | 12 – 25 |
| #100(150 um) | 15-30 | 10 - 21 | 7 – 18 |
| #200 (75 um) | 10-20 | 5 - 15 | 5 - 15 |

SS-1h, CSS-1h, QS-1h, and CQS-1h emulsions can be used for slurry seals (Caltrans Maintainance TAG, 2003). Emulsions should be compatible with the aggregate and meet mix design parameters. Some additives may be added to the mixture to improve its characteristics and control curing time. A small amount of mineral filler such as Portland cement limestone dust may also be added to stabilize the slurry. Latex modified emulsion is usually used for slurry seals. Latex is an emulsion of rubber particles which does not mix with the asphalt, but form a 3D structure with it. Table 6-2 presents emulsion requirements for slurry seal.

### Slurry Seal Machine

A specified machine is used to mix and apply slurry. The machine has the ability to deliver determined amounts of material to its mixing chamber and make the mixture. The mixture then is discharged uniformly of pavement surface. Figure 6-1 schematically demonstrates different parts of a slurry machine.

**Table 6-2 Typical Emulsion Properties For Polymer Modified Slurry Quick Set (Holleran, 2002)**

| Test | Typical Emulsion Specification | Method |
|---|---|---|
| **Residue** | 62% min | AASHTO T 59 |
| **Sieve Content** | 0.3% max | AASHTO T 59 |
| **Viscosity @ 25°C, SSF** | 15-90 | AASHTO T 59 |
| **Stability (1 day)** | 1% max | ASTM D244 |
| **Storage Stability (5 days)** | 5% max | ASTM D244 |
| **Residue pen @ 25°C** | 40-90 | ASTM D244 |
| **R&B SP, °C** | 57 min | AASHTO T 53 |
| **Torsional Recovery** | 18% min (LMCQS-1h) | CT 331 |
| **Polymer Content** | 2.5% min (LMCQS-1h) | CT 401 |

### Construction

First, pavement surface should be cleaned and pavement markings should be removed. Placement of slurry in hot weather or freezing temperatures should be avoided. Slurry seals should be placed when the temperature is at least 50°F (10°C) and rising and the forecast for the next 24 hours is above 40°F(4.4°C) (Pavement Preservation, 2010).

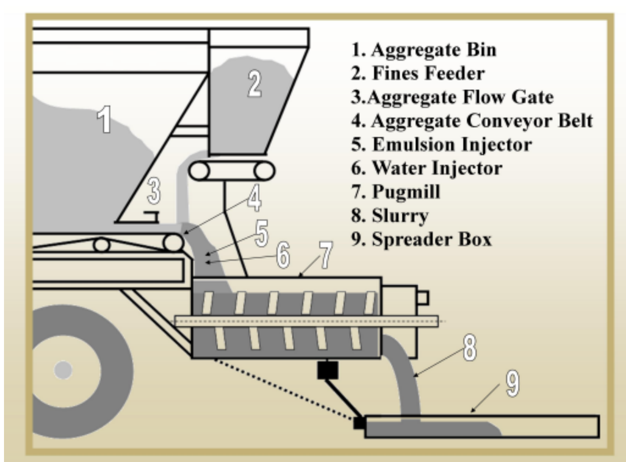



**Figure 6-1 Schematic Slurry Machine (Dynamite Paving & Sealcoat, 2013)**

Quick setting emulsions may cure in 1 hour, but others may require 2 to 4 hours. Premature opening to traffic or pavement marking should be avoided. Table 6-3 addresses some common problems in slurry seal construction and proposes solutions for them.

**Table 6-3 Slurry Seal Common Problems and Associated Solution (Caltrans, 2009)**

| PROBLEM | SOLUTION |
|---|---|
| **Uneven Surface**<br><br>**Wash Boarding** | - Ensure the spreader box is correctly set up.<br>- Ensure the viscosity of the mix is not too high.<br>- Make adjustments so that the mix does not break too fast.<br>- Wait until the ambient temperature is lower.<br>- Use water sprays on the front of the spreader. |
| **Poor Joints** | - Reduce the amount of water at start up.<br>- Use water spray if runners of spreader box are running on fresh material. |
| **Excessive Raveling** | - Add cement and reduce additive so that the mix breaks and cures faster.<br>- Check aggregate to ensure the clay fines are not too high.<br>- Control traffic longer and at low speeds.<br>- Wait until fully cured before allowing traffic.<br>- Wait until mix is properly set before brooming or opening to traffic. |

## REVIEW OF RECENT WORK

As microsurfacing has been developed and well established as a high performance slurry seal, recent studies on slurry seal has focused on cost benefit analysis, performance evaluation and timing of this technique.

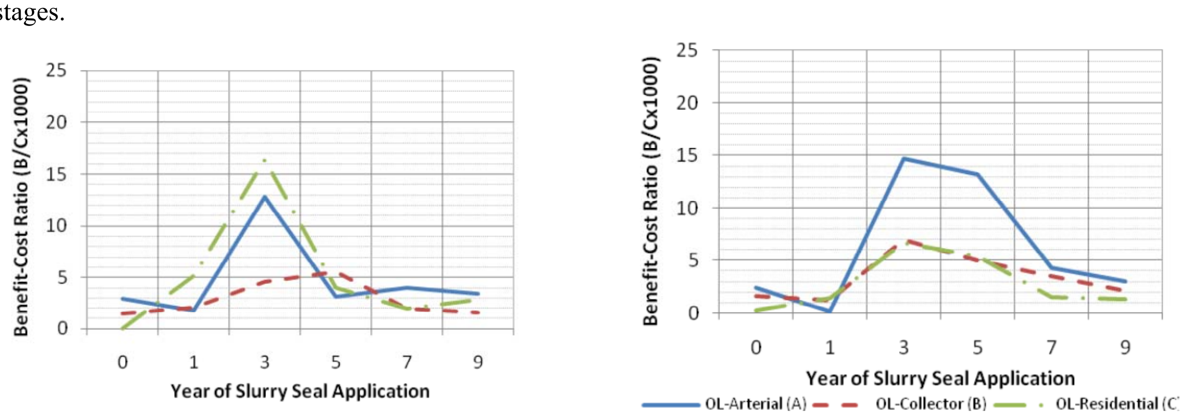
Field performance of slurry sealed pavement has been evaluated and compared to untreated pavements in a TRB paper (Hajj E. Y., Loria, Sebaaly, & Borroel, 2011). Slurry seals were applied on roads in several stages after road construction and their performance was compared to identify optimum time to apply slurry seal.

Long-term performance and cost effectiveness are evaluated using the MicroPAVER® system based on data collected during the past 15 years. Slurry seals were applied at 0, 1, 3, 5, 7, and 9 years after construction.

According to this study, a slurry seal application should be delayed at least 3 years after new pavement construction or overlay. Applying a slurry seal during the first year after construction is not cost effective.

However, at 3 years after construction, slurry seal treatment protects the pavement from excessive aging and improves its resistance to distresses. The performance curve for the pavements that received slurry seals 3 years after construction is significantly improved.

The optimum time for slurry seal treatment was found 3 years for new constructions and 3 to 5 years for overlaid roads. Figure 6-2 presents benefit-cost ratios for pavement subjected to slurry seal at different time stages.




**NC: New Construction; OL: Overlay**

**Figure 6-2 Benefit Cost Ratio for pavement subjected to slurry seal treatment (Hajj E. Y., Loria, Sebaaly, & Borroel, 2011)**

The authors of the aforementioned effort studied the effective timing of two sequential applications of slurry seals (Hajj E. , Loria, Sebaaly, & Cortez, 2013). The same methodology as the previous study has been implemented for this work.

The best time to apply first sequential slurry seal treatments on new constructions is found to be when PCI is 90 for first application and 86 for the second. For overlays, these values are respectively 87 and 77. According to this study, these PCI values correlate with 3 and 7 years after construction, regardless of the type of construction.

Optimization of timing for slurry seal has also taken place in China. (Xi-lan, Wei-n, & Yi-chang, 2012). Several factors, including crack ratio ($R_C$), rutting depth ($D_R$), and International Roughness Index (IRI), and sideway force coefficient ($C_{SF}$) were studied to determine the optimum timing for treatments. Treatment is applied with different timings. Using benefit-cost method, it was found for condition of roads at Hebei Province, China that:

> The proper range of following performance indicators for application of treatment is: $0.28\% < R_C < 1.4\%$ ; $10mm < D_R < 15$ mm ; $1.97 < IRI < 3.5$ ; $40 < C_{SF} < 50$
>
> According to the above pavement performance parameters, the fourth year is the optimum time to apply treatments for the condition of this case study.

### SASHTO STATE OF PRACTICE (SURVEY RESULTS)

Conventional slurry seal was reported to be used just by two agencies in Florida and Virginia. No further information was provided. It seems that practitioners tend to use microsurfacing, which is a high performance slurry seal, rather than conventional slurry seal treatment.

CHAPTER SEVEN

# MICROSURFACING

## TECHNIQUE DESCRIPTION

Microsurfacing is an improved version of slurry seal in which high quality aggregate and polymer modified binder is used. Design of microsurfacing mix and properties of material should meet the requirements of "Recommended Performance Guide for Micro-Surfacing A143," by the International Slurry Surfacing Association (ISSA, 2010) .

Microsurfacing generally consists of cationic polymer modified emulsion, 100% crushed aggregate, mineral filler, water, and additives. Major differences are identified at California Department of Transportation Maintenance Technical Advisory Guide as presented in Table 7-1.

**Table 7-1 Microsurfacing versus Slurry Seal (Caltrans, 2009)**

| Differences In: | Microsurfacing | Slurry Seal |
|---|---|---|
| **Asphalt Emulsion** | Always polymer modified, quick set | Could be polymer modified |
| **Aggregate Quality/Gradation** | Stricter specifications for sand equivalent; use only Type II and Type III | Can use Type I, II, or III |
| **Additives/Break** | Chemical break largely independent of weather conditions | Breaking and curing dependent on weather conditions |
| **Mix Stiffness/Equipment** | Stiffer mix, use augers in the spreader box and secondary strike-off | Softer mix, use drag box |
| **Applications** | Same as slurry seal + rut filling, night work, correction of minor surface profile irregularities | Correct raveling, seal oxidized pavements , restore skid resistance |

### Material

All emulsion used in microsurfacing should be polymer modified and quick setting. Latex is usually used as the modifier. The asphalt and latex do not combine, but their particles intermingle and form an integrated structure with aggregates as shown in Figure 7-1.

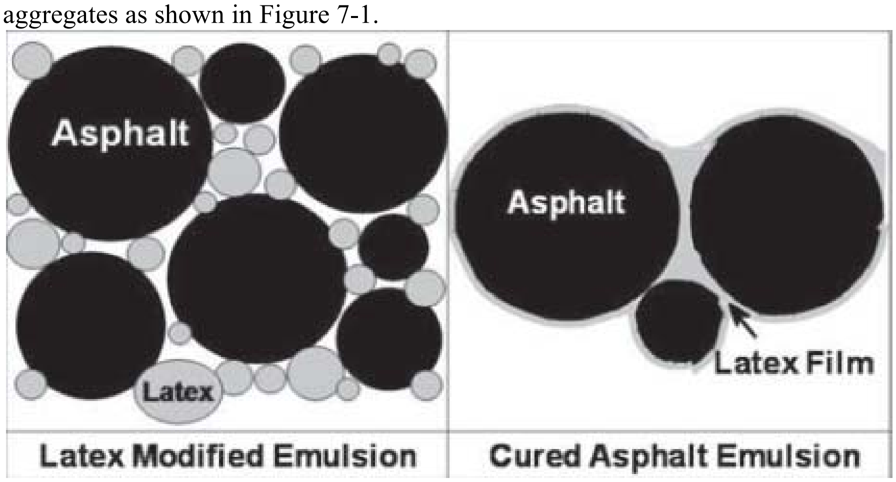



**Figure 7-1 Latex Modified Emulsion Before and After Breaking (Watson S. , 2005)**

The emulsion should pass requirements of AASHTO M208 or ASTM D2397. Some common binders for microsurfacing are CSS-1P, CSS-1h, CSS-1hP, CQS-1h, CQS-1hP, CRS-1P, CRS-2P, and Ralumac™.

Aggregate used for microsurfacing should be 100% crushed stone. Following criteria should be met for the aggregate:

- Sand Equivalent value: 60% min.
- (AASHTO T176/ASTM D2419)
- Soundness: 15% Max. using $NA_2SO_4$ or 25% Max. using $MgSO_4$ (AASHTO T104/ASTM C88)
- Los Angeles abrasion resistance: 30% Max.
- (AASHTO T96/ASTM C131)

Gradation of aggregate should be type II or type III as presented in Table 6-1. Type II is used for general resurfacing, sealing and renewal of surface friction. Type III is used to provide better performance for high volume roadways, rut filling, and producing high friction surfaces.

Non-air entrained Portland cement and hydrated lime are common mineral filers used for microsurfacing. Laboratory mix design determines the amount of mineral filler to be used. Additives might be added to the mix to set cure time and control breaking of the emulsion. Water should be drinkable and compatible with the mix.

The application rate should be 10-20 lb/yd$^2$ for roads with lower traffic volume (when Type II gradation is used) and 15-30 lb/yd$^2$ for high volume roads.

### Equipment

Microsurfacing slurry is mixed using a machine especially designed for this purpose. The automatic-sequenced, self-propelled microsurfacing mixing machine has a continuous-flow mixing unit that is able to deliver and proportion the aggregate, emulsion, mineral filler, additives, and water accurately to a revolving multi-blade, double-shafted mixer and discharge the resulting slurry on a continuous flow. Construction joints will be minimized if a self-loading mixing machine, which is capable of being fed while surfacing, is implemented.

The mixture is spread using the spreader box. Front and rear seals are provided to prevent loss of the mixture at the road contact point and make the final strike-off. Figure 7-2 exhibits a microsurfacing machine schematically.

### Construction

The surface should be clean and free of standing water prior to application of microsurfacing. Cracks wider than 1/4 in. should be sealed before the treatment. In hot, dry weather, it is recommended to pre-wet the surface slightly in order to prevent premature breaking of emulsion.

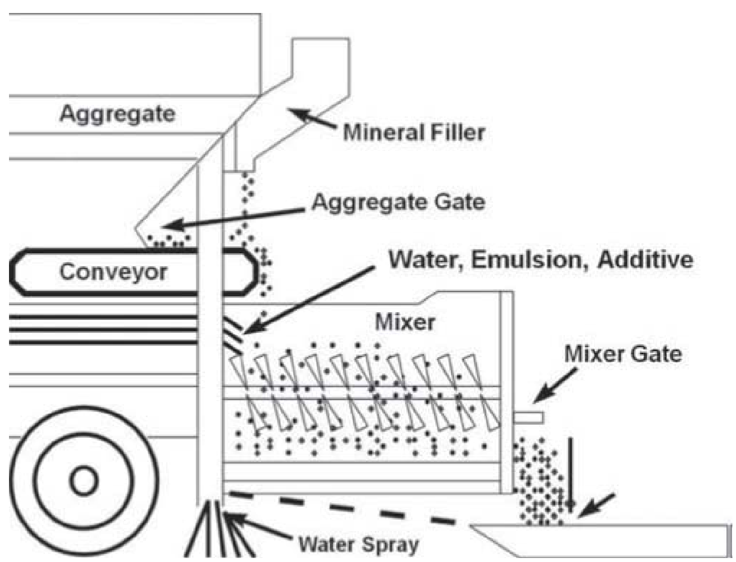



**Figure 7-2 Schematic Of Microsurfacing Machine (ISSA, Inspector's Manual for Slurry Systems 2010)**

## REVIEW OF RECENT WORK

Developed in Germany in the late 1960s and early 1970s, microsurfacing has been performed on United States roads since 1980 as a maintenance treatment. The research history of this treatment was addressed by Broughton, Lee, & Kim (2012).

### Advantages and Limitations

According to this study, microsurfacing has generally received positive scientific feedback and its application is encouraged. This treatment scored the highest in composite index score calculation, based on 11 performance criteria (Hicks, Seeds, & Peshkin, 2000). This technique is also cost effective. Microsurfacing was found more cost effective than thin overlays as an alternative treatment (Labi, Mahmodi, Fang, & Nunoo, 2007).

Good resistance against deformation at high temperature, good performance at wet-freeze environment, less environmental impact due to lower temperature applied and so lower energy consumption, improving rutting and friction resistance, avoiding vehicle damages due to loose aggregate, rapid opening to traffic and providing high and long lasting high PCI are some of advantages of microsurfacing that are reported in the literature and reflected in Broughton, Lee, & Kim (2012)'s work.

On the other hand, effectiveness of microsurfacing in terms of resistance against reflective cracking and also its applications for high traffic volume highways has been disputed in the literature. It is also reported that this treatment is not effective to level bumps and fill depressions (Broughton, Lee, & Kim, 2012).

### Best Practices

Best microsurfacing practices suggested by Banerjee, Smit and Prozzi (2012) are based on various scientific works studied. According to this review, the key to success of microsurfacing is conducting comprehensive mix design process, quality of material, and the use of a skilled contractor. Workmanship is reported to have significant influence on the quality of the treatment.

Fine material, sub-no. 200 (75 micron), affects set-rate of microsurfacing. In addition, layers thicker that 1.1–1.5" were reported to be prone to faster deterioration and should be avoided. Deep ruts are recommended to be filled in two passes.

Microsurfacing is not recommended to be placed on cracked or highly deflecting surfaces and pavements with base failures.

## SASHTO STATE OF PRACTICE (SURVEY RESULTS)

Ten agencies have reported application of surface treatment. Comparison of this with those reported using slurry seal suggests that conventional slurry seal has been generally substituted by microsurfacing. Okaloosa County is the agency which most often uses microsurfacing construction. They are currently constructing as many as 20 microsurfacing projects and have completed 50 microsurfacing projects. Nassau county and NCDOT have 4 projects each, and WVDOT has 8 ongoing microsurfacing projects. NCDOT has the experience of 30 completed microsurfacing construction projects, and other agencies reported less than 10 completed projects. Participants have reported adequate to proper familiarity with microsurfacing.

Microsurfacing is often applied when the pavement is deteriorated to fair condition ($60<PCI<69$). Seventy-three percent of agencies apply microsurfacing at this stage. Forty-three percent of them also apply this treatment when the pavement is still in good condition. One agency reported applying microsurfacing on highly distressed pavements ($40<PCI<59$). However, effectiveness of microsurfacing at this condition in debated.

In Florida, among five participants that have reported the specification they use for microsurfacing, three FDOT representatives indicated the use of Florida Developmental Specification 335, revised on 12/09/2011 and Pinellas and Nassua counties use their own specs. Also West Virginia and North Carolina use their Special Provisions for microsurfacing. Half of participants rated the specifications effective, 38% of them believe that they are just somewhat effective, and one considered it neither effective nor ineffective. There is also a desire for expanding allowable emulsions.

The procedure to control quality in Florida is that the engineer obtains two samples of microsurfacing mixture for each day of production. The samples are obtained at different periods during the production day. The engineer tests each sample to determine the residual asphalt content and the gradation of each sample. The QA/QC procedure is described in the spec. In West Virginia, materials are tested before acceptance and approval. The mix design is also evaluated for approval. QC is done during placement to monitor application rate, sample emulsion if desired, and sample for gradation. Penalties are considered for insufficient application and gradation. In North Carolina, to assure the quality, material samples are obtained at job site and verified to meet gradation and emulsion specifications.

Fifty-six percent of survey participants rated their microsurfacing performance good, and the other 44% consider it very good. No participants claim excellent performance of microsurfacing construction. Generally at least 5-7 years life extension due to microsurfacing construction is expected.

Figures 7-3 and 7-4 present purposes of implementation of microsurfacing and the obstacles that limits application of this technique. To delay deterioration of the pavement and improve ride quality are major adjectives of using microsurfacing. While it seems that specification are well established and there is no major issue of accessing proper material and equipment, lack of knowledge and skill regarding microsurfacing, both within agencies and with the contractors, seems to be the most serious problem in construction of this treatment.

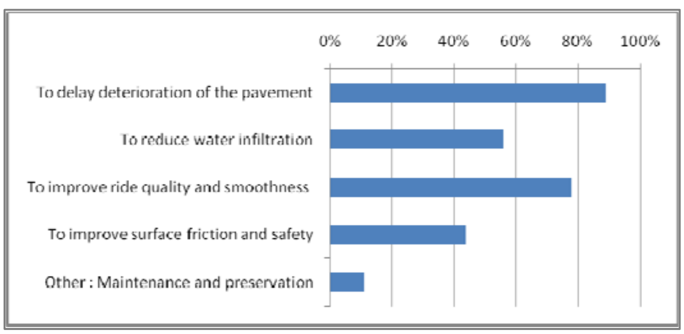



**Figure 7-3 Objectives of Microsurfacing Constructions**

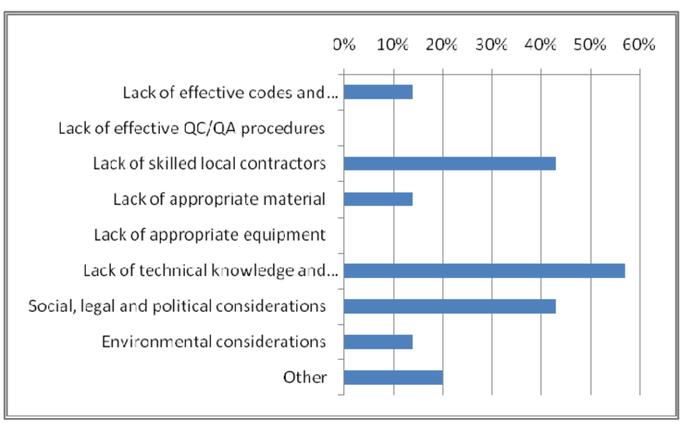



**Figure 7-4 Obstacles and Difficulties of Microsurfacing Constructions**

Due to the higher traffic volumes on the system, FDOT does not use microsurfacing. This is primarily to minimize the impact on the travelling public. A microsurfacing project that deteriorates after five years can be perceived by the public as a road that failed after only five years.

WVDOT indicated that there is still a need for better overall understanding of proper project selection for project designers. WVDOT needs to develop a better mechanism for implementation of a properly timed treatment other than the traditional resurfacing proposal and contract. Therefore, they are working on a tiered purchase order contract to allow implementation within a much shorter time-frame.

In West Virginia, microsurfacing was implemented as a three-year warranty project in 2010. The project was along a rural two-lane US highway and road condition was actually below desired rating at time of construction. The micro has performed admirably even on a road with the less than desirable condition. Therefore, WVDOT decided to incorporate it into its 2012 resurfacing program and issued seven contracts. A similar number will be issued within the 2013 program.

Microsurfacing cost is estimated at \$1.93 to \$2.50 per square yard by Florida counties. However, FDOT estimate is higher (\$1.90-\$3.00 /$yd^2$). North Carolina reported \$2.53 /$yd^2$. The estimate at West Virginia is \$2.75-\$3.00/ $yd^2$ for single course and \$3.75-\$4.00 / $yd^2$ for a double course.

CHAPTER EIGHT

# CAPE SEAL

## TECHNIQUE DESCRIPTION

Cape seal is an application of single layer chip seal followed by slurry seal or microsurfacing. The name of the techniques is derived from the Cape Administration of South Africa (Solaimanian & Kennedy, 1998).

Cape seal is effective for correcting medium severity fatigue cracks compared to other techniques, according to Illinois Department of Transportation Bureau of Design and Environment Manual (IDOT, 2012). It can also be implemented to address longitudinal, transverse, and block cracking, friction loss, raveling, minor roughness, minor to moderate bleeding and water infiltration.

Standard specifications and construction methods for slurry seal or microsurfacing and chip seal should be applied for cape seal treatment. Slurry should be placed 3 to 12 days after application of chip seal. Table 8-1 presents two typical designs for cape seal (Asphalt Institute, 2009).

**Table 8-1 Quantities of Emulsion and Aggregate for Cape seal (Asphalt Institute, 2009)**

| Thickness | Size No. | Nominal Aggregate Size | Aggregate Quantity (lb/yd$^2$) | Emulsion Quantity (gal/yd$^2$) | Slurry[1] Rate (lb/yd$^2$) |
|---|---|---|---|---|---|
| **1/2 in.** | 7 | No.8 to 3/8 in. | 25-30 | 0.3-0.45 | 6-10 |
| **3/4 in.** | 8 | 3/8 in. to 3/4 in. | 40-50 | 0.4-0.5 | 8-12 |

[1]ISSA type I slurry

There are two strategies in application of slurry in cape seal (Solaimanian & Kennedy, 1998):

- Applying a low rate of slurry just to fill the void between chip aggregates. Tops of the stone get exposed as a result of this practice (nodular effect). This provides a greater skid resistance.
- Applying a high rate of slurry on the chip seal. This practice provides a thin layer of slurry seal or microsurfacing at the top the chip seal.
- Figure 8-1 shows these two methods schematically.

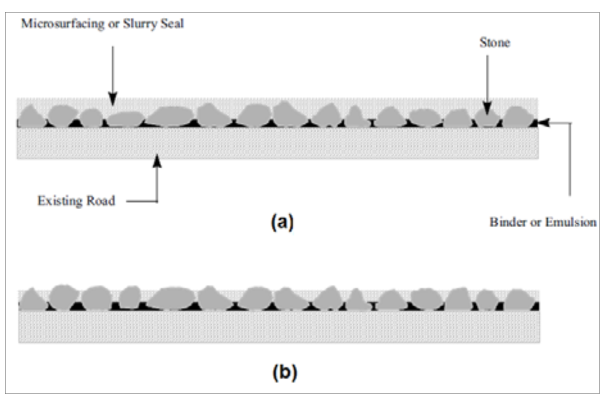



**Figure 8-1 Two Modes of Cape Seal Construction: (A) Complete Coverage of Chip Seal (B) Chips Exposed (Solaimanian & Kennedy, 1998)**

## REVIEW OF RECENT WORK

The Texas Department of Transportation and the University of Texas at Austin conducted a research project to evaluate the cape seal as a pavement rehabilitation practice (Solaimanian & Kennedy, 1998). Most of cape seal projects performed at U.S. to the date of this study were visited and evaluated. Field permeability tests as well as laboratory tests on laboratory-made cape seal specimens, including permeability, shear, and loaded wheel tests were conducted.

According to the results, permeability of the cape seal is almost similar to HMA overlays. Bleeding and shoving were observed to be most significant distresses associated with cape seals. Most failures were due to inappropriate chip seal construction. It is important to apply the chip seal properly prior to application of slurry. Because of typically higher shear stresses in cape seals, an important consideration was to ensure a strong enough bond between the chip seal and old pavement to avoid shoving.

## SASHTO STATE OF PRACTICE (SURVEY RESULTS)

Three participants, including representatives of NCDOT and Nassau County Engineering Services, and also a participant who has not provided name and affiliation data, reported implementation of cape seal.

North Carolina reported 20 completed but no ongoing cape seal projects and rated itself familiar with the technique. Other agencies have performed just one cape seal project and have only adequate familiarity with the treatment. Cape seal is usually applied when pavement are at fair condition (60<PCI<69). Agencies use their specifications for chip seal and microsurfacing for cape seal construction.

All participants reported postponing of pavement deterioration as a purpose of applying cape seal. It is also implemented to reduce water infiltration, improve ride quality, smoothness of the road, surface friction and safety. 6-7 years of life extension due to cape seal treatment was expected by agencies. Associated costs were estimated at $3.25 and $3.61 per square yard by Nassau county and North Carolina.

Agencies performing cape seal suffer a lack of skilled contractors for this technique. Lack of effective specifications, knowledgeable personnel, and proper material were reported as obstacles for use of this treatment.

CHAPTER NINE

# THIN OVERLAYS

## TECHNIQUE DESCRIPTION

Thin HMA overlay, also referred to as thin maintenance surfaces, is placing a non-structural hot-mix asphalt (HMA) layer with a thickness not more than 1.5 in. over an existing pavement. A thin overlay addresses pavement surface defects, such as cracking and rutting, and also improves ride quality and reduces surface permeability (in case of dense graded mix). Overlays also slightly increase structural capacity of the pavement. Pavements with fatigue cracking and rutting are not good candidates for thin overlays. Cracks should be sealed prior to overlay application. In urban areas where curbs should be maintained and milling is required, thin overlays are well applicable.

There are three types of maintenance thin overlays: dense graded, open graded, and gap graded (Caltrans, 2009). This classification is based on gradation of aggregate, void content, and binder content Figure 9-1 shows a schematic of these grades.

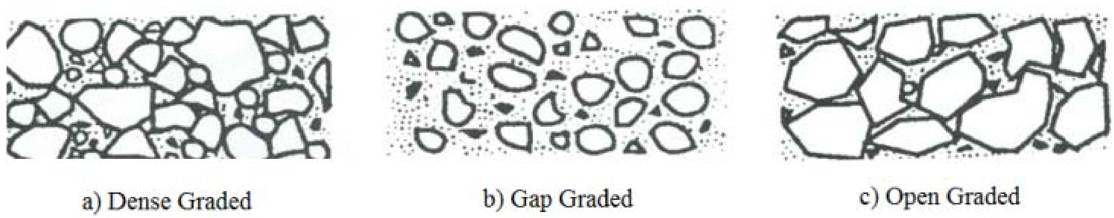



**Figure 9-1 Matrices of Different Types of HMA Overlays (Hicks, Fee, & Moulthrop, 2000)**

Dense-graded mixtures have a continuously sized aggregate structure, from the largest to the smallest aggregates. This type of mixture has relatively low air void contents and is designed as an impermeable abrasion resistant layer. This gradation is most common for asphalt overlays. Using asphalt rubbers for this grade makes compaction difficult and is not recommended. (Caltrans, 2009)

Open-Graded Asphalt Concrete (OGAC) is a surface course that provides a relatively open void structure comparing dense graded asphalt concrete. This overlay is also referred to as Open-Graded Friction Course (OGFC). Having 15 to 25% void content, the porous structure of OGAC mixtures make them highly permeable in comparison with Dense-Graded Asphalt Concrete (DGAC). Surface water easily flows through the mixture and is quickly drained away from the surface of OGAC. This leads to a significant reduction in splash and spray. Also, OGAC has a better friction performance and reduces tire noise (Caltrans, 2009)

Gap-graded mixture is made of an aggregate gradation that is a missing fraction. The advantage of gap grading is improving stone-to-stone contact by reducing the fine aggregate content and strengthening of aggregate skeleton and also creating space for more binder. Gap grading increases the Voids in the Mineral Aggregate (VMA) of a mixture. Stone matrix asphalt (SMA) is a gap-graded mixture that uses fibers to prevent drain-off. The fiber makes the binder thick enough to stand high binder content of gap graded mixture. (Caltrans, 2009)

Mix is generally designed based on specification for Superpave HMA or OGFC. Construction and rolling procedures also follow those of HMA. Design and thickness of HMA should be decided based on traffic demands. The minimum thickness of the overlay is three times the maximum aggregate size. As overlays cool quickly, compaction should be done properly and quickly. Warm mix asphalt technology is getting more popular in thin overlay constructions because of its low temperature and slow cooling down.

Table 9-1 lists some common problems of thin overlay constructions and provides some probable causes and propose solution for them.

## REVIEW OF RECENT WORK

As an old and common preventive maintenance treatment, performance and cost effectiveness of thin overlays has been evaluated and compared with other techniques. Based on a review of earlier literature conducted by Attoh-Okine and Park (2007), while thin overlay construction typically costs more than other treatment, it also extends the life of pavement more than others. As a result, this study concludes that HMA overlays are cost-effective for a long period of time. It should be mentioned that this conclusion is based on limited data and there are other studies that offer different results.

Performance of thin overlays, based on experience of five states, as well as Canada and Austria, is summarized by Newcomp (2009) in terms of expected performance years. This is presented in Table 9-2.

According to a literature review by Walubita and Scullion (2008), the advantages and disadvantages of thin overlays are as listed below. They have also summarized specifications of HMA used for thin overlay constructions by six states (Table 9-3).

Advantages:

- Long-term cost effectiveness when applied on structurally sound pavements.
- Good performance in all climatic conditions.
- Good resistance under heavy traffic loads and high shear stresses.
- Preventing vehicle damage due to loose stones after construction.
- Minimal dust generation during construction.
- Improved ride quality and skid resistance.
- Low noise generation and no binder runoff.
- Recyclability.
- Possibility of stage construction.
- Easy maintenance.
- Improving structural capacity, even if slightly.
- Improving appearance of the pavement aesthetically.

Disadvantages:

- High initial construction cost.
- Curb loss if old pavement is not milled.
- Prone to delamination, reflective cracking, and maintenance problems.

The long-term effectiveness of thin overlays was evaluated using effectiveness measurements such as service life, average pavement condition increase, and area bounded by the performance curve (Labi, Lamptey, Konduri, & Sinha, 2005). Three indicators were used for the evaluation: International roughness index (IRI), rutting, and pavement condition rating (PCR). The results had a wide range, as follows:

Service life (years) - IRI: 3-13 years; Rutting 3-14 years; PCR: 3-24 years

Pavement condition increase: IRI: 18%-36%; rutting decrease: 5%-55%; PCR increase: 1%-10%

The wide range obtained indicated a large influence of levels of traffic loading, weather severity, and route type on long term effectiveness of thin overlays.

**Table 9-1 Common Problems, Associated Causes and Solution for Thin Overlay Construction (Caltrans, 2009)**

| PROBLEM | CAUSES | SOLUTIONS |
|---|---|---|
| **Non Uniform Texture-Segregation** | - The mixture separating in the hopper or in transportation<br>- Poor paver set up.<br>- Low mix temperature or poor grading or mix design.<br>- Prone to occur in thin overlays.<br>- Weak base layer. | - Ensure thickness is at least twice that of largest stone size, mix design is correct, and the paver is properly set up.<br>- Ensure mix temperature is correct. |
| **Screed Marks** | - Transverse screed marks occur when the paver stops and starts and longitudinal screed marks occur when extensions are used on the screed.<br>- Poor paver set up or worn or dirty screeds.<br>- Low mix temperature or poor grading or mix design | - Set paver and screed correctly. Use windrowing to ensure paver does not stop.<br>- Ensure the mix is in specification. |
| **Surface Shadows** | - Caused by overloading augers in the paver.<br>- May be caused by low mix temperature or poor grading or mix design. | - Adjust the distance between the screed and the tractor of the paver.<br>- Ensure that the level of mix is near the center of the auger shaft. The augers should NOT be totally covered with mix. |
| **Roller Checking and Roller Marks** | - Deflection under the roller (i.e., mix too hot) or mix design is poor.<br>- Too much asphalt in the mix, too much middle size sand in the gradation (1.18-600μm sieve). | - Wait until the mix cools further or adjust the mix design. |
| **Bleeding and Fat Spots** | - High mix temperature or poor grading or mix design.<br>- Too much asphalt in the mix or amount of fines too low in the grading.<br>- Mix design not taking the correct traffic level into account.<br>- Moisture in the mix or on the pavement.<br>- Extremely high applications of tack coat.<br>- Existing bleeding surface. | - Ensure aggregates are dry during the mixing process, that pavement is not bleeding, that pavement is dry, and that mix is correctly designed for traffic and aggregate |
| **Shoving** | - Caused by excess asphalt in the mix.<br>- Improper roller operation such as sudden reversal.<br>- Rolling before the mat is stable enough.<br>- Roller going too fast. | - Ensure mix is at correct temperature.<br>- Ensure roller is not going too fast.<br>- Check and correct mix design if necessary.<br>- Consider use of modified binders. |
| **Delamination** | - Insufficient tack coat.<br>- Mix is too cold during compaction.<br>- Existing surface being too cold for paving.<br>- Dirty surface on which an overlay is being placed. | - Ensure paving temperatures are correct.<br>- Ensure the surface is substantially free of debris. |
| **Poor Joints** | - Paver operating at different elevations when paving adjacent lanes.<br>- Poor joint practice, especially in compaction of thin layers. | - Make sure joints are correctly formed and compacted at the correct temperature. |
| **Raveling** | - Insufficient asphalt in the mix.<br>- Poor compaction. | - Ensure mix design conforms to the specification.<br>- Ensure compaction is carried out at correct temperatures. |

**Table 9-2 Performance Summaries of Thin Overlays (Newcomp, 2009)**

| Location | Traffic Condition | Expected Performance (Years) |
|---|---|---|
| Ohio | High and Low | 16 |
| Georgia | Low | 10 |
| Illinois | Low | 7-10 |
| New York | – | 5-8 |
| Indiana | Low | 9-11 |
| Ontario, Canada | High | 8 |
| Austria | High and Low | More than 10 |

**Table 9-3 Summary of Thin HMA Overlay Specifications/Guidelines (Walubita & Scullion, 2008)**

| Agency | Name of Thin HMA Overlay | Mix-Design Method |
|---|---|---|
| Arizona | Asphalt Rubber (AR) | 1-Type AC-ACFC: Superpave (open-grade @ 15% AV)<br>2- Type AR-AC: Superpave (gap graded @ 3% AV) |
| Georgia | Superpave No. 4 NMAS-like HMA | Superpave-50 gyrations@Ndesign,4% AV |
| Maryland | No.4 NMAS-like HMA | Superpave-@ 4% AV |
| Ohio | Smooth seal | 1- Type A-Recipe<br>2- Type B- Marshall |
| NCAT (Alabama) | 1-SMA<br>(No.4 or 9.5-mm NMAS)<br>2-Superpave No.4 NMAS like HMA | 1- Superpave<br>2- Superpave-@ 4% AV and VMA≥16% |
| Michigan | Ultra-thin HMA | Marshall-@ 4.5 to 5.0% AV and VMA≥15% |

## SASHTO STATE OF PRACTICE (SURVEY RESULTS)

Thin overlay is the most common surface treatment according to results of the survey. More than 200 ongoing overlay projects and over 650 completed overlays in the past 5 years were reported.

Generally, overlays are applied on pavement with more severe distresses. All participants reported overlaying roads in fair condition (60 < PCI < 69). Application of overlays was also reported on pavements deteriorated to a very poor condition, with PCI lower than 40.

Generally either Superpave or friction course specifications are used for overlays based on their type. In Florida, section 334 (Superpave) and 337 (Friction Course) of FDOT specification are followed. West Virginia, however, has developed specifications dedicated to “Hot-Mix Asphalt High Performance Thin Overlays” (WVDOT Special Provision, Section 496). WVDOT still believes that specifications are not suitable for low thickness application. Aggregate segregation issues were reported in Florida due to non-mandatory use of material transfer device. Agencies are generally satisfied with the performance of their overlay constructions and expect over 10 years of life extension due to this treatment. In addition to addressing general expectations from a surface treatment, thin overlays are reported to be capable to correct wheel path rutting. Overlays generally cost more than other surface treatments (At least $6.5/yd$^2$). So their application for low-volume roads is not often recommended.

CHAPTER TEN

# ULTRATHIN BONDED WEARING COURSE

## TECHNIQUE DESCRIPTION

Ultra-thin bonded wearing course (UBWC) is a preventive maintenance surface treatment consisting of applying a thick polymer-modified emulsion membrane, immediately followed by a thin layer of gap-graded hot-mix asphalt (HMA). The thickness of the HMA layer is 3/8 in. to 3/4 in. NOVACHIP® is a UBWC process developed in France in 1986 (Kandhal & Lockett, 1997). It is defined as a paving process that places a thin (3/8- to 3/4-in.), gap graded coarse aggregate hot mix over a membrane (polymer modified asphalt emulsion seal coat) (Uhlmeyer, Pierce, & Watson, 2003). In fact the terms "Ultra-thin Bonded Wearing Course" and "NOVACHIP®" are interchangeable and refer to the same method.

UBWC is placed using an especially modified paving machine. The machine consists of an emulsion tank, sprayer, and a conventional HMA paving system. Figure 10-1 shows elements of a Novachip® paving machine. This machine is also known as spray paver. The role of polymer-modified asphalt membrane is to seal and protect the old pavement and provide strong adhesion of the HMA layer to the underlying surface. The hot mix is placed immediately after emulsion application, when the emulsion is not cured yet. The hot material evaporates the water of the emulsion quickly, and the residual binder gets absorbed by the new and old asphalt concrete. This provides an excellent bond between the two layers. The gap-graded mix, makes a stone-on-stone contact structure which has high rutting resistance. The finished product is a very smooth, open textured surface with good skid resistance and low road-tire noise.

**(Uhlmeyer, Pierce, & Watson, 2003)**

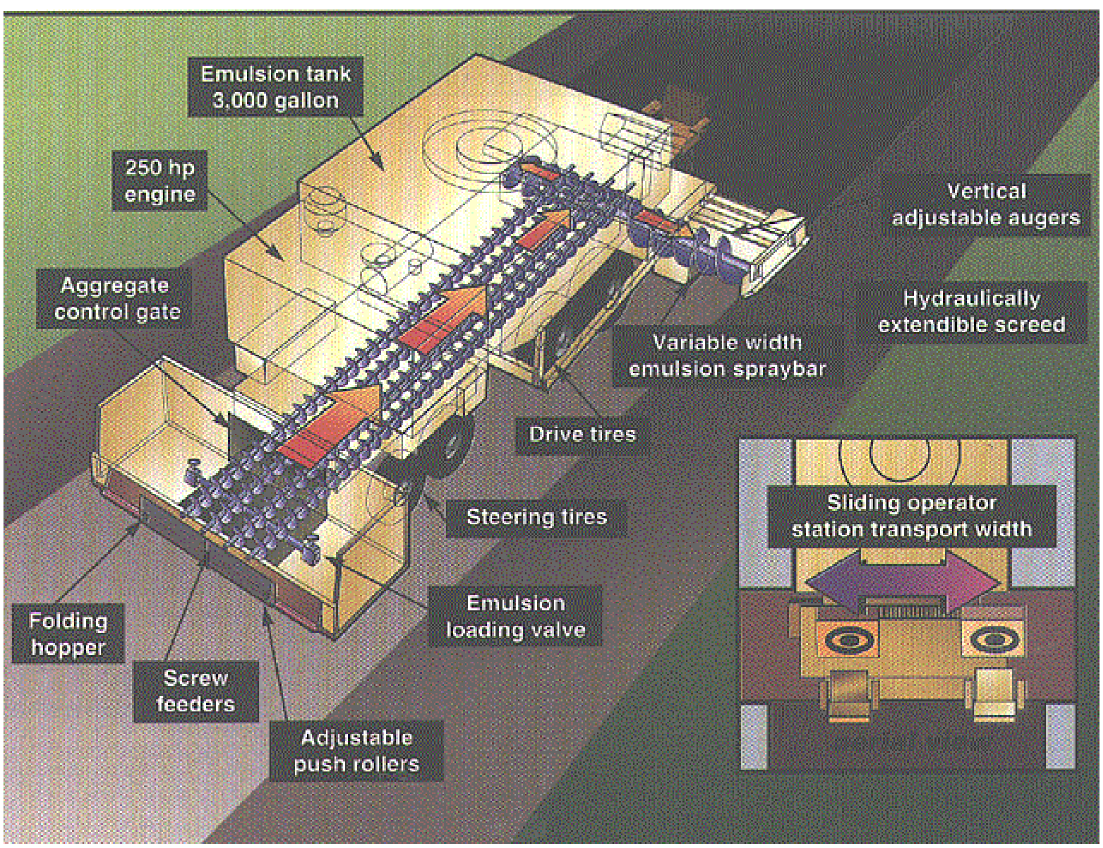



**Figure 10-1 Schematic of A UBWC Paving Machine (Uhlmeyer, Pierce, & Watson, 2003)**

The advantages of UBWC treatment are (Kandhal and Lockett 1997 ; Hanson 2001):

- Excellent adhesion to old surface
- Rapid construction and placement in one pass
- Quick opening to traffic and lower user delay costs
- Lower rolling noise (urban use)
- Excellent macrotexture matrix resulting in good skid resistance as well as reduced tire noise and back spray of road surface water

UBWC treatment cannot correct structural deficiencies of the pavement and should be used on structurally sound pavement. Any alligator cracking or potholes must be addressed prior to UBWC application. Minor cracks, thinner than 1/4 inch, can be sealed by the applied emulsion. UBWC can also correct ruts and other irregularities smaller than 1/2 in. (Hanson, 2001)

### Material

Novabond® is the polymer modified emulsion used for Novachip® (UBWC) membrane. It provides good bond between UBWC and the old pavement.

The application rate is 0.13 to 0.27 gallons per square yard based on the condition of the road surface.

The aggregates should have superior properties. They should be very durable and shaped nearly cubical. Table 10-1 shows test requirements for UBWC aggregates.

There are three types of UBWC mix design based on aggregate gradation. Type A (Max. aggregate size: 3/8 in.) provides the least skid resistance and is rarely used. Type C (Max. aggregate size: 3/4 in.) has the highest skid performance and is used for highest traffic volume. Type B (Max. aggregate size: 1/2 in.) is the most common and has a skid performance between types A and C.

**Table 10-1 UBWC Aggregate Test Requirements (Uhlmeyer, Pierce, & Watson, 2003)**

| Tests | | Method | Limit |
|---|---|---|---|
| **Coarse Aggregate** | | | |
| Los Angeles Abrasion Value, % loss | | AASHTO T 96-94 | 35 max |
| Soundness, % loss | Magnesium Sulfate or | AASHTO T104-94 | 18 max |
| | Sodium Sulfate | AASHTO T104-94 | 12 max |
| Flat & Elongated Ratio, % @ 3:1 | | AASHTO D4791 | 25 max |
| Percent Crushed, single face | | AASHTO D5821 | 95 max |
| Percent Crushed, two or more mechanically crushed faces | | AASHTO D 5821 | 85 max |
| Micro-Deval, % loss | | AASHTO TP 58-99 | 18 max |
| **Fine Aggregates** | | | |
| Sand Equivalent | | AASHTO T 176-84 | 45 max |
| Methylene Blue (on materials passing #200) | | AASHTO TP 57-99 | 10 max |
| Uncompacted Void Content | | AASHTO T 304-96 | 40 max |

## REVIEW OF RECENT WORK

Established first in 1986 in France, UBWC was introduced to the United States through a demonstration during a European Asphalt Study Tour in 1990. Two years later, the first UBWC construction took place in the state of Alabama. Soon after that, Mississippi and Texas started implementation on UBWC. (Kandhal & Lockett, 1997).

Louisiana's first UBWC project, constructed at 1997, was evaluated after 6 years (Cooper & Mohammad, 2004). The performance of this treatment is compared with conventional mill and overlay, constructed at the same time and same condition. Life cycle cost analysis showed that the Louisiana Department of Transportation and Development (DOTD) has benefited from application of this treatment. The Novachip treated pavement performed well in terms of rutting and also longitudinal, random, and transverse cracking.

Similar work was done for another early Novachip construction in Washington state (Uhlmeyer, Pierce, & Watson, 2003). The performance was compared with other rehabilitation methods executed by Washington Department of Transportation. The cost associated with the studied treatment is presented in Table 10-2. The practical advantages of easy material production and rapid construction were demonstrated by this experience. Twenty-two months after construction, the performance of the pavement was good, although the old cracks reflected. However, the long-term performance under the load of many vehicles with studded tires in Washington is still debated.

Using performance data from the Kansas Department of Transportation (KDOT), 1992 to 2007, cost effectiveness of UBWC and modified slurry seal (MSS) was evaluated by Liu, Manepalli, Gedafa, & Hossain (2010). In this case, despite a significant reduction in roughness, rut depth, fatigue, and transverse cracking after UBWC construction, a sharp drop-off in performance was observed after a couple of years. Also, UBWC was not more cost effective than conventional overlays according to this study.

**Table 10-2 Project Costs for Various Rehabilitation Treatments in Washington State (Uhlmeyer, Pierce, & Watson, 2003)**

| Rehabilitation Type[1] | Project Cost ($/Lane Mile) | Project Cost ($/yd$^2$) |
|---|---|---|
| Chip Seal | 14,000 | 1.49 |
| Hot Mix Asphalt (Class G)[2] | 50,000 | 5.33 |
| UBWC | 58,000 | 6.18 |
| Hot Mix Asphalt (Class A or ½ in. Superpave)[3] | 90,000 | 9.59 |

[1] Based on two 12-ft. lanes with 8-ft. shoulder in each direction.

[2] Class G compacted depth is 1.0 in.

[3] Class A or ½ inch Superpave compacted depth is 1.8 in.

## SASHTO STATE OF PRACTICE (SURVEY RESULTS)

The terms "Ultrathin Bonded Wearing Course" and "Novachip" are both used to refer to the technique discussed in this chapter. Six agencies from Florida, North Carolina, and Arkansas reported using UBWC. Four of those also know this technique as Novachip. North Carolina, with 10 ongoing and 50 completed UBWC projects, implements this technique most often. UBWC is performed on roads in good (70 < PCI < 84) or fair (60 < PCI < 69) condition. The specifications used in Florida and North Carolina are as follows:

Florida: Section 337- Asphalt Concrete Friction Courses, FDOT (Rev. 7-23-12). Table 10-3 presents emulsion test requirements for UBWC from this document

North Carolina: Open Graded Asphalt Friction Course, Permeable Asphalt Drainage Course, And Ultra-Thin Bonded Wearing Course, NCDOT (Rev. 4-17-12).

The specifications were evaluated as either effective (67%) or very effective (33%) by practitioners, and no gaps were reported.

All participants reported very good performance of UBWC and expected an 8- to 15-year life extension to be provided by this treatment.

All major objectives of surface treatments, including delaying deterioration of the pavement, reducing water infiltration, improving ride quality and surface friction were expected to be achieved by performing UBWC. Lack of skilled local contractors and appropriate equipment was major practical obstacles of constructing UBWC. Also resistance of the HMA industry against spray pavers was a concern in Florida. The machine used for UBWC is often called as “Spray Paver” in the asphalt industry.

**Table 10-3 FDOT Test Requirements for UBWC Emulsions**

| Test | Method | Limit |
|---|---|---|
| Viscosity @ 77ºF SSF | AASHTO T-59 | Max.100 Min. 20 |
| Sieve Test, % | AASHTO T-59 | Max 0.1 |
| 24-Hour Storage Stability, % | AASHTO T-59 | Max 1 |
| Residue from distillation @ 400ºF % | AASHTO T-59 | Min 63 |
| Oil portion from distillation ml of oil per 100 g emulsion | - | Max 2 |
| Demulsibility -35 ml 0.02 N CaCl2 or 35 ml, 08 % dioctyl sodium sulfosuccinate | AASHTO T-59 | Min 60 |
| **Test in Residue from Distillation:** | | |
| Solubility in TCE, % | AASHTO T-44 | Min 97.5 |
| Elastic Recovery, 50ºF, 20 cm elongation % | AASHTOT-301 | Min60 |
| Penetration @ 77ºF, 100 g, 5 sec, 0.1 mm | AASHTO T-49 | Max 150 Min 60 |

CHAPTER ELEVEN

# CRACK SEALING AND FILLING

## TECHNIQUE DESCRIPTION

Crack sealing and crack filling are methods used to repair cracks in pavement surfaces. This practice is not a treatment applied on the whole surface of the pavement, and as such, is not categorized as a surface treatment. However it is often considered as a prerequisite for surface treatments and is discussed briefly in this synthesis.

The main purposes of crack sealing/filling are (Asphalt Institute, 2009):

- Preventing water intrusion
- Preventing entrance of incompressible material

Crack filling is filling non-working cracks with asphalt cutback or emulsion. Crack sealing, which is done for cracks subject to expansion and contraction, is done using an especially prepared crack sealer. Filling requires less crack preparation than sealing. Also, filler materials have lower performance requirements. Crack filling is considered a temporary treatment to preserve the pavement between major maintenance operations.

It should be determined if the crack is working or non-working in order to decide whether crack sealing or filling is required. It should also be identified if the crack is subjected to horizontal or vertical movement. The criterion for distinguishing working and non-working cracks is total horizontal movement of the crack in one year. Table 11-1 presents FHWA Criteria for crack sealing and filling.

**Table 11-1 FHWA Criteria for Crack Sealing or Filling (FHWA-RD-99-147, 1999)**

| Crack Characteristics | Crack Treatment Activity | |
|---|---|---|
| | Crack Sealing | Crack Filling |
| **Width** | 3-25 mm | 3-25 mm |
| **Edge Deterioration** | Minimal to None<br>(<25% of crack length) | Moderate to None<br>(<50% of crack length) |
| **Annual Horizontal Movement** | $\geq$ 3 mm | < 3 mm |
| **Type of Crack** | Transverse Thermal Cracks<br>Transverse Reflective Cracks<br>Longitudinal Reflective Cracks<br>Longitudinal Cold Joint Cracks | Longitudinal Reflective Cracks<br>Longitudinal Cold Joint Cracks<br>Longitudinal Edge Cracks<br>Distantly Spaced Block Cracks |

An effective crack sealant and a crack filler should be able to (Caltrans, 2009):

Crack Sealant:

- Adhere to the walls of the crack.
- Elongate to the maximum opening of the crack and recover to the original dimensions without rupture.
- Expand and contract over a range of service temperatures without rupture or delamination.
- Resist abrasion and damage caused by traffic.

Crack Filler:

- Remains attached to the walls of the crack.
- Possesses some elasticity.
- Resists abrasion and damage caused by traffic.

There are several material placement methods, including the following (Caltrans, 2009):

- Flush Fill: Material forced into uncut crack; the crack is struck off flash with the pavement.

- Overband: Material forced into and placed over uncut cracks.
- Reservoir: The crack is cut or routed to form a reservoir the reservoir is filled with a sealant.
- Combination Method: Reservoir and Band-Aid.
- Combination Method, Sand Fill with Recessed Finish: Partially fill the crack with sand, sealant surface is slightly cupped below the adjacent pavement surface.

Table 11-2 presents some common problems occurring in crack sealing/filling and associated solution.

**Table 11-2 Common Crack Sealing/Filling Problems and Related Solutions (Caltrans, 2009)**

| Problem | Solution |
|---|---|
| **Tracking** | - Reduce the amount of sealant or filler being applied.<br>- For hot applied materials, allow to cool or use sand or other blotter.<br>- Allow sufficient time for emulsions to cure or use a sufficient amount of sand for a blotter coat.<br>- Ensure the sealer/filler is appropriate for the climate in which it is being placed. |
| **Pick Out Of Sealer** | - Ensure cracks are clean and dry.<br>- Increase temperature of application.<br>- Use the correct sealant for the climate.<br>- Allow longer cure time before trafficking |
| **Bumps** | - Check squeegee and ensure it is leaving the correct flush finish.<br>- Have squeegee follow more closely to the application.<br>- Decrease the viscosity of the sealer.<br>- Change the rubber on the squeegee. |

## REVIEW OF RECENT WORK

Al-Qadi, et al. (2009) documented several papers, journal articles, and technical reports to provide a reference for election of appropriate bituminous hot-poured crack sealant.

Extensive laboratory work has been done, and a new sealant tests were developed.

The following are criteria suggested for successful application (Al-Qadi, Masson, Yang, Fini, & Mcghee, 2009):

- Apparent viscosity of 1 to 3.5 Pa-s at installation results in good crack filling, but not being excessively fluid(for un-aged material)
- Resistance to tracking at high temperatures: Minimum flow coefficient of 4 kPa-s and a shear thinning exponent of 0.7. These are determined by a dynamic shear rheometer (DSR).
- To ensure low temperature withstanding, the maximum stiffness at 240 s, determined using modified BBR test (CSBBR) should be 25 MPa and the minimum average creep rate should be 0.31.
- Extendibility, measured with the CSDTT, can also be implemented to evaluate the performance of the sealant at expected low-temperatures.
- The direct adhesion test is best suited (among three developed adhesion tests) for use in a practical performance-based guideline.

Georgia Tech Research Institute (GTRI) has recently developed an automated pavement crack sealing system in conjunction with the Georgia Department of Transportation (GDOT) (Holmes, Holcombe, Daley, Coli, & Robertson, 2010). Through a comprehensive study, it was demonstrated that the system is viable. Solutions for high-speed firing of nozzles, automated crack detection, and navigation in a real-time system have been demonstrated on a limited-scale system. Figure 11-1 shows the developed system.

**Figure 11-1 Prototype Crack Sealing Hardware Developed by GTRI and GDOT (Holmes, Holcombe, Daley, Coli, & Robertson, 2010)**

## SASHTO STATE OF PRACTICE (SURVEY RESULTS)

Sealing and filling of the cracks are the most common pavement preservation practice. As mentioned at the beginning of this chapter, crack sealing/filling is not considered a surface treatment. The popularity of sealing and filling was reflected in the results of the survey. Seventy-eight percent of participants have reported their crack sealing/filling projects and the number of ongoing and completed projects reported was higher than any other technique. Also, the majority of participants rated themselves proficient in this practice or familiar with it.

Crack filling and sealing are done on pavements in a very wide range of deterioration levels. Figure 11-2 shows the condition of the pavements which were reported to be appropriate to crack sealing or filling.

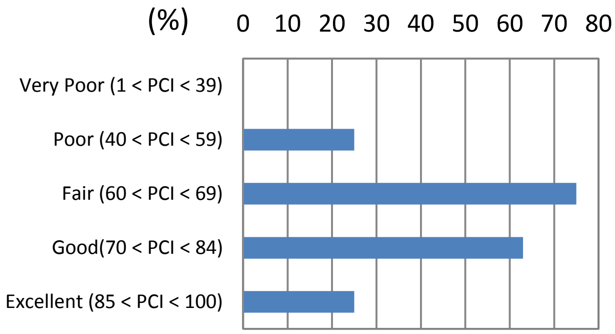



**Figure 11-2 Condition of the Pavements Subjected to Crack Sealing/Filling**

Typically, every agency follows its own crack sealing/filling specifications. The specifications are often rated effective. The performance of this practice was rated from fair to excellent. The major objectives of crack sealing and filling are to isolate the pavement against water penetration and delay its deterioration.

CHAPTER TWELVE

# CONCLUSIONS

Preventive maintenance techniques delay deterioration of the pavements. Proper maintenance of pavements results in decreasing their life cycle cost. Surface treatments are preventive maintenance techniques, which are applied on the whole surface of the road. This synthesis describes each technique, recent research work, and their implementation status in southeastern United States.

Ten surface treatment techniques including fog seal, rejuvenator seal, chip seal, sandwich seal, scrub seal, slurry seal, microsurfacing, cape seal, thin overlays, ultrathin bonded wearing course (Novachip), and crack sealing/filling have been described briefly. The mechanism of each treatment as well as its application and general procedure were summarized. This was followed by a summary of recent research work. This literature review can help surface treatment practitioners be aware of recent finding in the practice in which they are involved in. Some techniques such as rejuvenator seal, sandwich seal, scrub seal, and cape seal are variation of major techniques like fog seal, chip seal or slurry seal.

Nineteen participants from Florida, Georgia, Louisiana, North Carolina, Virginia, West Virginia, and Arkansas participated in a survey designed to investigate state of practice. Crack sealing/filling, thin overlays, microsurfacing, chip seal, fog seal, and ultrathin bonded wearing course were found to be the most popular practices. There were not enough data from the survey to address state of practice for other techniques. Figure 12-1 indicates the number of projects reported for most common surface treatments. Estimations have been done for responses not indicating a fixed number. It can be observed that thin overlays are the most common surface treatment practice. Chip seal and crack sealing/filing stand after thin overlays.

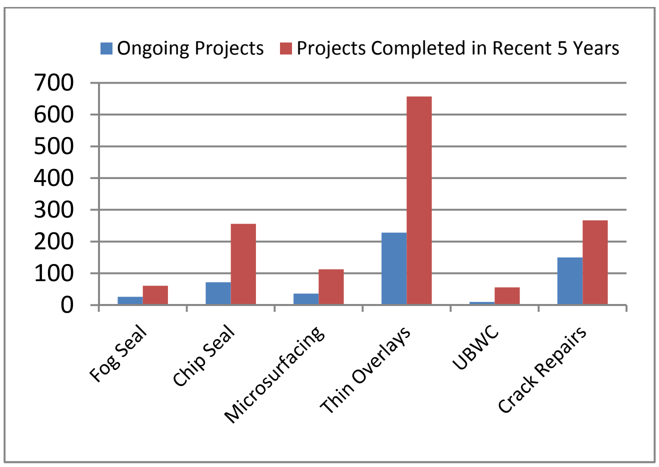



**Figure 12-1 Number for Treatments Projects Reported**

Table 12-1 presents the average condition of the pavements subjected to surface treatments, the life extension practitioners expect as a result of them, and their average cost. It can be seen that, as expected, the more severe the pavement deterioration, the more expensive the required treatment.

Delaying deterioration of the pavement and improving water infiltration are considered the main objectives for all treatments. In addition, practitioners often perform chip seals and UBWC to improve surface friction, microsurfacing and thin overlays to improve ride quality and fog seals to improve appearance of the pavement.

Social, legal, and political obstacles, as well as lack of skilled contractors, seem to be common problems of surface treatment constructions. In addition to these, some agencies reported suffering inefficient or inconsistent standard specifications and lack of knowledge and experience to perform surface treatments.

**Table 12-1 Average Pre-Treatment PCI, Expected Life Extension and Cost of Treatments**

| Treatment | PCI before[1] treatment | Expected life extension (years)[1] | Cost per yd[1] |
|---|---|---|---|
| Fog Seal | 79 | NA[2] | $0.5 |
| Chip Seal | 70 | 6.5 | $2.3 |
| Microsurfacing | 68 | 6.5 | $2.6 |
| Thin Overlays | 60 | 11 | $5 |
| UBWC | 67 | 11 | $5.2 |
| Crack Sealing/Filling | 70 | 5 | NA[2] |

[1]Average values

[2] Inconsistent values, highly dependent on project conditions

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# APPENDIX A: Survey Questionnaires

## Questionnaire 1 - Administrative Information

Respondent Information

Name

Agency

Title

Address

Tel.

Email

State

**Instructions:**

First, you will be asked to determine the techniques used in agency. Please check all methods which are currently implemented or have been used before and you have information for.

Then you will be asked to fill out two sheets for each technique you have checked.

If you believe that an entry is inapplicable or you do not have the information for, just leave it blank.

This survey consists of three questionnaires. Current questionnaires is asking administrative questions regarding surface treatment techniques. The second questionnaire will be about more technical issues and the last one will ask surface treatment research status.

☐ **I read the instructions**

## Surface Treatment Techniques

Which of following Surface treatment techniques are currently being used or has been used in recent 5 years in your agency?

☐ **Fog Seal**
A light spray application of eluted emulsion applied to the surface of a chip seal or w eathered hot mix

☐ **Rejuvenating**
Fog seals using specially formulated rejuvenators

☐ **Chip Seal**
Sprayed application of asphalt immediately covered by a single layer of uniform-size aggregate

☐ **Sandwich Seal**
Spreading of a layer of large aggregate w ithout asphalt, follow ed by applying of a chip seal w ith greater asphalt rate and smaller aggregate

☐ **Scrub Seal**
A variation of chip seal using scrub booms tow ed behind the distributor of chip seal, forcing emulsion into pavement cracks

☐ **Sand Seal**
A light spray application of asphalt covered by sand size aggregate

☐ **Slurry Seal**
Applying of a mixture of fine aggregate, mineral filler, emulsified asphalt and w ater

☐ **Micro Surfacing**
Applying of a stiff mixture of polymer-modified emulsion, high quality aggregate mineral filler, additives and w ater

☐ **Cape Seal**
A single layer chip seal follow ed by a slurry seal

☐ **Thin Overlays**
Thin overlay of conventional dense graded asphalt mix

☐ **Ultra Thin Bonded Wearing Course**
A thin overlay placed by specially modified pavers that simultaneously applies a heavy track/bond coat of polymer-modified emulsion, then a thin layer of gap graded hot mix

☐ **Nova Chip®**
Placing a thin layer of gap-graded hot mix w earing course over a special asphalt membrane(Nova Bond membrane) using a specialized equipment

☐ **Crack Sealing/Filling**
Placing of specialized materials into pavement cracks or obove them to prevent intrusion of w ater and debris into the cracks and further deterioration of the pavement.

☐ **Other**

## Fog Seal

**Experience, Specifications and Quality Control**

How many ongoing Fog seal projects are under construction in your agency?

How many Fog seal projects are completed during recent 5 years in your agency?

How do you describe familiarity of your agency with Fog Seal?

When do you usually use fog seals? How do you describe the condition of the pavements which your agency consider for fog sealing?

| Very Poor | Poor | Fair | Good | Excellent |
| --- | --- | --- | --- | --- |
| ( 1 < PCI < 39) | ( 40 < PCI < 59) | ( 60 < PCI < 69) | ( 70 < PCI < 84) | ( 85 < PCI < 100) |
| ☐ | ☐ | ☐ | ☐ | ☐ |

What specification do you use for this technique?
(Indicate the date of last version)

Please upload your specifications file (If available)

Choose File No file chosen

How effective are the specifications?

Is there any established quality control (QC) or quality assurance(QA) procedure for this technique in your agency?

☐ Yes ☐ No

If yes, please describe briefly.

Comments

**Fog Seal**
Performance and Cost

How do you evaluate the **performance** of this technique in your agency?

Based on your agency's experience, how many years of **life extension** does does the technique add to the pavement?

What are main objectives of implementation of this technique?

- [ ] To delay deterioration of the pavement
- [ ] To reduce water infiltration
- [ ] To improve ride quality and smoothness of the road
- [ ] To improve surface friction and safety
- [ ] Other

How much is the average overall cost of this technique?

Cost Per Lane-Mile($)
OR
Cost Per Square Yards($)

What are major obstacles and difficulties in implementation of this technique?

- [ ] Lack of effective codes and specification
- [ ] Lack of effective QC/QA procedures
- [ ] Lack of skilled local contractors
- [ ] Lack of appropriate material
- [ ] Lack of appropriate equipment
- [ ] Lack of technical knowledge and skilled personnel
- [ ] Social, legal and political considerations
- [ ] Environmental considerations
- [ ] Other

**Comments**

There are similar “Experience, Specifications and Quality Control” and “Performance and Cost” Pages for all other surface treatment techniques. They will be appeared based on techniques you have selected. The electronic questionnaire is available at https://fiu.qualtrics.com/SE/?SID=SV_6J4bdPDSb3h1SrX

## End of Questionnaire 1

**Thank you for taking the time to fill out this questionnaire.**

This survey is consisted of three questionnaires.
Questionnaire 2 is asking more technical question about surface treatment techniques. Questions are about pavement evaluation, material, design and construction,Cost and Performance. If you have required information to fill out questionnaire 2 please click on the link below to start. If not, please send the link to some one in your agency who can fill it out.

Questionnaire 2 :https://fiu.qualtrics.com/SE/?SID=SV_5sXy0ggDV2dnWv3

Questionnaire 3 is about surface treatment research status. Completed, ongoing and planned researches, as well as research needs in your agency in field of surface treatment will be questioned. If you have required information to fill out questionnaire 3 please click on link below to start. If not, please send the link to some one in your agency who can fill it out.

Questionnaire 3 : https://fiu.qualtrics.com/SE/?SID=SV_bxc8axPwY3XU3L7

## Questionnaire 2 - Technical Information

Respondent Information

| | |
|---|---|
| Name | |
| Agency | |
| Title | |
| Address | |
| Tel. | |
| Email | |

State

### Instructions:

First, you will be asked to determine the techniques used in agency. Please check all methods which are currently implemented or have been used before and you have information for.

Then you will be asked to fill out 4 sheets (Pavement Evaluation, Material, Design and construction, Cost and Performance) for each technique you have checked.

If you believe that an entry is inapplicable or you do not have the information for, just leave it blank.

## Surface Treatment Techniques

Which of following Surface treatment techniques are currently being used or has been used in recent 5 years in your agency?

☐ **Fog Seal**
A light spray application of eluted emulsion applied to the surface of a chip seal or w eathered hot mix

☐ **Rejuvenating**
Fog seals using specially formulated rejuvenators

☐ **Chip Seal**
Sprayed application of asphalt immediately covered by a single layer of uniform-size aggregate

☐ **Sandwich Seal**
Spreading of a layer of large aggregate w ithout asphalt, follow ed by applying of a chip seal w ith greater asphalt rate and smaller aggregate

☐ **Scrub Seal**
A variation of chip seal using scrub booms tow ed behind the distributor of chip seal, forcing emulsion into pavement cracks

☐ **Sand Seal**

A light spray application of asphalt covered by sand size aggregate

☐ **Slurry Seal**
Applying of a mixture of fine aggregate, mineral filler, emulsified asphalt and w ater

☐ **Micro Surfacing**
Applying of a stiff mixture of polymer-modified emulsion, high quality aggregate mineral filler, additives and w ater

☐ **Cape Seal**
A single layer chip seal follow ed by a slurry seal

☐ **Thin Overlays**
Thin overlay of conventional dense graded asphalt mix

☐ **Ultra Thin Bonded Wearing Course**
A thin overlay placed by specially modified pavers that simultaneously applies a heavy track/bond coat of polymer-modified emulsion, then a thin layer of gap graded hot mix

☐ **Nova Chip®**
Placing a thin layer of gap-graded hot mix w earing course over a special asphalt membrane(Nova Bond membrane) using a specialized equipment

☐ **Crack Sealing/Filling**
Placing of specialized materials into pavement cracks or obove them to prevent intrusion of w ater and debris into the cracks and further deterioration of the pavement.

☐ **Other**

## Fog Seal

How many Fog seal projects are under construction or already done in your agency?

**Fog Seal- Site valuation (Pavement Distresses)**

## Fog Seal - Site Evaluation (Pavement Distresses)

Which of the following types of distresses was observed on pavement before the treatment is done? Determine how severe each was?

| | N/A | Minor | Moderate | Severe |
|---|---|---|---|---|
| Alligator Cracking | ○ | ○ | ○ | ○ |
| Block Cracking | ○ | ○ | ○ | ○ |
| Edge Cracking | ○ | ○ | ○ | ○ |
| Longitudinal Cracking | ○ | ○ | ○ | ○ |
| Transverse Cracking | ○ | ○ | ○ | ○ |
| Reflection Cracking | ○ | ○ | ○ | ○ |
| Slippage Cracking | ○ | ○ | ○ | ○ |
| Raveling | ○ | ○ | ○ | ○ |
| Patholes | ○ | ○ | ○ | ○ |
| Corrugation (Shoving) | ○ | ○ | ○ | ○ |
| Rutting | ○ | ○ | ○ | ○ |
| Grade Depression (Settlement) | ○ | ○ | ○ | ○ |
| Upheaval or swell | ○ | ○ | ○ | ○ |
| Patch Failure | ○ | ○ | ○ | ○ |
| Bleeding(Flushing) | ○ | ○ | ○ | ○ |
| Polished Aggregate | ○ | ○ | ○ | ○ |
| Loss of Cover Aggregate | ○ | ○ | ○ | ○ |
| Longitudinal or Transverse Streaking | ○ | ○ | ○ | ○ |
| Other | ○ | ○ | ○ | ○ |

Site Evaluation Remarks

## Fog Seal - Material

Asphalt Emulsion Used in This Technique

| | | | |
|---|---|---|---|
| ☐ RS-1 | ☐ CRS-1 | ☐ CQS-1h | ☐ CRS-2L |
| ☐ SS-1 | ☐ CSS-1 | ☐ CRS-2 | ☐ HFRS-2 |
| ☐ SS-1h | ☐ CSS-1h | ☐ CRS-2h | ☐ HFRS-2h |
| ☐ RS-2 | ☐ CSS-1hp | ☐ CRS-2p | ☐ Other: |

Emulsion Type

☐ Anionic ☐ Cationic ☐ Nonionic

Emulsion Curing Speed

☐ Rapid Setting (RC) ☐ Medium Setting (MC) ☐ Slow Setting (SC) ☐ Quick Setting (QC)

Emulsion Other Characteristics

☐ Diluted

☐ Polymer Modified

Rejuvenator

Other Material

# Fog Seal - Design and Construction

Number of applying passes

Quantity of emulsion

(gal/ yd$^2$)

(Ltr/ m$^2$)

Construction Equipment

Asphalt Distributer

Cleaning Equipment

Other Equipment

**Seasonal and Environmental Limitations**

**Determine the weather condition in which the technique can be implemented. Explain if there is any environmental limitations.**

**Construction Sequence**

**Briefly describe the sequence of construction tasks**

**Construction Common Problems**
**Describe the problems which may occur while implementing this technique**

**Traffic Control Requirements**
Road Close Time and number of Road Lanes to be closed during construction.

## Fog Seal - Cost and Performance

### COST

Cost Per Lane-Mile(US Dollar)

Cost Per Sq Yards(US Dollar)

Other Expenses
Mobilization Costs and additional material

### PERFORMANCE

**Expected life extension of the pavement (Years)**

**Actual life extension of the pavement (Years)**
(If treatment is old enough to know)

**Surface Condition just after treatment is done**

**Remarks**

There are almost similar “Site Evaluation” “Material”, “Design and Construction” and “Cost and Performance” Pages for all other surface treatment techniques. They will be appeared based on techniques you have selected. The electronic questionnaire is available at https://fiu.qualtrics.com/SE/?SID=SV_5sXy0ggDV2dnWv3

## General Remarks

Please provide any other information which which you believe that might be useful for this survey

**End of Questionnaire 2**

**Thank you for taking the time to fill out this questionnaire.**

Questionnaire 3 is about surface treatment research status. Completed, ongoing and planned researches, as well as research needs in your agency in field of surface treatment will be questioned. If you have required information to fill out questionnaire 3 please click on link below to start. If not, please send the link to some one in your agency who can fill it out.

**Questionnaire 3 :** https://fiu.qualtrics.com/SE/?SID=SV_bxc8axPwY3XU3L7

## Questionnaire 3 - Research Status

Respondent Information

Name

Agency

Title

Address

Tel.

Email

State

How many research projects on "Pavement Surface Treatment" are conducted by your agency during recent 5 years?

Please list completed "Pavement Surface Treatment" research projects conducted by your agency.

How many ongoing research projects on "Pavement Surface Treatment" are currently being conducted by your agency?

Please list ongoing "Pavement Surface Treatment" research projects conducted by your agency.

How many research projects on "Pavement Surface Treatment" are planned to be conducted by your agency?

Please list planned "Pavement Surface Treatment" research projects to be conducted by your agency.

Please list "Pavement Surface Treatment" research needs recognized by your agency.

It would be appreciated if you upload some of your agency's research reports .How many research report files are now

available for upload?

Research Report 1

Research Report 2

Research Report 3

Research Report 4

Research Report 5

Research Report 6

Research Report 7

Research Report 8

Research Report 9

Research Report 10

**Please check surface treatment techniques that you have research information for.**

- [ ] **Fog Seal**
  A light spray application of eluted emulsion applied to the surface of a chip seal or w eathered hot mix

- [ ] **Rejuvenating**
  Fog seals using specially formulated rejuvenators

- [ ] **Dust Palliative**
  Application of diluted asphalt emulsion to an unpaved surface

- [ ] **Chip Seal**
  Sprayed application of asphalt immediately covered by a single layer of uniform-size aggregate

- [ ] **Sandwich Seal**
  Spreading of a layer of large aggregate w ithout asphalt, follow ed by applying of a chip seal w ith greater asphalt rate and smaller aggregate

- [ ] **Scrub Seal**
  A variation of chip seal using scrub booms tow ed behind the distributor of chip seal, forcing emulsion into pavement cracks

- [ ] **Sand Seal**
  A light spray application of asphalt covered by sand size aggregate

- [ ] **Slurry Seal**
  Applying of a mixture of fine aggregate, mineral filler, emulsified asphalt and w ater

- [ ] **Micro Surfacing**
  Applying of a stiff mixture of polymer-modified emulsion, high quality aggregate mineral filler, additives and w ater

- [ ] **Cape Seal**
  A single layer chip seal follow ed by a slurry seal

- [ ] **Thin Overlays**
  Thin overlay of conventional dense graded asphalt mix

- [ ] **Ultra Thin Bonded Wearing Course**
  A thin overlay placed by specially modified pavers that simultaneously applies a heavy track/bond coat of polymer modified emulsion, then a thin layer of gap graded hot mix

- [ ] **Nova Chip®**
  Placing a thin layer of gap-graded hot mix w earing course over a special asphalt membrane(Nova Bond membrane) using a specialized equipment

- [ ] **Other Techniques**

  ____________________

- [ ] **General Surface Treatment Researches**

## Research classification

Please indicate:
1-If any researches regarding to listed below issues related to this technique are already completed in your agency.
2-If there is any ongoing or planned researches regarding to listed issues related to this technique.
3- If you recognize any need for researches regarding to listed issues related to this technique.

| | Completed Researches | Ongoing or Planned Researches | Need for Researches |
|---|---|---|---|
| Standards and specifications | ☐ | ☐ | ☐ |
| QC/QA specifications and procedures | ☐ | ☐ | ☐ |
| Selections of the technique | ☐ | ☐ | ☐ |
| Asphalt | ☐ | ☐ | ☐ |
| Aggregates | ☐ | ☐ | ☐ |
| Crack and joint sealants | ☐ | ☐ | ☐ |
| Other Material | ☐ | ☐ | ☐ |
| Equipment | ☐ | ☐ | ☐ |
| Construction techniques | ☐ | ☐ | ☐ |
| Performance and ride quality | ☐ | ☐ | ☐ |
| Life cycle analysis | ☐ | ☐ | ☐ |
| Economic issues | ☐ | ☐ | ☐ |
| Social and environmental impacts | ☐ | ☐ | ☐ |
| Other ______ | ☐ | ☐ | ☐ |
| Other ______ | ☐ | ☐ | ☐ |
| Other ______ | ☐ | ☐ | ☐ |

**There are similar pages for all other techniques. They will be appeared based on techniques you have selected.**

The electronic questionnaire is available at
https://fiu.qualtrics.com/SE/?SID=SV_bxc8axPwY3XU3L7