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Guide Specifications for the Construction of Chip Seals, Microsurfacing, and Fog Seals

FINAL REPORT

Prepared for
NCHRP
Transportation Research Board

of

The National Academies of Sciences, Engineering, and Medicine

Scott Shuler
Shuler Consultants, LLC
Fort Collins, Colorado 80521

R. Gary Hicks
R. Gary Hicks, LLC
Chico, CA 95926

James Moulthrop and Tahmidur Rahman
Fugro Roadware, Inc.
Austin, Texas 78754
July, 2018

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AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 14-37 by Shuler Consultants, LLC, Fugro Roadware, Inc. and R. Gary Hicks, LLC. Dr. Scott Shuler, P.E., Principal at Shuler Consultants, LLC, was the Principal Investigator. The other authors of this report are Dr. R. Gary Hicks, P.E. of R. Gary Hicks, LLC, James Moulthrop, Senior Consultant at Fugro Roadware, and Tahmidur Rahman, Consultant at Fugro Roadware. The work was done under the general supervision of Dr. Shuler of Shuler Consultants, LLC.

ABSTRACT

This report presents the results of NCHRP Project 14-37. The objective of this project was to develop construction guide specifications for emulsified asphalt chip seals, hot asphalt chip seals, microsurfacing and fog seals. These construction guide specifications were developed from information gathered by the research team from existing construction specifications, a survey questionnaire sent to state materials, construction and pavement management engineers, and the expertise of the research team. The resulting guide specifications are intended to be used in part or in total by agencies wishing to construct chip seals, microsurfacing and fog seals.

SUMMARY

This project discovered considerable variety among states regarding specifications for construction of chip seals, microsurfacing, and fog seals. This variety ranges from specifications containing very comprehensive descriptions of the materials and methods to be used to those that significantly lack such descriptions. The research did not uncover any specifications that contained every part of what should be included in a completely comprehensive construction specification for chip seals, microsurfacing and fog seals. Therefore, the construction guide specifications developed from this research are intended to help agencies fill gaps in existing construction specifications where gaps exist, or to be utilized as complete construction specifications.

The attachments at the end of this report contain the construction guides for chip seals, microsurfacing and fog seals. These guide specifications were designated Section 406 (Emulsion Chip Seals), Section 407 (Hot Chip Seals), Section 408 (Microsurfacing), and Section 410 (Fog Seals) to conform to the relevant sections of Division 400, Flexible Pavements of the AASHTO Guide Specifications for Highway Construction, last updated in 2008. At the time of this writing, these sections had not been assigned to other specifications.

CHAPTER 1 - BACKGROUND

Problem Statement

Chip seals, microsurfacing and fog seals are frequently used as pavement preservation treatments on flexible pavements. Pavement preservation provides a means for maintaining and improving the functional condition of an existing pavement. Although pavement preservation is not expected to substantially increase structural capacity of a pavement, it can lead to improved pavement performance and longer service life.

Although a great deal of information on the design, materials, and construction practices of chip seals, microsurfacing and fog seals is available, there are no national guide construction specifications for these treatments. NCHRP Project 14-37, "Guide Specifications for the Construction of Chip Seals, Microsurfacing and Fog Seals", was initiated to address this need.

Because construction guides for pavement preservation treatments lag behind those available for hot mix asphalt and portland cement concrete pavements, many states have experienced early distress with pavement preservation treatments. This sometimes prompts limited or even moratoriums on their use.

This document describes how the construction guides for chip seals, microsurfacing and fog seals were developed and presents recommendations dealing with the implementation of these products. Finally, the products themselves; construction guides for emulsion and hot applied chip seals, microsurfacing and fog seals, are included as Attachments at the end of this report.

Since many agencies already possess construction specifications for chip seals, microsurfacing and fog seals, these guide specifications are not necessarily intended as replacements for existing documents, although they are complete enough to serve this purpose, rather they are intended to supplement existing specifications and provide additional guidance where needed.

Research Objective

The objective of this research was to develop construction guidelines for chip seals, microsurfacing and fog seals. The guidelines for chip seals include both asphalt emulsions and modified and unmodified asphalt cements.

Report Organization

Chapter 2 of this report is a review of the state of the art and the practice of constructing chip seals and microsurfacing. This chapter has been subdivided into four sections including both emulsion-based and hot applied chip seals, microsurfacing and fog seals. Chapter 2 ends with a summary of the results of a survey sent to all states to identify the current state of the practice in the U. S.

Chapter 3 provides a summary of the findings about the research and recommendations for how future construction specifications could be crafted to further improve performance.

Finally, attachments at the end of this report contain the construction guides for chip seals, microsurfacing and fog seals. These guide specifications were designated Section 406 (Emulsion Chip Seals), Section 407 (Hot Chip Seals), Section 408 (Microsurfacing), and Section 410 (Fog Seals) to conform to the relevant sections of Division 400, Flexible Pavements of the

AASHTO Guide Specifications for Highway Construction. At the time of this writing, these sections had not been assigned to other specifications.

CHAPTER 2 – RESEARCH APPROACH

Summary of the State of the Practice

Emulsion Chip Seals

Chip seals where emulsified asphalt is used as the adhesive have been used for pavement preservation and maintenance for nearly 100 years. The first references to the use of chip seals appear in the literature nearly 100 years ago (Johnstone 1929, Goshorn 1937) as a means of providing low cost resurfacing for asphalt pavements. Many other published articles followed (Shelbourne 1940, Nevitt 1948, Schuelie, et al 1955). Rational design of chip seals began with work in New Zealand (Hanson, 1934-1935) and later in Texas (Kearby, 1953). From this early work most design methods used today are derived (McLeod, 1960, 1969; Potter and Church, 1976; Marais, 1981). These methods are essentially based on the concept that aggregate in a chip seal should be as one-sized as possible and that embedment of the aggregate in the asphalt binder should occupy a specific percentage of the aggregate dimension. How the aggregate dimension is determined and how the volume of asphalt binder is calculated vary between methods but usually require measuring the gradation of the aggregate in order to obtain the average least dimension (ALD) in the case of the Hanson method or the unit weight, specific gravity and spread quantity in the case of Kearby. The shape of the aggregate is considered important and is measured using the Flakiness Index in the case of the Hanson method and the percent embedment is varied as a function of traffic for both methods. However, although both of these methods are rational procedures, based on sound engineering principles, they have been shown to produce different results when applied to the same aggregates and emulsions on the same pavement (Shuler, 1998). Consequently, a measure of experience is needed to obtain the optimal quantity of materials for a specific project.

Loss of chips during construction leads to construction delays and loss of chips during early trafficking may lead to vehicular damage. Therefore, reducing this potential has been a focus of research. Benson (Benson and Gallaway, 1953) evaluated the effects of various factors on the retention of cover stone on chip seals. Among other factors this study evaluated the effects of cover stone and asphalt quantity, aggregate gradation, time between asphalt and aggregate application, and dust and moisture content of chips on retention of cover stone. The type of binder used in the chip seal can have an effect on performance. Studies have been conducted to measure binder viscosity as function of chip size, precoated or not, damp or dry (Kari, 1962; Major, 1965; Kandhal, 1991) and make recommendations regarding the optimum consistency for desired performance. In addition, the performance of the chip seal after long term trafficking can be affected by the properties of the cover stone and the substrate pavement. A process of evaluating the ability of the substrate pavement to resist chip penetration is practiced in the UK and Africa (Hitch, 1981; Colwill, et al, 1995). Predicting early chip retention has been done using laboratory abrasion tests, impact tests, and traffic simulators (Kari, 1965; Shuler, 2011; Stroup-Gardiner, 1990; Davis, 1991).

The performance of chip seals has been reported by many (Jackson, 1990; Shuler 1991; Sebaaly, 1995; Temple, 2003; Chen, 2003; Jahren, 2004; Gransberg, 2005).

The remainder of this literature review describes terminology, best practices, and specifications currently in use regarding chip seals.

Terminology

Emulsion-based chip seals consist of an application of asphalt emulsion to a substrate followed by an application of either natural or synthetic aggregate chips. As will be discussed later in this section, this operation is known by many names including 'seal coat', 'surface treatment', 'surface seal', 'surface dressing', 'sprayed seal', and others. In this report, they will be referred to as chip seals.

Chip seals can be applied to an unsurfaced road to produce an all-weather surface or can be applied to a paved surface to extend pavement life or improve friction. Many unsurfaced low volume roads have become pavements by applying chip seals. The National Park Service, many cities, county highway departments, and foreign countries routinely utilize this technique to obtain an inexpensive paved road surface (NCHRP 1975). Chip seals are also commonly used as a pavement preservation tool. When used for pavement preservation, chip seals serve three purposes: 1) seal small cracks in the pavement, 2) reduce further oxidation, and 3) improve surface texture (Asphalt Institute 1967). Although chip seals are most often applied to low volume roads, they have also demonstrated utility on facilities with traffic volumes exceeding 7500 vehicles per day per lane (Shuler 1998).

Best Practices

A synthesis for chip seal design and construction, (Gransberg and James 2005) summarized the best practices of many states and several countries around the world. This included the highly technical practices of Austroads and South Africa (Austroads 2004, Beatty 2002) where chip seals account for a major portion of the road network. Later, NCHRP published a user's manual (Shuler, et al 2011) for owner agencies wishing to build chip seals which provided practical procedures for determining where and when to use chip seals, the type of seal to use, design, construction, quality control and expected performance. Currently, the FHWA emulsion task force (ETF), now part of the AASHTO Transportation System Preservation Technical Services Program (TSP^2), is developing materials specifications and design practices for emulsion chip seals as a standard AASHTO specification for distribution to the states (FHWA 2015). The construction guides appearing as Attachments 1 through 4 of this report will be the final documents needed to support the chip seal, fog seal and microsurfacing needs of the states.

Specifications

The specifications from all fifty states were reviewed to determine the current state of the practice. One conclusion from this effort is that there are many similarities among state specifications for emulsion-based chip seals. However, there are also significant differences and no case were any of the specifications performance-based.

Forty nine states have specifications for chip seals, even though the term 'chip seal' may not appear in the specification as indicated above. Florida was the only state reviewed that has no specification for either emulsion-based or hot applied chip seals.

A brief description of what each subsection of a typical specification for chip seals contains is included in Table 1. Following the table is a discussion of what was found in a variety of state specifications for each of the specification sections. Interestingly, none of the state specifications reviewed contained all of the subsections discussed here.

Table 1. Typical Chip Seal Specification Sections

Specification Section	Description
Description	This is often the first section of the specification and briefly describes what the specification covers.
Terminology	Definitions are sometimes included in the specification in this section.
Material Quantities	The quantities of chips and asphalt emulsion are sometimes indicated in this part of the specification either in terms of a range of quantities or as a calculation dependent on factors such as unit weight of aggregate or specific gravity.
Fog Sealing	Some states apply a fog seal after the chip seal
Pressure Distributor	Usually a subsection under equipment, details regarding the distributor are described here.
Chip Spreaders	Usually a subsection under equipment, details regarding the chip spreader are described here.
Rollers	Usually a subsection under equipment, details regarding the rollers are described here.
Trucks	Some specifications identify the types and size of trucks to be used.
Weather	Environmental conditions are directly related to the probability of success of chip seals and are described in detail in this section.
Sweeping	Sweeping shall be done before the chip seal is placed and after it is completed and this activity is described here.
Traffic	Some states allow traffic on the chip seal before construction is completed. Some states prohibit traffic. This is one area of the specifications that varies significantly.
Joints	How both longitudinal and transverse joints are constructed are described by this section.
Stockpiles	How the aggregate stockpiles are handled during construction is covered in this section.
Job Mix Formula	Some states recognize that changes in aggregate gradation and asphalt content of the chip seal can have a detrimental effect on performance. This section describes how the control of materials will be handled.
Test Strip	Adjustments to design quantities during construction are always needed and some states allow for a test strip to get these adjustments established.
Quality Control/Assurance	This section specifies the number of tests on materials and methods to be done during construction.
Surface Protection	This describes how objects not to be covered with the chip seal shall be protected.
Pavement Markings	Paint stripes must be duplicated after the seal is placed. This section describes how.

Signage	Safety warnings are described in this section including speed limits, loose rocks, and no markings.
Sequence of Construction	Sometimes the length of chip seal is specified so that adjacent lanes are not left without a matching surface.
Vehicle Damage	Some specifications require the contractor to pay for vehicle damage caused by the chip seal.
Reuse of Swept Chips	Whether or not chips that have been swept off the surface can be reused are described by this section.
Payment	How the chip seal is paid for is described here.

A review of the state specifications for chip seals revealed many similarities but also, significant differences both in the sections included in the specifications shown above and also in the content of the sections. Some of these similarities and differences are discussed below:

Description

This section of a specification for chip seals provides a brief description of the scope of the specification. For example, Indiana (2016) states that: "*This work shall consist of one or more applications of asphalt material, each followed by an application of cover aggregate in accordance with …..*", while Rhode Island (2013) states that: "*This work consists of providing a surface treatment consisting of an application of bituminous material on a prepared gravel foundation, to be followed by an application of cover coat material, …",* and Oklahoma (2009): "*This work consists of constructing a single or double surface treatment of aggregates and bituminous materials."*

Terminology

An application of asphalt followed by cover aggregate has many names. Bituminous surface treatment is the term used in Alabama (2016), while California (2015) uses the term asphaltic emulsion seal coat, Tennessee calls this treatment bituminous seal coat (2015), and Utah (2012) uses the term chip seal coat. Some states specify double and even triple applications of binder and aggregate chips. For example, a double chip seal in Alabama (2016) is called 'Surface Treatment L' which consists of a single chip seal, 'choke' stone, then a second chip seal. But, in Iowa a double chip seal is a single chip seal, followed by an application of a steel-wheel roller, then a second chip seal and rubber tire rollers. A single chip seal in North Carolina (2015) is called a 'straight seal', a double is called a 'split seal' and a triple a 'triple seal'. Interestingly, only two other states specifically reference triple chip seals; Alabama with a triple bituminous surface treatment, and Iowa with bituminous seal coat. Although many states reference multiple applications of asphalt and aggregate in the description section of the specification, this project deals primarily with the construction of single chip seals.

Material Quantities

Application rates for asphalt emulsion and aggregate chips are sometimes specified. However, the units can vary. Alabama uses cubic feet per cubic yard for aggregate rate and gallons per square yard for emulsion. However, in most cases, pounds per square yard are specified for aggregate and gallons per square are specified for emulsion. Some states specify rates for materials. For example, California (2015), Iowa (2012) and South Carolina (2014) have tables indicating a range of rates for aggregate and emulsion, while Tennessee specifies ranges

depending on the size of the aggregate and whether a single or double application is used and Utah bases the aggregate rate on unit weight and emulsion rate on embedment depth, before and after rolling.

Fog Sealing

Three states specify fog seals (sometimes referred to as a flush coat) be applied after chip sealing. Called dust control in Iowa if the aggregate is limestone or crushed gravel, the rate is 0.12 gallons per square yard diluted. Minnesota (MnDOT 2016) applies a fog seal one day after the chip seal is constructed, in California (2015) it is optional, and in Utah (2012) it is called a flush coat applied not less than six days after chip sealing at 0.11 gallons per square yard.

Pressure Distributors

Pressure distributors are usually specified for applying the emulsion, but in some states more details are provided. For example, Alabama (2016) identifies the pressure at 30 to 75 psi and the height of the bar to obtain exactly a single or double overlap. Utah (2012) requires the bar be adjusted to give a triple overlap. Texas (TxDOT 2014) is the only state reviewed that requires a variable transverse spray rate if directed and Iowa requires that nozzles in the bar be identified to assure the correct size is being used. Two states indicated that calibration of the distributor was required.

Chip Spreaders

Self-propelled aggregate spreaders are specified in most states. In many cases a simple statement indicating the equipment be self-propelled is all that is specified. However, Iowa gets more specific and describes the scalping screen that should be attached to the front of the spreader which prevents fine aggregate from dropping before the coarse aggregate. Minnesota (2016) specifies that calibration be by ASTM D5624, and that chips be applied 1 minute after the emulsion. South Carolina (2014) specifies calibration be done once per week and Utah (2012) does not allow broadcast spreaders.

Rollers

Rollers specified can be steel wheel or rubber tire. Alabama (2016) and Tennessee (2015) indicate steel rollers are required and South Carolina specifies they be used ‘if needed’. Weights of 5 to 8 tons and not greater than 8 tons are called for by Alabama (2016) and South Carolina (2014). Tennessee (2015) does not specify weight. Self-propelled rubber tire rollers are almost universally specified. However, the number of rollers, number of coverages and weights vary. For example, California (2015) specifies 1.5 tons per wheel while South Carolina (2014) and Texas (2014) specify greater than 5 tons and ‘light’, respectively. Tire pressures, if specified, are generally 85 to 105 psi. Sometimes the number of rollers is specified, as is the case for South Carolina (2014) with two, minimum, Minnesota (2016) and Utah (2012) with three, minimum. Texas (2014) specifies that the number of rollers be sufficient to cover the pavement width in one pass in one direction. The number of coverages before sweeping is three in Utah (2012), four in California (2015) and five in Iowa (2012) and Texas (2014). Roller width is specified by California (2015), South Carolina (2014) and Utah (2012) at ‘greater than 48 inches’, ‘greater than 60 inches’, and ‘greater than 72 inches’, respectively. Minnesota (2016) requires that all rolling be completed within 2500 feet of the chip spreader operations, South Carolina (2014) specifies rolling be completed in 30 minutes and Tennessee (2015) requires rolling be completed

in 1 hour after emulsion application. Rollers speed is important to the success of chip embedment and is specified as less than 5 mph by Minnesota (2016) and Iowa (2012) and less than 7 mph by South Carolina (2014).

Trucks

Trucks are often not specified except to indicate the beds shall be clean and free of debris. However, the Utah (2012) specification indicates that enough should be supplied so as not to disrupt the forward progress of the spreader and large enough to minimize hookups.

Weather

Weather conditions allowed for chip sealing are described in two ways. Some states simply limit the lowest air temperature or lowest pavement temperature. Sometimes months of the year are specified along with low temperatures. Sometimes both months of the year and air and pavement temperatures are specified. Alabama (2016) and Minnesota (2016) take this one step farther by identifying regions of the state where the limits apply. For example, in Alabama (2016), the region north of latitude 33N may chip seal from May to October unless the air temperature may fall below 32ºF at night or if the air temperature during construction is below 60ºF. Utah (2012) places a low and a high air and pavement temperature range of 50-110ºF air and 70-136ºF pavement if the forecast indicates not less than 40ºF within three days and not after 6pm if the temperatures are expected to fall below minimums.

Sweeping

Sweeping may be specified before the chip seal is placed to clean the surface to accept the chip seal, and then, after construction to remove any loose chips. Usually, language in the specifications indicates that loose material, dust, debris, dirt, or caked clay shall be removed prior to sealing. California (2015) specifies the brooms shall not have steel tines when brooming to remove loose chips and that brooming shall continue for four consecutive days after applying the chips. Utah (2012) allows steel and nylon tines. When sweeping begins is often described simply as ‘after the emulsion has set’, or ‘as soon as chips have bonded’, in the case of South Carolina (2014) and Texas (2014).

Traffic

When public traffic is allowed onto the fresh chip sealed surface is described in several ways in the current specifications. Sometimes a minimum time limit is specified (Iowa 2012) with the requirement of 2 hours, “…spread, smoothed, rolled, and cured for a minimum of 2 hours, the road may be open to traffic”. However, in short sections traffic may be allowed on the chip seal before rolling after the emulsion has set if speeds are kept below 25 mph for 2 hours (Iowa 2012). South Carolina (2014) specifies ‘after sweeping’, and Tennessee (2015) allows slow traffic after the chips are spread. Utah (2012) specifies no traffic the same day on interstates and that sweeping and traffic cannot touch the chip seal until 6am the day after construction.

Joints

Longitudinal and transverse chip seal joints are usually specified according to the overlap allowed. Some states specify overlap for both types of joints and some only one or the other. Alabama specifies a less than 4-inch overlap for longitudinal joints as does California (2015) and Utah (2012) does not allow any gaps between passes. The three states of Utah (2012), Tennessee

(2015) and Iowa (2012) require starting the shot on paper to make sure there is no overlap creating a bump. Tennessee (2015) requires the shot end on paper, as well, if directed.

Stockpiles

Stockpiling practice was described in only one state reviewed (Iowa 2012). The specification requires that the base of the stockpile be clean and that stockpiles be kept to 500 tons to promote even moisture dispersion. The stockpiled chips must be approved by the engineer 1 to 7 days before they are used.

Job Mix Formula (Mixture Design)

In most states, the materials quantities are specified based on a range depending on the chip size or unit weight of the material. However, Minnesota (2016) has a design procedure for chip seals based on the actual project materials. This 'job mix formula' is much like that of hot mix asphalt, in that it is an estimate of what will be used on the project based on actual materials planned for use and then is adjusted depending on what is actually produced during construction.

Test Strip

Materials quantities often need to be adjusted during construction and two states (Iowa 2012, South Carolina 2014) require a test strip be constructed to verify quantities to be used.

Quality Control/Quality Assurance

Aggregate moisture, gradation, and cleanliness are tests most often specified as well as asphalt emulsion properties such as viscosity, sieve, demulsibility and elastic properties if polymer modified asphalts are required. Moisture content in Alabama (2016) has a range of surface dry if air temperature is greater than 70F but dry if air temperature is below 70ºF. Emulsion temperatures are often specified as a range. Application rates, when measured, have variations allowed such as 15% transverse and 10% longitudinal (Caltrans 2015).

Surface Protection

Most specifications require some form of protection for accessories in the pavement such as valve boxes, grates, manholes and reflective markers. Usually, these are covered with some type of material that can be discarded after the chip seal is applied.

Pavement Markings

Paint stripes and other surface markings are usually specified to be marked prior to chip sealing with raised markers so the original paint can be duplicated after covering with the chip seal. Utah (2012) requires this be done no sooner than 7 days after the fog seal is applied.

Signage

Warning motorists of chip seal construction usually consists of 'loose gravel', or 'no pavement markings next ____ miles', or combinations of these warnings along with a reduced speed limit to 25 mph or 35 mph. These signs are required until no loose chips are present.

Sequence of Construction

Some specifications require that chip seal application be limited to certain lengths of roadway if adjacent lanes are not sealed to match. Other ways to limit the length is to specify the amount

of time allowed for each application, for example Iowa (2012) requires the spread length to not exceed 30 minutes of operation time. Some specifications limit the distance between the emulsion distributor and the chips spreader to no more than 150 feet and others control when the rollers begin seating the chips.

Vehicle Damage

Most states do not pay for vehicle damage, or at least, do not specify payment for damage. However, one state (Minnesota 2016) specifies that the contractor will pay for damage claims until the roadway is free of loose chips and permanent pavement markings have been installed.

Reuse of Swept Chips

Most states do not address the possibility of reusing chips that have been swept off after initial application, however California (2015) specifically forbids this practice while South Carolina (2014) allows reuse if the chips are clean.

Payment

Payment for chip seals is either in place by the square yard or by material quantity. Sometimes quantities are in tons for the chips and the emulsion or tons for the chips and gallons for the emulsion. California (2015) applies pay factor deductions if material quantities vary from specified quantities.

Hot Applied Chip Seals

Terminology

Hot applied chip chips are used by eight states in the U. S. Hot applied chip seals started in the 1970s with the use of asphalt rubber in Arizona. Initially, the binder contained about 18-20 percent crumb tire rubber. These chip seals were initially used as interlayers under asphalt overlays to reduce reflection cracking. These first asphalt rubber binders required significant agitation to keep the rubber particles suspended in the asphalt binder. As the process of asphalt rubber evolved the crumb rubber content was reduced and is currently a minimum of 15 percent according to ASTM D6114 (1998)

Later, in the mid 1980s a variation of the asphalt rubber process was developed called ‘terminal blend’. It was first used in Texas and is now sometimes also used in Arizona and California. Terminal blends contain about 5 to 18 percent rubber and some polymer.

Polymer modified hot applied chip seals have been used less frequently for chip seals, but hybrids of polymer and asphalt rubber are common both in terminal blends and asphalt rubber.

Users of Hot Applied Chip Seals

Asphalt rubber chip seals have much higher binder application rates than more conventional emulsion chip seals. Typically, this rate is 0.55 to 0.70 gals/yd². The higher application rates are possible because of the much higher binder stiffness. And, with higher binder application rates, these chip seals can provide improved chip retention and sealing capabilities. Aggregates used in these applications are usually pre-coated with a small quantity of asphalt to reduce dust. This practice leads to less short-term chip loss and, consequently, less risk of vehicle damage.

Terminal blends generally contain crumb rubber contents of 5-10 percent by weight of the binder, but can contain up to 18 percent. These binders are produced at asphalt terminals and sometimes contain rubber polymer of 3-5 percent. Originally, terminal blends were proprietary products, but now more generic forms of the binder are appearing. Terminal blends use a finer mesh crumb tire rubber than asphalt rubber and application rates for chip seals range between 0.35 to 0.50 gals/yd².

Scofield (1989) presented a history on the development and performance of asphalt rubber for Arizona DOT which evaluates nearly two decades of experience with asphalt rubber materials. Arizona began using asphalt rubber for chip seals in the 1970s and in hot mixes in the late 1980s. He discussed the use of asphalt rubber in both maintenance and rehabilitation. Specifications were developed for the construction of asphalt rubber products based on the performance of these experiments. Current Arizona specifications resulted from the evolution of this early work.

Epps (1994) developed an NCHRP synthesis on the use of recycled tire rubber in highways through 1993. The report addresses the use of ground tire rubber in hot mix asphalt, chip seals, interlayers and the following:

- Design considerations
- Technical strengths
- Construction considerations
- Performance
- Costs
- Specifications.

This synthesis provided an excellent background to help agencies understand the utility of using ground tire rubber in asphalt pavements. The type of equipment and practices required to produce successful projects and example specifications for asphalt rubber are included. However, terminal blends are not discussed.

Potgieter et al. (2000) reported on the use of asphalt rubber membranes and chip seals in South Africa introduced in 1983. The product used was similar to that used in Arizona. During the first 15 years of use, it was found the use of asphalt rubber interlayers and seals performed above expectations and outperformed conventional products. They reported that higher construction costs are offset by improved performance. Specifications for these products were developed as a part of this study.

Van Kirk (2003) also discussed the history of asphalt rubber chip seals. In his paper, he reports the chip seals to be very resistant to reflection cracking in Arizona, California, and Texas. He discusses the importance of temperature and application rate in the success of chip seals. The binder design for the asphalt rubber as well as the selection of the maximum aggregate size is also important. These factors should be specified for asphalt rubber chip seals.

Shatnawi and Holleran (2003) presented a paper on asphalt maintenance strategies used in California, including chip seals. Their paper focuses on specifications, binder and materials requirements, job selection criteria, application techniques, and performance. These chip seal binders contain an extender oil and high natural rubber. Material requirements discussed include binder design, reaction time, aggregate quality, and pre-coating of the aggregate. They discuss the temperature for application and the application rates as well as compaction and sweeping requirements for the chip seal. Based on the performance of the asphalt rubber products, specifications and guidelines were developed for asphalt rubber products.

Potgieter and Visser (2003) discuss the use of asphalt rubber chip seals including the need for higher spray rates. The paper presented the design and construction procedures which were used to achieve good success in the field. Case studies are presented to describe the performance history of the seals.

Van Wyngaard (2003) also discussed the practices related to the design and construction of asphalt rubber chip seals. In his paper he discusses the design and construction of 3/8 inch and ½ inch chips for the chip seals using asphalt rubber. Pitfalls on the design and construction of chip seals are also discussed. These include placing the binder at the proper viscosity and temperature, bleeding requirements for the asphalt rubber, aggregate requirements and temperatures during construction.

Zareh and Way (2006) provide an excellent summary on the use of asphalt rubber used in chip seals and hot mixes by Arizona DOT since 1971. The paper discusses the development of asphalt rubber by Charles McDonald and the evolution of the chip seal using this binder.

Shatnawi et al. (2006) provided an update to his 2003 paper and discusses the two types of asphalt rubber binders that have evolved over the years, namely Type I used in Arizona and Type II used in California. The differences between these binders mainly being in the extender oils and type and size of ground tire rubber used to formulate the binder.

Rouen and Toepfer (2006) reported on the performance of five asphalt rubber chip seals in California that did not perform as expected. Bleeding of the asphalt binder in the wheelpaths resulted in failure of these seals. The findings indicated that high truck volume, highway geometry, high binder application rate in the wheel paths, and graded aggregates produced the failures. As a result of this study several changes were made to the specifications. These included:

- Establishment of a maximum truck AADT for asphalt rubber chip seals
- Do not use on small diameter radii curves, on steep grades, or in areas with major acceleration/deceleration lanes
- Use a variable rate distribution spray bar in order to apply reduced binder rates in the wheel paths
- Use a higher viscosity binder (PG 70-10) in hot climates.
- Eliminate or reduce the extender oil usage for chip seals in hot climates

The Asphalt Institute (2008) reported that terminal blends had advantages over conventional asphalt rubber because they are manufactured at a terminal or refinery like polymer modified binders and can be made to meet PG gradings. Specifications or construction guides were not included in this article, but states cited to be using the products were Arizona, California, Louisiana, Nevada, and New York. Oregon and Washington have also experimented with hot applied chip seals and have developed experimental specifications.

Santucci (2009) developed a technical brief for the University of California Pavement Research Center which provides an excellent history on the use of rubber modification of asphalt beginning as early as the 1950s. He discusses both the asphalt rubber process developed by McDonald in Phoenix and the terminal blend process developed in Texas. His report discusses the use of these products in asphalt pavements not only in California, but also in several other states. He concluded that both the asphalt rubber and terminal blend products can produce successful hot mixes and chip seals.

Smith (2009) reported on the use of various hot applied and highly modified binders used in the U. S. in chip seal and cape seal applications. He discussed the importance of binder design for asphalt rubber, aggregate retention testing to determine materials compatibility prior to constructing the project and appropriate binder and aggregate application rates. He also discussed the importance of aggregate quality, construction methods and procedures including traffic and climate considerations.

Hicks, et al. (2010) published a summary of agencies using terminal blends for both hot mix asphalt and hot applied chip seals. The study concluded that terminal blends and asphalt rubber products performed better than conventional hot mix and chip seals under the conditions studied.

Shatnawi (2012) provided a comparison between the two different rubberized asphalt binders, asphalt rubber and terminal blends. Discussed are the processes used to incorporate these binders into chip seals and hot mixes. The paper also discussed the performance history, and specifications used. He concluded the following:

- Asphalt rubber and terminal blends can be successful in chip seals and hot mixes.
- Asphalt rubber performs better than terminal blends in most cases.
- Both binders can improve performance.
- The viscosity of the terminal blends is lower; hence they cannot be applied at the same application rates as that of asphalt rubber.
- Higher viscosity relates to greater film thickness and better performance in the field.
- Terminal blend binder specifications can also be met with a polymer modified asphalt.

Smith and Way (2012) discussed the design and construction of two chip seal projects in Arizona. One was a large highway project on the Navajo Indian Reservation using asphalt rubber. The other was a residential street in Scottsdale, AZ using a rubberized asphalt binder containing a polymer. The paper describes specifications, binder design, chip seal design and application techniques used for construction. The specifications are now used by the Bureau of Indian Affairs (BIA) for all projects within the Navajo Indian Reservation and for local agencies in Arizona. These specifications are summarized later in this section of the report (Bureau of Indian Affairs, 2015).

Way et al (2012) developed an asphalt rubber standard practice guide. The guide provides basic information on the design and use of asphalt rubber in a number of applications including chip seals. The guide includes the following chapters;

- History
- Design and Manufacture
- Chip Seals
- Hot Mix
- Thickness Design
- Construction
- Performance, and
- Environmental Benefits

It also includes typical specifications for the construction of asphalt rubber chip seals.

Rizzutto et al. (2012) presented the findings from a field experiment in which several types of hot applied binders were used to reduce flushing and bleeding in asphalt rubber, terminal blends,

and hybrids of asphalt rubber and polymer chip seals. Aggregate size was varied from ½ inch to 3/8 inch top size. The findings include the following:

- Using a stiffer PG binder and the coarser aggregate reduced the amount of flushing or bleeding in the wheel paths.
- The recommendations are applicable to very hot climates.
- Reducing the spray rate in the wheel paths was helpful.
- The terminal blends did not perform as well as the other binders.
- Binder application is extremely import to the success of the project. Therefore calibration and verification of the application rates used is important.
- Hot pre-coated aggregates increased chip retention.
- Quality control is important, particularly with regard spray rate.

Cheng et al. (2015) compared the performance of asphalt rubber with terminal blends on a Caltrans project in northern California. The binders also contained warm mix additives so the experiment included sections with and without additives. Specifications were developed for all products and extensive quality control was involved in the construction. Performance evaluation sections were established so the same sites could be evaluated over several years. This was the first of three projects to evaluate these products in various climatic conditions, some of which are subject to snow plows and chain wear. The warm mix additive has not affected the performance of the products.

ASTM (2015) developed a Standard Practice, D7564-15 for the construction of asphalt rubber cape seals. This includes a practice for the asphalt rubber chip seal followed by the application of a slurry seal.

Typical Specifications

Specifications for hot applied chip seals are available from some of state and local agencies that have had success with these systems. The specifications include materials, design practices, as well as construction guides. A summary of the agencies that have specifications for both types of hot applied chip seals are summarized in Tables 2 and 3. A few agencies routinely specify the use of asphalt rubber or terminal blend chip seals. The major users of asphalt rubber are in the west and northeast while the major users of terminal blends are in the southwest. A few agencies have used polymer modified hot applied binders.

Table 2. Typical Specifications for AR Chip Seals

Agency	Materials Used	Design practices	Construction Methods and procedures	QC and acceptance testing	Sweeping practices and traffic control
Arizona DOT, Item 404, 2014	Asphalt rubber Type I binder	Experience. Binder design required prior to construction	Binder applied hot, uses pre-coated aggregate. Aggregate set with rubber tired rollers. Weather limitations are imposed	None specified. Samples for binders and aggregate taken and tested	Commences within 90 minutes Minimum traffic free period is 3 hours
Arizona, local agencies, 2012	Polymer modified asphalt rubber	Experience. Binder design require prior to construction. Use Vialet test for aggregate retention	Binder applied hot at 350 to 375 F, use pre-coated aggregates. Use pneumatic tire rollers operating at 5 mph	None specified. Samples of binder and aggregate taken and tested	Commences with 12 hours. After final sweeping flush coat is applied
Arizona-BIA 2015	Asphalt Rubber	Binder design required. Requires that the contractor be prequalified	Specifies asphalt rubber blending process, application rates for the materials, use of pneumatic rollers with 3 complete coverages, and a fog seal	None specified. Samples of binder and aggregate taken and tested	Loose aggregate shall be removed from the treated surface by brooming no later than 36 hours after completion of the chip seal.
ASTM D 7564 Updated in 2015	Asphalt Rubber Cape Seals,	Guidance provided in the appendix for binder design and application rates for the binder and the aggregate.	Detailed discussion of construction steps include application of the binder, aggregates, workmanship compaction and more	No specific guidance for quality control or acceptance testing	Initial sweeping shall be completed prior to letting traffic on the surface
Caltrans Section 37, 2015	Asphalt rubber type II,	Guidance provided for binder dosing and application rates for binder and aggregate	Detailed discussion of construction methods, equipment required, application temperatures and rates, and rolling and sweeping. Fog seal is optional	No specific guidance provided for quality control and acceptance testing	Perform a final sweeping before contract acceptance
California Greenbook	Asphalt rubber chip seal,	Binder design required and	Detailed discussion on the application of the binder and	No specific guidance or provided for quality	Traffic is not allowed on the chip seal until the initial sweeping is

Agency	Materials Used	Design practices	Construction Methods and procedures	QC and acceptance testing	Sweeping practices and traffic control
Section 302-10, 2015.		application rates provided	pre-coated rock. Guidance on rolling the chips including the use of 4 coverages is provided. Pneumatic tired rollers and a steel drum finish are specified. Flush coats are optional	control and acceptance testing	completed. This occurs during the first day
New Hampshire DOT, Section 410, 2013	Rubber-polymer Chip Seal Surfaces	Contractor to provide design at least 2 weeks before work. This includes proposed sources of the binder and aggregate as well as application rates for both.	Construction methods are included for the application of the binder and the pre-coated chips. It also includes requirements for rolling. No flush coat is used	No quality control or acceptance testing guides are included	Power brooming is done after construction, but if it causes excessive rock loss a 24 hour wait period may be required
Rhode Island DOT Section 412,, 2016	Rubberized asphalt chip seals	Contractor to provide binder design before work begins. This includes proposed sources of the binder and aggregate as well as application rates for both	Construction equipment and methods are included in the specs. Only pneumatic roller are allowed	No quality control or acceptance testing guides are included	After the aggregate has been rolled, all loose material is swept within a timeframe that the sweepers do not displace the rock chips. Traffic is permitted on the surface once the binder has cured to minimize loss of rock chips
Texas DOT Item 316, Asphalt Rubber Seal Coat, 2014	Rubberized asphalt chip seals	Contractor to provide binder design before work begins. This includes proposed sources of the binder and aggregate as well as application rates for both	Construction equipment and methods are included in the specs. Only pneumatic roller are allowed	No quality control or acceptance testing guides are included	After rolling, sweep as soon as aggregate has sufficiently bonded to remove excess aggregate

Table 3. Typical Specifications for Hot Applied Terminal Blend or Asphalt Chip Seals

Agency	Materials Used	Design Practices	Construction Methods and Procedures	QC and acceptance testing	Sweeping Practices and Traffic Control
Arizona DOT, 2014	PG 70-22TR And PG 64-28 TR	Application rates for binder and aggregate are included. No binder design necessary for terminal blends	Constriction equipment and procedures are included in the spec.	No guides are provided for quality control and acceptance testing	Removal of the loose aggregate begins about 90 minutes after rolling. The action of the broom shall not dislodged the particles
Arizona, local agencies, Maricopa County, 2010	Rubberized asphalt binder. Maybe field or terminal blended	Application rates for binder and aggregate are included. No binder design necessary for terminal blends Application rates are provided	Constriction equipment and procedures are included in the spec. Pneumatic rollers are used	No guides are provided for quality control and acceptance testing	Requirements are provided to keep the loose stone swept from the surface All sweeping shall be in the direction of traffic
Caltrans, Section 37, 2015	Modified binder PG 76-22 TR and 70-10TR	Application rates for binder and aggregate are included. No binder design necessary for terminal blends	Construction procedures are included in the specs	No guides for quality control and acceptance testing	Performed after the initial rolling. Subsequent rolling is done d after final rolling
Louisiana DOT, Section 507, 2016	PAC-15, polymer asphalt cement	Uses both asphalt emulsions and hot polymer asphalt cement. Application rates are provided	Construction procedures are provided in the specs. Steel wheel rollers are not allowed	No guides for quality control or acceptance testing provided	Lightly broom or blow to remove loosed material. No guides provided on timing
Mississippi DOT, Special provision 907-410-7, 2013	Hot applied asphalt,	Uses asphalt cement or asphalt emulsions. No binder design required. Application rates are provided	Construction procedures are included in Section 410. Steel wheel rollers are not allowed	No guides are provided for quality control and acceptance testing	Initial sweeping takes place the same day. Contractor's operations scheduled such that all lanes of traffic are open to the public at the end of each day
Nevada DOT. 2014	PG 64-28NV and PG 76-22NV	Terminal blend asphalts. Application rates provided	Construction procedures are included in the spec	No guidance provided	After rolling, broom to remove any loose aggregate. Delay if brooming damages the surface

Oregon DOT, 2015	AC 15-5TR spec or AC-15P	Terminal blend and polymer modified asphalts. Pre-coated aggregate. Application rates provided	Construction procedures are included in the spec	No guidance provided	After rolling broom to remove loose aggregate. Delay if the brooming damages the surface
Texas DOT, Section 318, 2014	Tire rubber (TR) specification,	Polymer modified and terminal blend asphalts used. Application rates provided and pre-coated aggregate used	Construction procedures are included in the spec. Storage and application temperatures provided	No guidance provided	After rolling, sweep away excess aggregate as soon as it has bonded
Washington DOT, 2016	AC-15-P	Polymer modified asphalt. Pre-coated aggregates used. Application rates are given in the spec	Construction procedures are included in the spec	No guidance provided	Brooming shall take place at least twice the first day and completed before allowing uncontrolled traffic on the surface

Construction Guides

Construction guides for hot applied chip seals usually are organized like other construction guides with the following sections:

- Description
- Materials
- Construction
- Measurement
- Payment

A summary of some of the construction guides collected are discussed below. The materials and construction processes used for hot applied chip seals are somewhat different than those used for emulsion chip seals. Those differences have been captured and are reflected in the guides developed for both systems appearing the attachments to this report.

Materials

The binders used consist either of an asphalt rubber defined by ASTM 6114 (at least 15% crumb tire rubber) or a terminal blend consisting of 5-10 % crumb tire rubber. Few agencies use a polymer modified hot applied chip seal. Most agencies use pre-coated chips with about 0.5 to 1.0 percent asphalt binder.

Application rates for hot applied asphalt rubber or terminal blends are generally specified. For asphalt rubber the rates are 0.55 to 0.70 gals/yd² while for the terminal blends it is 0.40 to 0.50 gals/yd². Polymer modified asphalt application rates are lower. Material quantities often need to be adjusted during construction and some require a test strip be constructed to verify material quantities.

Several states call for a flush coat or fog seal after construction. An emulsion is generally used with an application rate of about 0.10 gal/yd² of 50:50 diluted emulsion. The fog seal can be applied the same day or later in the construction process. The fog seal not only provides a blacker surface but can aid in the retention of rock chips if insufficient binder was applied, initially.

Equipment

Pressure distributors are usually specified for applying the hot binder, but in some states more details are provided. For example, some states provided information on pressure while others specify the use of lower application rates in the wheelpaths to reduce potential bleeding. Some states require equipment calibration.

Self-propelled aggregate spreaders are specified by most states. In fact, a simple statement indicating the equipment be self-propelled is all that is specified. Some states require calibration once per week, while others only require calibration at the start of the project.

Rollers specified are both steel wheel or rubber tire. However, most specify rubber tired rollers. Steel rollers specified range from 5 to 8 tons, and some states specify not greater than 8

tons. The number of rollers, number of coverages and weights vary. Tire pressures, if specified, are generally 85 to 105 psi. Sometimes the number of rollers is specified, but generally ranges of 2-3 rollers is specified. The number of coverages before sweeping ranges from 3-5 where roller width varies in width from greater than 48 inches to greater than 72 inches. Other requirements include the time for rolling to be completed as well as roller speeds. Roller speed is sometimes specified as less than 5 mph to less than 7 mph.

Trucks are often not specified except to indicate the beds shall be clean and free of debris. However, some specifications indicate that enough trucks should be supplied so as not to disrupt the forward progress of the spreader and large enough to minimize the number of hookups.

Construction Methods and Procedures

Weather conditions specified for chip sealing are described in two ways. Some states simply limit the lowest air temperature or lowest pavement temperature. Sometimes months of the year are specified along with low temperatures. Sometimes both months of the year and air and pavement temperatures are specified.

Some specifications require that chip seal application be limited to certain lengths of roadway if adjacent lanes are not sealed to match. Other ways to limit the length is to specify the amount of time allowed for each application. Some specifications limit the distance between the asphalt distributor and the chip spreader to less than 150 feet and others control when the rollers begin seating the chips.

Longitudinal and transverse chip seal joints are usually specified according to the overlap allowed. Some states specify overlap for both types of joints and some only one or the other. The overlap is typical less than a 4 inch overlap for longitudinal joints. Several states require starting the shot on paper to make sure there is no overlap.

Sweeping may be specified before the chip seal is placed to clean the surface, and then, after construction to remove any loose chips. Usually, language in the specifications indicates that loose material, dust, debris, dirt, or caked clay shall be removed prior to sealing. Most agencies specify the brooms not be allowed to remove loose chips and that brooming continue as needed. For hot applied chip seals brooming can begin as early as 30 minutes after rolling.

When vehicular traffic is allowed on the fresh chip seal sometimes a minimum time limit is specified along with a maximum speed. Warning motorists of chip seal construction usually consists of ‘loose gravel’, or ‘no pavement markings next ____ miles’, or combinations of these warnings along with a reduced speed limit to 25 or 35 mph. These signs are required until no loose chips are present.

Quality Control/Quality Assurance

Aggregate gradation and cleanliness are tests most often specified as well as properties of the binder. Application temperatures for the binder and the aggregates are also specified. Application rate variations are allowed from 15 percent transverse and 10 percent longitudinal.

Payment

Payment for chip seals is either by the square yard or by material quantity. Sometimes quantities are in tons for the chips and the emulsion or tons for the chips and gallons for the emulsion. Most agencies do not apply pay factor deductions if material quantities vary from specified quantities.

Microsurfacing

Terminology

Microsurfacing is defined by the International Slurry Surfacing Association (ISSA A143, 2010) as "a mixture of polymer-modified emulsified asphalt, mineral aggregate, water, and additives, proportioned, mixed and uniformly spread over a properly prepared surface as directed by the Buyer's Authorized Representative". Microsurfacing must be capable of filling ruts, and applied in thin applications such as scratch courses, and over milled surfaces. Microsurfacing is further defined in this document as "a quick-traffic system that allows traffic to return shortly after placement".

Microsurfacing and slurry seal are considered slurry surfacing systems. The following literature review discusses both microsurfacing and slurry seal slurry surfacing systems. According to ISSA, slurry seal (ISSA A105, 2010) "consists of a mixture of an approved emulsified asphalt, mineral aggregate, water and specified additives, proportioned, mixed and uniformly spread over a properly prepared surface…" It is further defined as "the completed slurry seal shall leave a homogeneous mat, adhere firmly to the prepared surface, and have a skid resistant surface texture".

Microsurfacing often uses dense-graded aggregate, asphalt emulsion (about 7% by weight of total dry mix), polymer additive (about 3 % by weight of total dry mix), water, and mineral fillers (about 1% by weight of total dry mix) to correct or prevent deficiencies in pavement conditions. The treatment may be as thin as 3/8 inch or it can fill wheel ruts up to 2 inches deep using multiple passes. Microsurfacing shall not be applied if either the pavement or air temperature is below 50F nor if there is a possibility of the treatment freezing within 24 hours of placement. Due to the increased viscosity of the mix, more powerful mixers are needed for microsurfacing than are required for slurry seals and in order to provide a uniform flow of the mixture into the spreader box, a twin-shafted paddle or spiral auger is needed. Proper preparation of the pavement surface is important and includes cleaning and sealing tight cracks, filling wide cracks, and thoroughly brooming and cleaning the pavement to remove loose dirt and contaminants.

Literature Review and Survey

Slurry surfacing systems have been used since the 1920s in Germany (Moulthrop, et al 2014). At that time, the product consisted of a mixture of very fine aggregates, asphalt binder, and water. It was mixed by introducing the ingredients into a tank outfitted with an agitator. However, it was not until the 1960s that real interest was shown in the use of slurry seals as a pavement maintenance treatment. The work by Benedict, which is contained in the Design

Technical Bulletins, (ISSA, 1990) on mix design procedures and specifications is still in use today and incorporated into mix design and performance guides (ISSA-A143, 2010). Microsurfacing was also pioneered in Germany in the late 1960s and early 1970s. It consisted of placing thicker layers of materials into wheel track ruts on the autobahn and was first introduced into the USA in the 1980s.

The International Slurry Surfacing Association (ISSA-A143, 2010) has published a guideline with "the intent to aid in the design, testing, quality control, measurement and payment procedures for the application of microsurfacing". Such treatment shall consist of a mixture of polymer modified emulsified asphalt (minimum of 3% polymer solids), mineral aggregate (crushed stone), water and additives. Two sets of aggregate gradation are generally recommended: Type II gradation (90-100 % passing the #4 sieve) to provide a durable wearing surface and Type III gradation (70-90 % passing the # 4 sieve) to provide maximum skid resistance. Test specifications and the mix design procedure of different material components are specified in this document.

The guidelines note that all equipment, tools and machines used in the application of microsurfacing shall be specifically designed and manufactured. The material shall be mixed in a continuous flow, automatic-sequenced and self-propelled machine. "The mixture shall be agitated and spread uniformly in the surfacing box by means of twin-shaft paddles or spiral augers fixed to the spreader box. Suitable surface preparation equipment, traffic control equipment, hand tools, and other support and safety equipment necessary to perform the work" shall be provided by the contractor. "Microsurfacing shall not be applied if either the pavement or air temperature is below 50F and falling, but may be applied when both pavement and air temperatures are above 45F and rising".

In terms of surface preparation, prior to the application of microsurfacing, "the surface shall be cleared of all loose material, silt spots, vegetation, and other objectionable material". Emulsified asphalt (SS, CSS or the microsurfacing emulsion) could be used as tack coat if the surface to be covered is extremely dry and raveled or is concrete or brick. The tack coat distribution rate shall be 0.05-0.15 gal/yd^2. The microsurfacing mixture shall be of the proper consistency at all times so as to provide the application rate required by the surface condition. The suggested application rate for Type II and Type III aggregate are 10 – 20 lb./yd^2 and 15 – 30 lb./yd^2 respectively for urban/residential streets and primary/interstate highways.

Proper mix consistency is the primary objective of inspection and quality control. If mixes are too dry, streaking, lumping and roughness will occur in the mat surface. Mixes applied too wet will flow excessively and not be straight within lane lines. Excessive liquids may also cause an asphalt-rich surface with segregation. Representative samples for testing may be taken directly from the microsurfacing machine. The method of measurement and payment is usually based on the area covered (in square feet or square yards) for small projects, and tons of aggregate and gallons of emulsified asphalt used for larger projects over 50,000 square yards.

The California Department of Transportation (Caltrans 2004) provides an overview of the microsurfacing products presently used in California, including materials and specifications, mix design, project selection, and construction. The mixture of asphalt emulsion, graded aggregates, mineral filler, water and other additives is made and placed continuously using a slurry surfacing machine. The resulting material is a free flowing composite spread forming an adhesive bond with the pavement.

Microsurfacing can be laid at two to three times the thickness of the largest stone in the system. Microsurfacing can be used for the same applications as slurry seals. However, microsurfacing uses better quality aggregates and a fast setting emulsion of higher stiffness. This allows thicker layers to be placed. Microsurfacing is only applied as a maintenance treatment, not for crack treatment or improving structural capacity.

Common polymer modified quick setting emulsions that can be used are: PMCQS-1h and PMQS-1h. Emulsions are usually modified with rubber latex. Two aggregate gradations are specified for microsurfacing termed Type II and Type III (Caltrans, 2004). Type II microsurfacing is a mixture recommended for urban and residential streets and airport runways. Type III microsurfacing has the coarsest grading and is appropriate for filling minor surface irregularities.

The current state of the practice in Texas is described in a report (Broughton and Lee 2012) where the research team analyzed material selection and mix design methods, construction practices, equipment practices and performance for microsurfacing based on the results of a survey, literature reviews, case studies and site visits. It was concluded that project selection is the most important contributor to a successful microsurfacing project followed by construction practices.

Texas is the only state that has their own microsurfacing mix design developed in 1996 (Andrews, et al) and is covered in the TxDOT Standard Specification Item 350 (TX DOT, 2014). This specification requires a cationic polymer-modified asphalt, mineral aggregate, mineral filler, water, and other additives, if required. The specific binder that is used for microsurfacing is cationic polymer-modified asphalt: CSS-1P, which is relatively harder than CSS-1hP which has been used nationally. Two aggregate gradations are used: the smaller Type II which leads to less road noise and Type III with greater macro texture resulting in less spray in wet weather but higher noise.

A microsurfacing paving train used on highway projects usually consists of a self-propelled, continuous travel mixer with onboard storage for aggregate and additives continually being replenished by specialized trucks.

Construction practices are the most significant contributors to the success of microsurfacing (Broughton and Lee 2012). Project selection, contractor experience and workmanship are consistently the main factors discussed in the literature as being crucial to success of microsurfacing. Because of this, certification of contractors has been suggested as a means to obtain consistent quality (Broughton and Lee 2012).

The Pavement Preservation Committee in Arizona (Arizona 2013) published a document containing best practice information for suppliers, contractors, agencies and owners to improve consistency in microsurfacing and slurry seal treatments. Several variables for a successful application were noted as follows:

- Existing surface – Surface has to be suitable for the application.
- Surface preparation – Significant deficiencies shall be repaired before the application. Ruts of ½" or greater in depth shall be filled with a rut-filling box. Ruts deeper than 1" may require multiple lifts of microsurfacing.
- Materials – Arizona DOT's emulsion specifications shall be used. Quality aggregates composed of clean and durable crushed rock with the proper gradation, particle shape,

cleanliness, soundness, and resistance to abrasion are mandatory. Three standard aggregate gradations can be used for microsurfacing, where Type I is the least coarse size gradation and Type III is the coarsest gradation.

- Equipment – The mixer shall be a continuous flow-mixing unit. A spreader shall be a mechanical type box attached to the mixer.
- Placement Practices – A mix design procedure shall be utilized to establish targets for emulsion, aggregate, mineral filler and additive application rates.
- Construction Procedures - Prior to the application, the existing surface must be cleaned of all foreign materials by mechanical sweepers or brooms. Microsurfacing shall be applied when the surface temperature is 50F or higher and the ambient temperature is 45F and rising. Sweeping with a mechanical broom and high efficiency vacuum sweepers is the best method to clean the pavement surface. All traffic, with the exception of necessary construction equipment, shall be kept off the newly applied microsurfacing until these materials have had time to properly set.

NCHRP 411 (Gransberg, 2010) provides a report of the state of the practice of microsurfacing and identifies critical knowledge gaps that could be filled by additional research. The results are summarized based on the following components used to collect the information contained in the synthesis: a comprehensive literature review, survey of U.S. and Canadian agencies, microsurfacing specification content analysis, and case studies.

- Definition: "A mixture of cationic polymer modified asphalt emulsion, 100% crushed aggregate, water, and other additives properly proportioned and spread over a prepared surface." Microsurfacing is best suited to address rutting, raveling, oxidation, bleeding, and loss of surface friction.
- Specifications: Microsurfacing and slurry seals have the potential for confusion in the literature and state specifications because they have been used interchangeably. International Slurry Surfacing Association advocates categorize both treatments as 'slurry systems' and the key distinction is the microsurfacing treatment always contains polymer modified emulsion. Out of all standard specifications obtained in the NCHRP survey, only 18 of 51 had sections that specifically contained the word "microsurfacing." Only two agencies (Indiana and Utah) use microsurfacing on a regular preventive maintenance cycle and a number of survey respondents indicated that their agency uses microsurfacing to extend the life of the underlying pavement. A service life of 6 years was reported by the US DOTs with a range of 1 to 15 years, whereas Canadian agencies reported a 7 year life with a range of 3 to 10 years.
- Mix Design: The mix design methods summarized in this synthesis include:
    - ISSA Design Method for Microsurfacing (ISSA A143, 2010)—12 states (USA), 4 provinces (Canada)
    - ASTM Design Method for Slurry Seals (ASTM D3910-15)—3 states
    - ASTM Design Method for Microsurfacing (ASTM D 6372-15)—2 states

- Texas Transportation Institute Design Method for Microsurfacing: TTI 1289—TX (Andrews, et al, 1996):
- Empirical Method – 11 states (USA) and 4 provinces (Canada)

The majority of the respondents using microsurfacing assign mix design responsibility to the contractor. These projects can be procured using a performance-based contract. Some of the factors summarized in the NCHRP study include:

- Environmental Impact: Only a few agencies have a formalized approach to their microsurfacing program that evaluates the potential impact to the environment. Considering smaller environmental footprint and reduced work zone delay (roughly 1 hour of lane closure after the placement) for microsurfacing, its use can be justifiable over other low-cost pavement preservation and maintenance treatments.
- Materials: Most agencies only use a single microsurfacing emulsion, and all agencies rated their microsurfacing performance as satisfactory. Therefore, an agency can select a single emulsion that works best for its specific climatic and traffic environment and achieve satisfactory results. The physical properties of the aggregate are important to achieving the design service life. Type II and Type III aggregate gradations were the most commonly used per ISSA A143.

  Mineral fillers were: Portland cement, hydrated lime, limestone dust, crushed rock screenings, fly ash, kiln dust, and baghouse fines. Additives found in the study were: aluminum sulfate crystals, ammonium sulfate, inorganic salts, liquid aluminum sulfate, amines, and anti-stripping agents.
- Application Rates: Some types of microsurfacing can be placed in relatively thick lifts. The correct application rate of the treatment can have a significant effect on the success of the project. Typically, a maximum application rate of 30 lbs/SY for Type III aggregate is recommended.
- Contracting: Most of the U.S. and Canadian agencies do not have an adequate level of competition among qualified microsurfacing contractors for their programs. The concept of requiring warranties on microsurfacing projects was found to be less onerous than for other pavement work because most agencies require the contractor to furnish the job mix formula. Few agencies require microsurfacing contractors and agency personnel to complete microsurfacing training and/or a certification program.
- Construction Practices: All of the specifications reviewed contained a requirement to thoroughly clean the surface of the pavement. In addition, all the specifications included a requirement to pre-wet the pavement surface before beginning microsurfacing. Another common practice was the requirement to spray a tack coat before microsurfacing. The tack coat application rates ranged from 0.05 gallon per square yard to 0.25 gal/sq.yd. ISSA (A143-2010) recommends that the tack coat consist of CSS-1h, although some of the specifications required SS-1h. The Michigan DOT specifications (NCHRP, 2010) require a “bond coat” and the New Mexico DOT requires a “paint binder” as a tack coat on concrete pavement surfaces (NCHRP, 2010).

- Equipment: Well-calibrated and well-functioning equipment will consist of the following:
  - Mixing machine – self-propelled or truck mounted
  - Mobile support units – to replenish the materials in the mixing machine
  - Broom sweepers – rotary or suction
  - Rollers – pneumatic or static steel wheel
- Test strips: 500 to 1,000 foot test strips are recommended so the agency and the contractor know the equipment is properly calibrated and any workmanship issues are resolved before full-scale microsurfacing production proceeds.
- QC/QA: Contractor experience was cited as the most important factor affecting microsurfacing quality. Most agencies do not prequalify microsurfacing bidders. This may be because the pool of competent and qualified contractors is limited.

Ideal microsurfacing weather conditions are those with low humidity, a slight breeze, and sustained high temperatures after construction. ISSA recommends microsurfacing only be placed if the humidity is 60% or lower (ISSA 2010). The Georgia DOT specification allows microsurfacing placement up to 80% relative humidity (NCHRP, 2010) and the New Mexico DOT specification limits humidity to no more than 50% (NCHRP. 2010). Most of the DOTs require an ambient temperature of 50F.

There are four types of microsurfacing applications: full lane width, scratch coats, rut filling, and hand-applied. Three passes are typically used for a two lane highway with a maximum overlap of three inches.

The main components of the construction process include:

- Safety and Traffic Control – Traffic control is required to ensure safety of the public and to provide adequate time for curing.
- Equipment Requirements – A microsurfacing spreader box has to move a much stiffer mixture than a slurry spreader box, so it must be applied quickly before the emulsion breaks.
- Stockpile/Project Staging Area Requirements – The stockpile and staging area should be as close as possible to the job site.
- Surface Preparation - Immediately before the microsurfacing is applied, the road must be swept clean. High power pressure washing may be required if clay or hard-to-remove materials are present. Utility inlets shall be covered with heavy paper or roofing felt cemented to the surface of the inlet.
- Application Conditions – Humidity, wind conditions, and air and surface temperature are important and need to be considered to ensure that the emulsions are able to break and form continuous films. Microsurfacing shall only be placed when the ambient

temperature is 50F and rising and the high temperature for the day is expected to be at least 68F.

- Types of Applications – A standard spreader box can be used for a full width seal. Three passes are typically used for a two-lane roadway to ensure clean edges and minimize overlaps (usually 3 in). When applying a scratch coat (longitudinal ruts of less than 0.5 inches in depth), a steel strike-off is substituted for the secondary strike-off in the standard microsurfacing drag box. Scratch coats shall always be covered with a surface seal.
- Quality Issues - Quality control is critical during the constriction process to achieve a uniform surface finish. Longitudinal joints may be over-lapped or butt jointed with overlaps not placed in the wheel paths and shall not exceed a 3in. width. Transitions at transverse joints must be smooth to avoid creating a bump in the surface. Considering that working by hand is difficult, handwork shall be kept to a minimum for microsurfacing.
- Post Construction Conditions – The water loss process for microsurfacing can take several weeks, so projects shall not be started if freezing temperatures are anticipated within 2 weeks.
- Post-Treatments – An approximate 3 percent loss of surface stone is acceptable. One to two passes of pneumatic rolling at a slow speed are recommended. On heavily trafficked roads or where traffic has led to excessive stone loss, sweeping with a vacuum broom is essential.

Although slurry seals and microsurfacing are used in many states, current tests and design methods are primarily empirical and not related to field performance. There is very limited knowledge on the relationships among certain test parameters, environmental factors, and mix performance in the field. Thus, there is a need to develop construction guide specifications for slurry seal and microsurfacing. The current International Slurry Seal Association procedures for Slurry Seal Mix Design (A-105, 2010) and Microsurfacing (A-143, 2010) and the corresponding ASTM Standards (ASTM D3910 and D6372) have their origin in the 1980s before the widespread use of microsurfacing and the use of polymer modified emulsions in slurry seals. These test methods and design procedures remain in use today because there is no test method or mix design procedure that specifically addresses microsurfacing and the adequate representation/characterization of its performance indicators.

Texas Transportation Institute (Andrews, et al, 1996) studies documented the problems associated with using the existing methods for microsurfacing and suggested the development of a comprehensive mix design and analysis procedure. While differences exist between slurry seal and microsurfacing applications (i.e., traffic volume, application thickness, and curing mechanisms), the similarities of the tests currently used indicate that the two systems must be studied together.

Recognizing the need for more rational design methods for slurry seal and microsurfacing, the Federal Highway Administration (FHWA) enlisted the California Department of Transportation (Caltrans 2004) to form a pooled fund study to which fourteen states contributed. The purpose

and scope of the study was to improve the performance of slurry seal and microsurfacing systems through the development of a rational mix design procedure, guidelines, and specifications. Phase I of the project had two major components; the first consisted of a literature review and a survey of industry and agencies using slurry and microsurfacing systems; the second part of Phase I dealt with the development of a detailed work plan for Phases II and III. In Phase II, the project team evaluated existing and potential new test methods, evaluated successful constructability indicators, conducted ruggedness tests on recommended equipment and procedures, and prepared a report that summarized all the activities undertaken. In Phase III, the project team developed guidelines and specifications, a training program, and provide expertise and oversight in the construction of pilot projects intended to validate the recommended design procedures and guidelines.

The most recent report on microsurfacing, (Moulthrop, et al 2014), describes best practices for slurry surfacing systems and discusses the following:

- Applications for slurry surfacing systems and performance issues
- Materials used in slurry surfacing systems
- Mix design and performance tests
- Specifications
- Quality control and inspection
- Gaps in the current knowledge
- Areas of needed research and potential funding sources

The mix design technology used for these products is somewhat dated and needs to be updated to ensure improved performance. Twenty four states were identified by the survey, literature review, and in NCHRP Synthesis 411 (Gransberg, 2010) as having a microsurfacing specification. Nine of these state specifications are annotated in Table 4.

Table 4. Typical Microsurfacing Specifications

Agency	Material Used			Material Rate/Percentage			Mixing Equipment	Spreading Equipment	Rut Fill	Weather	Joints: Vertical Spacing
	Asphalt Emulsion	Aggregate	Mineral Filler	Aggregate	Asphalt	Mineral Filler					
Alabama, Section 403	CQS-1HP (cationic) or CSS-1H (cationic or Polymer modified)	Crushed aggregate; max 30% carbonate stone for 5000 vpd (Type II and Type III gradations)	non-air entrained Portland cement or hydrated lime	Type II: 10 - 20 lbs/SY, Type III: 15 - 30 lbs/SY	Type II: 6 - 10%, Type III: 5 - 9%	Max 3%	Self-propelled	Hydraulically adjustable type spreader box	<0.5" : leveling course, >0.5": rut-filling box, >1.5": multiple application	50 F and rising, 32 F within 48 hours	0.25"
California, Section 37-3	Polymer modified asphalt emulsion grade PMCQS-1h	Rock dust or sand such as plaster sand, size larger than no 50 sieve must be 100% crushed rock. Three gradations - Type I, II, III	Portland cement Type I, II or III	Type II: 10 - 20 lbs/SY, Type III: 20 - 32 lbs/SY	5.5% - 9.5%	0 - 3%	Self-loading mixing machine or truck mounted mixer spreader	Spreader box	<0.04': scratch coat; >0.04': WP depression rut box; 0.12': multiple pass	50 F and rising, 36 F within 48 hours	0.04': L-jt and 0.03': T-jt
California, Advisory Guide, 2009	Polymer modified quick setting asphalt emulsions	Type II and Type III	Cement	NA	NA	NA	NA	Spreader box	NA	> 46F and rising	NA
Minnesota, Section 2354	Polymer modified CQS-1P or CQS-1HP	well-graded crushed mineral aggregate	NA	NA	NA	NA	Self-propelled front feed and continuous loading machine	Mechanical type spreader box	NA	50F and rising; 32F within 48 hours	0.25" for L-jts and 0.125" for T-jts
Missouri, Section 413	Cationic polymer modified asphalt emulsion	Mineral aggregate, Type II and Type III or IIIR	Type I portland cement or hydrated lime	Type II: 10 -20 lbs/SY, Type III: 15 - 30 lbs/SY, Type IIIR: as necessary	5.5% - 10.5%	0 - 3%	Self-propelled continuous loading machine or truck mounted machine	Mechanical type spreader box	NA	50F and rising, avoid days of 32F within 24 hours	0.5" L-jts, 0.25" T-jts

Mississippi, Section 907-405	Latex modified asphalt emulsion CSS-1HP	Crushed aggregate, max 50% crushed limestone, Type II and III gradations	Portland cement or hydrated lime	Type II: 18 lbs/SY, Type III: 25 lbs/SY	6 - 9%	0.5 - 3%	self-propelled positive, non-slipping aggregate delivery system	NA	<0.5" : leveling course, >0.5": rut-filling box	NA	0.5" L-jts, 0.25" T-jts
South Carolina, Section 410	Cationic Latex modified asphalt emulsion (quick setting)	Crushed mineral aggregate screening (no limestone)	Portland cement Type I or Hydrated Lime	20-22 lbs/SY	5 - 10.5%	0.5 - 3%	Self-propelled continuous flow mixing machine	Mechanical type spreader box	NA	60F and rising	0.25" for L-jts and 0.125" for T-jts
Texas, Item 350	Polymer modified asphalt emulsion CSS-1P	Crushed aggregate (single source)	non-air-entrained cement or hydrated lime	NA	6% to 9%	0.5% to 3%	Self-propelled self-loading device	Mechanical type spreader box	<0.5" - scratch coat, >0.5" rut filling spreader box	50F and rising	0.5" L-dir., 0.25" T-dir
Tennessee, Section 414	CQS-1hp emulsified asphalt (latex polymer based)	Mineral aggregate	Portland Cement	Rut-fill course: No crown; Leveling course: 14±2 lbs/SY, Surface course: 18±1 lbs/SY	5% - 9%	0.5% - 3%	Self-propelled, front feed, continuous loading mixing machine	hydraulically adjustable spreader box	NA	50F and rising	0.25"
Utah, Section 02735	Quick set polymer modified emulsified asphalt (CQS-1h)	100% crushed aggregate	Non-air entrained Type I/II Portland cement or hydrated lime	minimum 25 lbs/SY	7% minimum	0.5 - 2%	automatically sequenced, self-propelled mixing machine	hydraulically adjustable spreader box	<0.5" - scratch coat, >0.5" - Rut filling box with multiple passes	50F and rising, projected low of 37 F within 48 hours	0.25"

NA: The topic was not available/not discussed in corresponding state specification.

STATE DOT SURVEY RESULTS

After reviewing the literature it became clear that a wide variety of practices exist regarding the construction of chip seals, microsurfacing and fog seals. Therefore, to assess the current state of the practice in the U. S. a brief survey was sent to all states regarding current experience in the state and what specifications are currently being used. This survey validated what was believed to be the state of the sentiment/belief of the practitioners. Results of the survey were used to identify or confirm challenges faced by states so these issues could be addressed in the guide specifications. The survey was sent to the state materials, construction, maintenance and pavement management engineers of all 50 states. A total of 40 states responded to the survey. Results of the survey indicate that 32 states utilize emulsion based chip seals, 9 states have used hot chip seals, 31 states use microsurfacing and 36 states use fog seals. Problems experienced with emulsion based chip seals include chip loss (28 states), bleeding (18 states), vehicle damage (15 states), and tire noise (10 states). Problems associated with hot chip seals include chip loss (7 states), bleeding (3 states), noise (4 states), and vehicle damage (2 states). Micorsurfacing problems include delamination (18 states), raveling (12 states), and noise (6 states). Non-uniform application was the the biggest problem for 18 states using fog seals, followed by bleeding (5 states) and friction loss (4 states). Twenty four states indicated they had good construction specifications for emulsion chip seals, but only four states thought their specifications for hot chip seals were adequate. Twenty five states said their microsurfacing specifications were good, and thirty states thought they had a good fog seal specification. Poor performance experienced by the states was attributed to contractors in twenty five states, poor construction specifications in twelve states, poor design in ten states and poor material specifications in eight states. Sixteen states indicated poor results were related to various factors including:

- Moisture/Debonding
- Flushing/lack of embedment
- Snowplow damage
- Chip Loss/Vehicle damage
- Public Perception
- Hot mix asphalt industry resistance

Results of this review of the state of the practice in chip seal and microsurfacing construction indicate that these treatments are widely used throughout the U. S. In fact, only three states indicated they did not use chip seals or microsurfacing and only one state does not have a specification for chip seals after reviewing all 50 states' specifications.

There is some agreement in what the process is called and the content of specifications varies from fairly comprehensive to less than comprehensive. However, most users agree that chip loss, vehicle damage and bleeding are the most common challenges associated with the use of emulsion-based chip seals. The same was true of users applying hot asphalt chip seals where chip loss and bleeding were the biggest issues. Problems with microsurfacing were performance related where the treatment separated from the substrate by delamination or raveling mechanisms. However, the causes for the difficulties with both emulsion chip seals and

microsurfacing were tied to inexperienced contractors and specifications that did not ensure performance.

The results of the survey were not especially surprising. The types of problems associated with emulsion chip seals are chip loss, vehicle damage and bleeding. Problems with hot chip seals were primarily chip loss and bleeding. Problems associated with microsurfacing are raveling and delamination. Most respondents felt these problems were associated with the skill of the contractors performing the work. However, only 24 of 40 responding indicated they had construction specifications that ensure good, consistent performance for emulsion chip seals and only 25 of 40 indicated they had good specifications for microsurfacing.

GUIDE SPECIFICATION DEVELOPMENT

This project began like most research projects with a review of the published literature on the subject. That literature was summarized at the beginning of this chapter. But, because there was less published on construction specifications than on materials and design, the survey reported in the previous portion of this chapter was developed and sent to construction engineers, maintenance engineers, pavement managers, and materials engineers in each state. Then, in addition to the conventional literature search and the survey questionnaire, construction specifications from the state departments of transportation, highway departments and departments of roads were procured and studied from all fifty states. The best ideas from these existing specifications were combined with the best ideas from the literature, the questionnaires and from the personal experience of the research team. The compilation of this information along with research team experience was used to develop drafts of each of the guide specifications. These drafts were reviewed and edited until the final specifications appearing in the attachments to this report were produced.

CHAPTER 3 – SUMMARY OF FINDINGS

A review of relevant literature and a survey of state DOT specifications for chip seals, microsurfacing and fog seals were conducted as part of this research. The information obtained from this effort revealed a variety of features regarding the use of chip seals, microsurfacing, and fog seals and related construction specifications. Among these feature are the following:

- Most agencies use chip seals, microsurfacing, and fog seals, however, no national guide for the construction of these preservation treatments is available.
- Some agencies apply fog seals over chip seals immediately after placing the chip seal, and others apply the fog seal later in the life of the chip seal.
- Most agencies do not have quality assurance procedures for the construction of preservation treatments.
- Most agencies use method specifications.
- Very few agencies specify pay adjustment factors as part of the construction of preservation treatments.

This project identified considerable differences among state DOT specifications for construction of chip seals, microsurfacing, and fog seals. Some specifications contain comprehensive descriptions of the materials and methods to be used while others lack such descriptions. This research did not uncover any specifications that contained all information that should be included in a comprehensive construction specification for chip seals, microsurfacing, and fog seals. This research developed proposed construction guide specifications for these preservation treatments. Each of these guide specifications, provided as attachments to the report, can be used in its entirety or to fill gaps in existing construction specifications.

To facilitate incorporation in the AASHTO Guide Specifications for Highway Construction, the proposed guide specifications were prepared in the format of the AASHTO guide specifications and designated Section 406 (Emulsion Chip Seals), Section 407 (Hot Chip Seals), Section 408 (Microsurfacing), and Section 410 (Fog Seals) to conform to the designations used in the relevant sections of Division 400, Flexible Pavements of the AASHTO guide specifications.

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ATTACHMENT 1 – PROPOSED CONSTRUCTION GUIDE SPECIFICATIONS FOR EMULSIFIED ASPHALT CHIP SEALS

"*These Guide Specifications are the recommendation of the research for NCHRP Project 14-37 that was conducted by Shuler Consultants, LLC. The Guide Specifications have not been approved by NCHRP or any AASHTO committee; nor have they been formally accepted for the AASHTO specifications*".

SECTION 406
EMULSIFIED ASPHALT CHIP SEAL

406.01 Description

This guide specification is intended to provide information needed for owners or contractors to construct emulsified asphalt chip seals. An emulsified asphalt chip seal is the application of emulsified asphalt, followed immediately by a single layer of aggregate chips to a prepared surface.

This guide specification refers to quality requirements for materials and a design method for chip seals available in other AASHTO documents. However, the main purpose is to provide guidance for the construction of emulsified asphalt chip seals applied in one layer.

Commentaries are included in this Guide in places where added emphasis is needed to explain the section being discussed or when there are options to be considered by the user of the Guide, or, as sources of additional information. An example of these commentaries is shown below:

Commentary
This Guide covers construction of single application chip seals. If this process is repeated with another application of emulsified asphalt and another layer of cover aggregate, the process is known as a double chip seal. A triple chip seal would require yet another application of emulsified asphalt and cover aggregate. Other terms have been used referring to chip seals such as 'seal coat', 'surface treatment', 'surface seal', 'surface dressing', 'sprayed seal', and others. Sometimes, a fog seal is applied over the completed chip seal.

A. Referenced Documents

1. AASHTO Standards:

   - M 140, Emulsified Asphalt
   - M 208, Cationic Emulsified Asphalt
   - M 316, Polymer-Modified Cationic Emulsified Asphalt
   - MP 27, Standard Specification for Materials for Emulsified Asphalt Chip Seals
   - PP 82- Emulsion Chip Seal Design
   - T 27, Sieve Analysis of Fine and Coarse Aggregates
   - T 49, Penetration of Bituminous Materials

- T 50, Float Test for Bituminous Materials
- T 59, Emulsified Asphalts
- T 96, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
- T 301, Elastic Recovery Test of Asphalt Materials by Means of a Ductilometer
- T 335, Standard Method of Test for Determining the Percentage of Fracture in Coarse Aggregate

2. ASTM Standards:
   - D 5624-13, Standard Practice for Determining the Transverse-Aggregate Spread Rate for Surface Treatment Applications

3. Other:

   - The Asphalt Institute Manual Series 19, "A Basic Asphalt Emulsion Manual", 4th Edition.
   - Shuler, S. 1991, High Traffic Chip-Seal Construction: The Tulsa Test Road, *Transportation Research Record No. 1300*, National Academy of Sciences, pp 116-124.
   - NCHRP Report 680, "Manual for Emulsion-based Chip Seals for Pavement Preservation", Shuler, S., Epps-Martin, A., Lord, T., and Hoyt, D., Transportation Research Board, Washington, D. C., 2011.
   - Federal Lands Highway, FLH T508, Flakiness Index Value

B. Terminology

1. *CRS-2 polymer modified* – a cationic rapid setting emulsified asphalt that includes a polymer modifier typically in the form of a styrene-butadiene latex rubber or a styrene-butadiene or styrene-butadiene styrene block copolymer modified base asphalt binder.

2. *CRS-2* – a cationic emulsified asphalt without a polymer that is rapid setting

3. *RS-2 polymer modified* – an anionic rapid setting emulsified asphalt that includes a polymer modifier typically in the form of a styrene-butadiene latex rubber or a styrene-butadiene or styrene-butadiene styrene block copolymer modified base asphalt binder.

4. *RS-2* – an anionic emulsified asphalt without a polymer that is rapid setting.

5. *HFRS-2 polymer modified* – an anionic high float rapid setting emulsified asphalt that includes a polymer modifier typically in the form of a styrene-butadiene latex rubber

or a styrene-butadiene or styrene-butadiene styrene block copolymer modified base asphalt binder.

6. *HFRS-2*– an anionic high float emulsified asphalt without a polymer that is rapid setting.

7. C*HFRS-2 polymer modified* – a cationic high float rapid setting emulsified asphalt that includes a polymer modifier typically in the form of a styrene-butadiene latex rubber or a styrene-butadiene or styrene-butadiene styrene block copolymer modified base asphalt binder.

8. *CSS-1h* – a cationic emulsified asphalt that is slow setting and has a residual binder residue with lower penetration than CSS-1.

9. *SS-1h* – an anionic emulsified asphalt that is slow setting and has a residual binder residue with lower penetration than SS-1.

406.02 MATERIAL

A. Emulsified Asphalt

Emulsified asphalt for chip seal shall meet the requirements of AASHTO MP27, M140, M208, M316 or the requirements shown in Tables 1, 2 and 3 for high float asphalt emulsions.

***Table 1** – Requirements for High Float Rapid Setting Polymer-Modified Emulsified Asphalt*

Test	Requirements	
	Min	Max
Viscosity, Saybolt Furol, s @ 50C (122F), AASHTO T59	50	450
Storage Stability, 24 hour, %, AASHTO T59		1.0
Sieve Test, %, AASHTO T59		0.10
Demulsibility, %, AASHTO T59	60	
Residue by Distillation, %, AASHTO T59	65.0	
Oil Distillate by Volume of Emulsion, %, AASHTO T59		3.0
Penetration of Residue, 25C (77F), AASHTO T49	100	200
Float Test on Residue, 60C (140F), sec, AASHTO T50	1200	
Elastic Recovery for Polymer Modified HFRS, %, AASHTO T301	58	

***Table 2** – Requirements for High Float Rapid Setting Emulsified Asphalt*

Test	Requirements	
	Min	Max
Viscosity, Saybolt Furol, s @ 50C (122F), AASHTO T59	50	450
Storage Stability, 24 hour, %, AASHTO T59		1.0
Sieve Test, %, AASHTO T59		0.10
Demulsibility, %, AASHTO T59	60	
Residue by Distillation, %, AASHTO T59	65.0	
Oil Distillate by Volume of Emulsion, %, AASHTO T59		3.0
Penetration of Residue, 25C (77F), AASHTO T49	100	200
Float Test on Residue, 60C (140F), sec, AASHTO T50	1200	

***Table 3** – Requirements for Cationic High Float Rapid Setting Emulsified Asphalt*

Test	Requirements	
	Min	Max
Viscosity, Saybolt Furol, s @ 50C (122F), AASHTO T59	100	400
Sieve Test, %, AASHTO T59		0.10
Demulsibility,%, 35ml 0.02 N $CaCl_2$, % AASHTO T59	60	
Residue by Distillation, %, AASHTO T59	65	
Oil Distillate by Volume of Emulsion, %, AASHTO T59		0.5
Penetration of Residue, 25C (77F), 100g, 5 secs, AASHTO T49	80	130
Float Test on Residue, 60C (140F), sec, AASHTO T50	1800	
Elastic Recovery, 50F %, AASHTO T301	55	

B. Aggregate

Chip seal aggregate shall conform to the requirements specified in AASHTO MP27, Section 6.1, Tables 1 and 2.

406.03 CONSTRUCTION

A. Weather Limitations

Construct chip seal per the following conditions:

1. Ambient or pavement surface temperatures shall be 50F and rising.
2. Application of the chip seal shall be only during daylight hours.
3. Suspend chip sealing if the pavement surface temperature exceeds 140F.
4. The road surface shall be dry to damp.

B. *Mix Design*

Design the chip seal to determine aggregate chip spread rate and asphalt emulsion application rate using a design method such as that described by the Asphalt Institute MS-19 or by AASHTO PP 82.

C. *Preconstruction Meeting*

Coordinate a preconstruction meeting prior to construction with the engineer to discuss the following topics:

1. construction process
2. quality control plan, required to be submitted
3. mix design, required to be submitted
4. materials control
5. materials measurement
6. equipment calibration, required to be submitted
7. traffic control plan
8. equipment/process overview
9. inspection
10. test strip
11. unique project conditions
12. project documentation
13. expectations

D. Road Surface Preparations

1. Cleaning Pavement

   Clean the roadway surface by sweeping no more than 30 minutes prior to application of the asphalt emulsion and chips. However, this 30-minute window may be extended if authorized by the engineer in cases where extending the time does not jeopardize a clean surface prior to chip seal operations. Sweep the pavement with a motorized broom to remove loose material. Clean depressions not reached by the motorized broom with a hand broom. Clean the outer edges of the pavement to be sealed including an adjacent paved shoulder.

2. Protecting Accessories

   Cover utility castings (manholes, gate valve covers, catch basins, sensors, etc.) to prevent coating with emulsified asphalt. Suitable covering includes plywood disks, Kraft paper, roofing felt or other approved methods. Remove the protective coverings before opening the road to traffic.

3. Stripe Removal

   Thermoplastic pavement markings shall be removed by grinding or other approved methods prior to chip seal operations. Other pavement markings may be left in place.

E. Equipment

1. Pressure Distributor

   The pressure distributor shall be self-propelled with a ground speed control device interconnected with the emulsified asphalt pump such that the specified application rate will be supplied at any speed. The pressure distributor shall be capable of maintaining the emulsified asphalt at the specified temperature. The spray bar nozzles shall produce a uniform double or triple lap application fan spray, and the shutoff shall be instantaneous, with no dripping. All nozzles shall be oriented at the same angle between 15 and 30 using the wrench supplied by the distributor manufacturer. Each pressure distributor shall be capable of maintaining the specified application rate within +/- 0.015 gal/yd^2 for each load.

   Commentary
   Obtaining a triple overlap from the spray bar is the most desirable arrangement because the emulsion application will generally be more uniform than with double overlap. However, when equipment is calibrated and set up properly very acceptable results have been obtained with double overlap

2. Aggregate Spreader

   A self-propelled mechanical type aggregate spreader with a computerized spread control, capable of distributing the aggregate uniformly to the required width and at the designed rate shall be used.

3. Pneumatic-Tire Rollers

   A minimum of three (3) self- propelled pneumatic-tire rollers capable of ballast loading, either with water or sand to allow the weight of the machine to be varied from 6 to 8 tons to achieve a minimum contact pressure of 80 lbs./in^2 shall be used. The alignment of the axles shall be such the rear axle tires, when inflated to the proper pressure, can compact the voids untouched by the front-axle tire. All tires shall be as supplied by the roller manufacturer. Width of the rollers shall exceed 60 inches.

   Commentary
   Steel-wheel rollers have been used as the final roller on some chip seals with success. The advantage is a more even final elevation. This produces fewer prominent chip

edges extruding above the surface which can be susceptible to snow plow damage. The disadvantage of steel-wheel rollers is the potential for crushing of aggregate chips that cannot withstand the high stress imparted at the steel roll-chip interface. Therefore, if used, steel rollers should be limited to 5 tons. Vibration shall not be used if the rollers are so equipped.

4. Brooms

   Motorized brooms with a positive means of controlling vertical pressure shall be used to clean the road surface prior to spraying emulsified asphalt. Plastic bristle brooms are required to remove loose aggregate after chip sealing.

   Commentary
   Vacuum brooms are preferred in urban or residential areas, but push brooms are acceptable in rural areas where chips being scattered off the roadway do not pose a hazard to pedestrians or vehicles.

5. Trucks

   Unless otherwise approved, use trucks of uniform capacity to deliver the aggregate. Provide documentation showing measurements and calculation in cubic yards. Clearly mark the calibrated level. Truck size may be limited when shown on the plans.

F. Equipment Calibration

The contractor shall provide proof of calibration of the pressure distributor and the aggregate spreader. Calibration shall be repeated once per week or after every five full days of chip seal operations. The contractor shall submit the results of the calibration procedure to the Engineer.

Flow from each nozzle in the pressure distributor must be within +/-10 percent of the average flow of all nozzles as measured by the procedure described below.

Uniformity of the aggregate applied transverse to the pavement centerline in accordance with ASTM D5624, "Determining the Transverse Aggregate Spread Rate for Surface Treatment Applications". Tolerance for each pad tested for transverse spread rate shall be +/-10 percent of the average of the total transverse rate.

Commentary
Calibration is very important to assure the quantity of emulsion and chips applied to the pavement is correct. Although many modern asphalt distributors and aggregate spreaders are computer controlled, calibration is required to tell the computer how much emulsion is being applied. This quantity must be checked prior to spraying emulsion and

spreading chips and checked against the quantity the computer (if the distributor is so equipped) indicates is being applied.

1. Pressure Distributor

All nozzles shall be the same size, provide the same flow rate, be oriented in the same direction, and be the same distance above the pavement.

Commentary: The distributor truck applies emulsified asphalt to the pavement surface. This application must be done uniformly both transverse and longitudinal to the centerline of the pavement.

When lower application rates are determined necessary or shown in the plans, smaller nozzles shall be inserted in the spray bar where the emulsion rate is reduced.

Commentary: Due to minor rutting or heavy truck traffic, it may be desirable to reduce the emulsion application rate in the wheel paths.

a. *Nozzle Angle*

Nozzles shall be positioned at an angle of 15 to 30 degrees from the horizontal of the spray bar in accordance with the spray bar manufacturers recommendation. All nozzles shall spray a full fan except for the right and left edge nozzles. The right and left edge nozzle shall be adjusted to a half fan such that the spray stays to the inside of the spray bar.

Commentary: The next step in calibrating the distributor is adjustment of the spray bar nozzle angles. Each nozzle has a slot cut across the face of the nozzle. When the nozzle is threaded into the spray bar, the slot should all be positioned at an angle of 15 to 30 degrees to the direction of the spray bar as shown in Figure 1. This angle provides the best position for achieving uniformity in the spray and the triple overlap coverage. The angle should be adjusted using the wrench supplied with the distributor. This wrench is designed when used properly to set the correct angles for each nozzle. Any wrench that fits the hexagonal nozzle can adjust the nozzle angle but correctness of the angle would have to be visually verified.

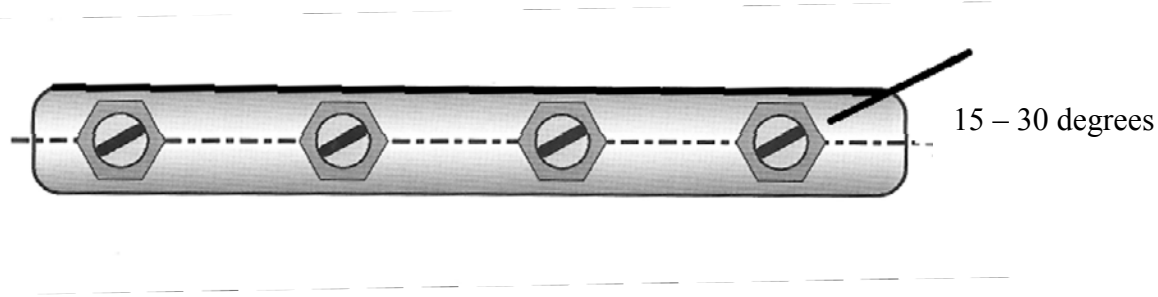

Figure 1- Spray Bar Nozzle Orientation in Spray Bar

The angle at which the nozzles are positioned shall be adjusted using the wrench supplied with the distributor.

However, in cases where this wrench is unavailable, a wrench that fits the hexagonal nozzle will suffice but the angle must be judged visually.
All nozzles fitted to the spray bar shall be full fan nozzles except for the right and left edge nozzles. These nozzles shall be half fan nozzles adjusted so the spray from the nozzle remains to the inside of the spray bar.

b. Spray Bar Height

The spray bar height must be adjusted so that the emulsion provides exactly two or three overlaps across the entire spray width.

Commentary
Streaking of the emulsion will occur if the spray bar is set too high or too low as shown in Figures 2 and 3.

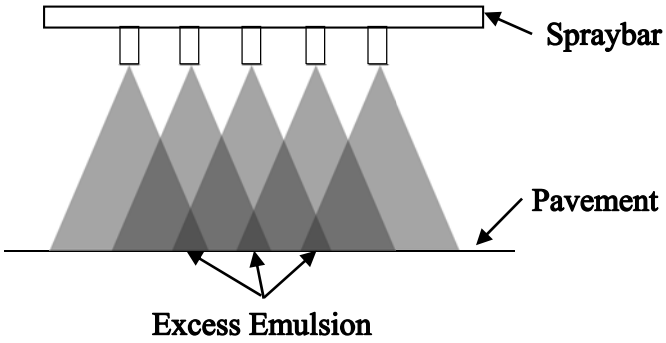

Figure 2- Streaks with Spray Bar Too High for Double Overlap

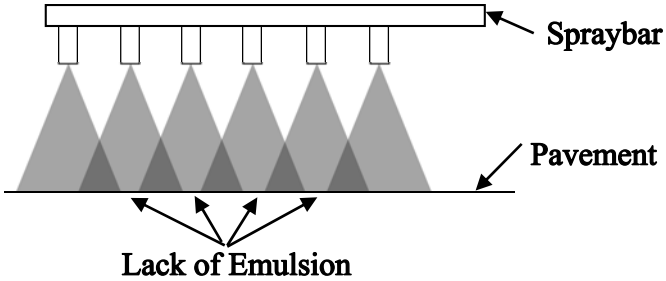

Figure 3 - Streaks With Spray Bar Too Low for Double Overlap

To avoid this streaking the bar must be adjusted to the correct height. This adjustment process is accomplished by shutting off nozzles to determine where the spray pattern contacts the pavement as shown in Figures 4 and 5.

Bar Height Adjustment to Achieve Double Lap
Every second nozzle shall be turned off when a double lap application is desired as shown in Figure 4. The distributor operator shall spray emulsion onto the pavement surface for as short an interval as possible while an observer watches where the emulsion hits the pavement from each nozzle left open. If there is overlap of emulsion from adjacent nozzles, the bar is too low. If there is a lack of emulsion from adjacent nozzles, the bar is too high.

Once it is confirmed the bar height is correct, the nozzles that were turned off can be turned back on and a double application of emulsion will result when spraying resumes.

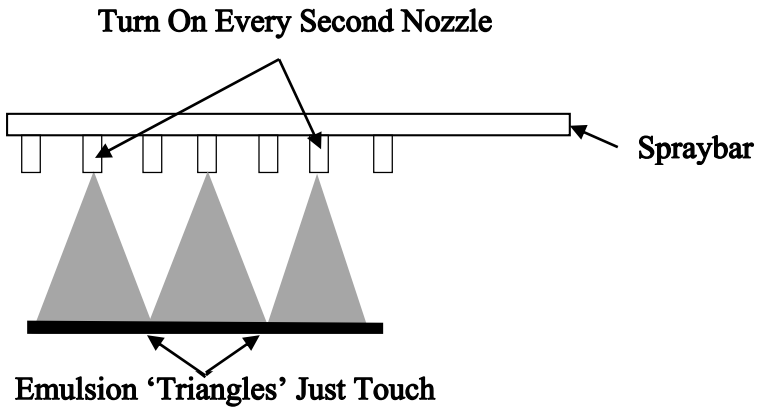

Figure 4 - Adjustment of Spray Bar Height for Double Overlap

Triple Lap Application Bar Height Adjustment
Every third nozzle shall be turned off when a triple lap application is desired as shown in Figure 5. The distributor operator shall spray emulsion onto the pavement surface for as short an interval as possible while an observer watches where the emulsion hits the pavement from each nozzle left open. If there is overlap of emulsion from adjacent nozzles, the bar is too low. If there is a lack of emulsion from adjacent nozzles, the bar is too high.

Once it is confirmed the bar height is correct, the nozzles that were turned off can be turned back on and a double application of emulsion will result when spraying resumes.

As the distributor empties during spraying, the bar height will rise. However, this is not usually enough to cause significant streaking worth adjustment of the spray bar.

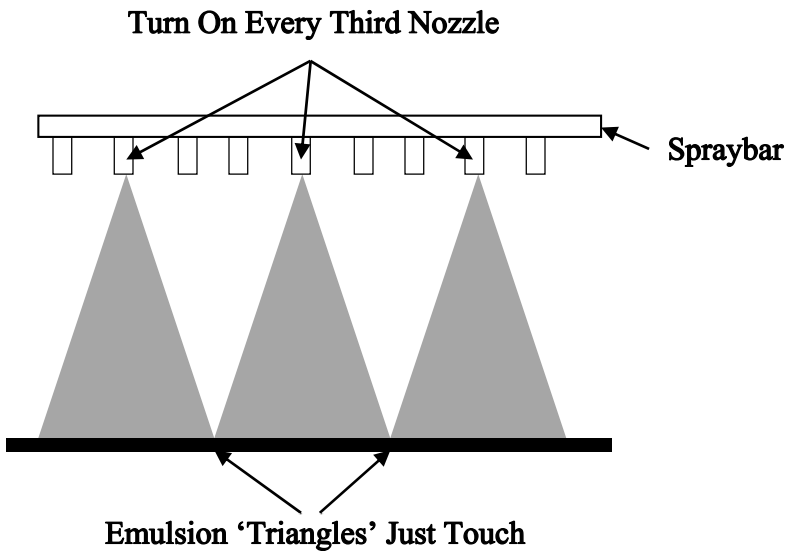

Figure 5 - Adjustment of Spray Bar Height for Triple Overlap

c. Transverse Flow Rate

The flow rate across the spray bar shall be uniform with each nozzle spraying within +/-10 percent of the average flow rate.

<u>Commentary</u>
This is done by measuring the width of the slot in the nozzle and by measuring the orifice diameter. Also, some nozzles are labeled by the manufacturer. Manufacturers supply a list of nozzles in the owner's document describing which nozzles shall be used for various application rates or on a placard mounted on the equipment.

However, nozzles of the same apparent size have been measured with different flow rates. Therefore, it is recommended that all nozzles be checked for flow rate before chip seal operations begin. This is easily accomplished by fabricating a flow apparatus. This apparatus consists of a pipe to which each nozzle can be fitted, in turn, on one end and a water source can be fitted to the other end. The flow of water through each nozzle shall be measured by filling a one gallon container in a measured period. This shall be done for each nozzle to be used on the project. If the flow rate of any of the nozzles is greater than 10 percent of the average of all the nozzles to be used these nozzles shall be discarded, or modified to flow within the 10 percent tolerance.

Determination of uniform lateral flow from the spray bar is determined by collecting a measured volume of emulsion in containers placed under each nozzle. This process is practical using standard 6-inch by 12-inch concrete cylinder

molds lined with one-gallon zip-lock freezer bags. The cylinder molds can be reused and the zip lock bags discarded appropriately with the contents.

d. Longitudinal Flow Rate

The longitudinal spray rate shall be accomplished by measuring the volume of emulsion in the distributor before and after spraying enough emulsion to reduce the volume of emulsion in the distributor by 70 to 90 percent.

Commentary

The longitudinal flow rate must be measured with all nozzles inserted in the distributor bar. First, the quantity of emulsified asphalt in the truck must be determined. Although there is a volume indicator on the rear of most modern distributors, these are not calibrated in small enough increments to be of use for longitudinal flow rate calibration and shall not be used for this purpose. Instead, the dip stick supplied with the distributor must be used. This dip stick is usually carried on the top of the tank near the inspection hatch. Prior to shooting emulsion, take a volume reading with the dip stick.

Pay attention to how the dipstick is used. Many dipsticks are not intended to be submerged in the emulsion, but instead, are inserted into the top of the tank only until the tip of the dipstick touches the surface of the emulsion. Then, the volume in the tank is read by indexing the top of the inspection cover to the reading on the dipstick.

Record this volume as 'beginning volume'. Set up the truck to shoot emulsion and shoot a minimum of 3000 feet by 12 feet of emulsion at the design rate using the gallon per minute pump flow volume and truck speed required by the manufacturer to attain this flow rate. Take a second dip stick reading. Record this reading as 'ending volume'. Subtract 'ending volume' from 'beginning volume' and record this as 'volume used'. Determine the area of emulsion sprayed. Divide 'volume used' by the area sprayed in square yards. This is the gallons per square yard applied to the pavement. This value shall then be compared to the distributor computer, if equipped, to evaluate the accuracy of the computer. A correction factor may then be applied to the computer output, if needed, and used for the remainder of the day. This calibration shall be accomplished each day.

An example of this calibration is presented below:

Given:

1800-gallon capacity asphalt distributor
12-foot-wide spray width
Trial spray distance = 3630 feet
0.32 gallon/yd^2 design spray rate
Dipstick reading beginning of shot = 1765 gallons

Dipstick reading end of shot = 265 gallons

Calculations:

1. *Check to see if enough volume shot. 1765-265=1500 gallons*
2. *1500/1765 = 85 percent >70% and <90%. OK, enough applied to be valid*
3. *Calculate spray rate = 1500 gallons / (12 x 3630/3) = 0.31 gallons/yd^2*

Therefore, decrease distributor speed, or recalibrate computer and re-check.

2. Aggregate Chip Spreader

a. *Transverse Spread Rate*

<u>Commentary</u>
Various methods of calibrating this equipment have been used and the ASTM D5624 procedure can be effective. However, a visual assessment of the lateral distribution of chips is a good place to start the process since non-uniform distribution can easily be seen. The veil of chips deposited on the pavement from the spreader box can be viewed from behind with the spreader moving away from the observer or from the front. Either position for the observer is adequate for viewing how uniform the veil of chips is falling out of the spreader box. However, viewing from either front quarter affords the observer a better view of the entire spreader width and is, of course, safer than directly in front of the spreader. Any variation in light passing through the veil of chips indicates variation in application rate. More light means a lack of chips. Variation in light means the machine shall be stopped, the gates on the spreader contributing to the non-uniformity adjusted and the trial rerun. This procedure provides adjustment to the transverse spread rate. Then, to obtain an objective means of measuring the amount of chips being deposited, ASTM D5624, "Determining the Transverse Aggregate Spread Rate for Surface Treatment Applications" is a good procedure to use.

b. *Longitudinal Spread Rate*

Once the transverse spread rate is adjusted the longitudinal rate can be adjusted. This is also done visually, at first. Begin spreading chips into the fresh emulsion when a few chips cast by hand stick to the emulsion and do not roll over. This shall be done well before the emulsion begins to 'break' or 'set', but not immediately after spraying unless temperature, wind, or high demulsibility demand it.

The application rate of the chips shall be similar to the design rate. This is a rate where immediately upon dropping the chips, the appearance of the surface has some emulsion showing between the chips. In fact, the chip quantity should seem somewhat inadequate. The chip spread rate should not be low enough to cause

pickup problems on rubber-tire rollers. However, the rate should be such that a small decrease in rate would cause pickup. Emulsion should be visible between the chips upon dropping the chips and before rolling. If all emulsion is covered before rolling, there is an excess of chips and the rate shall be reduced. It is the responsibility of the construction superintendent to achieve this application rate.

Evaluating the quantity of chips being placed is important after the rate is established. This provides a quantitative baseline for future work. The best method to accomplish this evaluation is by weighing the chip spreader before and after applying the chips and calculating the spread rate based on the area covered. This is often not practical. Therefore, a suitable alternative includes estimating the quantity of chips spread over a known area by knowing the weight of each transport truck supplying the spreader and dividing the estimated weight of chips spread by the area covered for that load.
An example follows:

Given:
Trucks loading the chip spreader are 12-ton capacity tandem dumps
12-foot-wide pavement
28 pounds per square yard design spread rate

Calculations:

1. *Check Truck No. 1*
a. *Load = 23,803 lbs.*
b. *Spreader distance = 213 feet*
c. *Rate = 23,803/213x12/3 = 27.9 lbs./yd^2*
2. *Check Truck No. 2*
a. *Load = 23,921 lbs.*
b. *Spreader distance = 211 feet*
c. *Rate = 23,921/211 x 12/3 = 28.3 lbs./yd^2*
3. *Check Truck No. 3*
a. *Load = 23,848 lbs.*
b. *Spreader distance = 213 feet*
c. *Rate = 23,848/213 x 12/3 = 28.0 lbs./yd^2*
4. *Average Rate = (27.9 + 28.3 + 28.0) / 3 = 28.1 lbs./yd^2*
5. *No adjustment needed since measured rate is within 1 percent of design.*

Compensation for moisture on chips must be considered when calibrating chip spreaders. The above example indicates no adjustment is needed since the measured spread rate is within 0.10 lbs/yd^2 of the design spread rate. However, if the chips above had contained as much as 1.02 percent moisture that was unaccounted for, the application rate would have been too low.

G. Test Strip

A test strip shall be constructed on or near the project site. Construct the test strip under similar placement conditions of time of day, temperature, and humidity as expected for the duration of the project. The test strip shall be a minimum of 300 feet in length and shall be constructed with the job mix proportions, materials, and equipment to be used on the project. Adjustments to the mixture formula shall be permitted provided they do not exceed the values stated in the mix design. The Agency shall evaluate the test strip to determine whether project specifications are met. If specifications are not met, additional test strips will be constructed until specifications are met, at no additional cost to the Agency.

H. Application of Emulsified Asphalt

Apply the asphalt emulsion at the rate determined by the design. This rate shall be within +/-5 % of the chip seal design rate. After applying the emulsified asphalt, place the cover aggregate at the design application rate. Adjust the rate of application, if necessary, so that some emulsified asphalt can be seen between the aggregate chips, but not so much that aggregate chips adhere to the pneumatic rollers. Inspect the aggregate in the wheel paths for proper embedment. Embedment shall be 50 to 60 percent after rolling. Make additional adjustments to the rate of application during the project, if needed.

The temperature of the emulsified asphalt at the time of application shall be above 120F.

Commentary
If the temperature is lower than 120F there is risk of less material being applied than desired due to high viscosity.

The longitudinal construction joint for a single course chip seal must coincide with the painted lane line or at the outside edge of shoulder. There shall be no overlap of the longitudinal construction joint for a single application chip seal.

I. Application of Cover Aggregate

Provide uniformly moistened aggregates, which are damp at the time of placement. Damp chips shall be saturated but surface dry with an approximate moisture content between 1 and 3 percent depending on the aggregate absorption capacity.

Commentary

This moisture content makes the chips appear as though they have a mat or satin finish, using a painting analogy, and not glossy. A damp chip draws emulsion into the pores of the chip thus providing better adhesion once the emulsion has set.

Immediately (within one minute) after the emulsified asphalt has been sprayed, apply the aggregates. The speed of the spreader shall be restricted to prevent the aggregates from rolling over. Starting and stopping of the spreader should be minimized. The edges of the aggregate applications shall be sharply defined. Previously used aggregates from sweeping may not be returned to the stockpile or the spreader for reuse.

Commentary
Although a design was done in the laboratory to determine the chip application rate, adjustments are almost always needed in the field. This should be done during the first day of construction to make sure the chip quantity is correct. This is best done by observing the appearance of the chips after they have been dropped into the emulsion, but before rolling. Some emulsion should be visible between many of the chips. If emulsion cannot be seen between the chips, the chip rate is too high. Conversely, too much emulsion showing through between the chips will cause pickup on rubber tires.

J. Transverse Paper Joints

When beginning a new application of the chip seal transversely abutting the previously placed chip seal a transverse paper joint shall be used so excess asphalt and chips are not placed at the joint. The transverse paper joint shall be formed by placing 36-inch-wide Kraft paper on top of the previously applied chip seal so the edge of the paper aligns with the joint that will be formed when the previously placed chip seal meets the newly applied chip seal. The asphalt distributor shall begin applying asphalt emulsion by starting the application on top of the Kraft paper. After the distributor moves forward and over the joint the paper shall be removed.

Commentary
Ideally, the paper should also be placed at the end of the distributor shot, as well. This creates a clean, edge with the correct emulsion and chip quantity at the joint. Where the paper should be placed is calculated based on the emulsion shot rate and the quantity of emulsion in the distributor. The distance the distributor travels before encountering the paper and turning off the bar should be approximately equivalent to 80 percent of the distributor tank volume. This assures the distributor does not spray until empty which can result in less emulsion applied than desired at the end of the shot.

K. Rolling Operations

Complete the first roller pass as soon as possible but not longer than two minutes after applying the aggregate. Proceed in a longitudinal direction at a speed less than or equal to three miles per hour. Three complete roller passes of the aggregate chips are required as a minimum. One pass is defined as the roller moving over the aggregates in a single direction. Ensure the rolling is completed quickly enough to embed the aggregate, before

the emulsified asphalt breaks and no longer than 15 minutes after the emulsion is sprayed. Position the rollers in echelon so the entire width of the pavement lane is covered in one pass of the rollers.

Commentary
If desired, final rolling may be accomplished using the steel wheel roller in one pass

L. Sweeping

Excess chips shall be swept off the new surface in accordance with Table 4.

Table 4 – Sweeping Sequence

Chip Seal Class*		
I	II	III
Within 24 hours after rolling	No later than the following morning	Before Traffic is allowed without traffic control

* Class I is less than 500 AADT, Class II is 501 to 5000 AADT, Class III is greater than 5000 AADT

Do not sweep embedded aggregate until at least 85 percent of the total moisture present in the chip seal has evaporated or aggregates may become dislodged. Moisture present consists of moisture in the aggregate chips and moisture present in the asphalt emulsion. Moisture content shall be determined by the procedure reported in NCHRP Report 680 (Shuler, et al 2011). Re-sweep areas the day after the initial sweeping. The Contractor shall dispose of the surplus cover aggregate in a manner satisfactory to the Agency. In no case, shall the excess aggregates swept from the surface exceed 10 percent of the total amount placed. If this quantity is exceeded, work shall cease until an adjustment is made to reduce the spread rate within tolerances.

M. Traffic Control

Traffic may be allowed onto the fresh chip seal after rolling is completed and before sweeping in accordance with Table 5.

Table 5 – Timing for Traffic

Chip Seal Class*		
I	II	III
Traffic controlled with speed limit signs	Traffic controlled with pilot cars	Traffic controlled with pilot cars

* Class I is less than 500 AADT, Class II is 501 to 5000 AADT, Class III is greater than 5000 AADT

A pilot car shall be used on 2-lane roadways during construction and until the roadway and shoulders have been swept free of loose aggregate.

N. Protection of Motor Vehicles

The Contractor is responsible for claims of damage to vehicles until the roadways and shoulders have been swept free of loose aggregate and permanent pavement markings have been applied. If permanent pavement markings are to be applied by Agency forces, the Contractor's responsibility ends after completion of the chip seal and placement of temporary pavement markings.

O. Fog Seal

If, in accordance with the plans, a fog seal is applied to the surface of the completed chip seal, spray the fog seal after sweeping and before placement of permanent pavement markings, but not sooner than 24 hours after final rolling. Refer to the AASHTO Construction Guide Specification for Fog Seals in the section for application over chip seals for specific requirements.

Commentary

Fog seals are applied to the surface of completed chip seals for two reasons: 1) The dark color provides more contrast to pavement markings, 2) the fog seal provides a slight increase in binder residue to increase chip retention.

A fog seal may also be applied to recent hot mix asphalt patches in the pavement to be chip sealed. These fresh hot mix patches can be more absorptive than the surrounding pavement due to higher air void content. The fog seal helps prevent the new chip seal emulsion from being absorbed into the substrate unevenly.

P. Sequence of Work

Construct the chip seal so that adjacent lanes are sealed on the same day when possible. If the adjacent lane(s) has not been sealed sweep all loose chips from the unsealed lane(s) before traffic is allowed on the surface without traffic control.

Permanent pavement markings shall not be placed for 24 hours after placing the chip seal when no fog seal is applied.

The permanent pavement markings shall not be placed for three days after placing the fog seal, if used, for water borne pavement marking or ten days for other types.

Commentary
The chip seal will usually cure within 24 hours under dry conditions and temperatures above 60F. The fog seal can be applied after the chip seal coat is cured. The fog seal will usually cure within 2 hours under dry conditions and temperatures above 60F. Interim pavement markings can be placed after the fog seal cures.

Q. Quality Control

1. General

The Contractor is responsible for quality control (QC) sampling and testing and shall submit a QC plan including materials and procedures for verifying the quality of the chip seal aggregates and emulsified asphalt(s). The Contractor's QC plan shall include but is not limited to sampling, testing, inspection, monitoring, documentation, and corrective action procedures during transport, stockpiling and placement operations.

A written Quality Control Plan (QCP) shall be developed which details the Contractors's QC program that meets the requirements of these specifications. The QCP shall be contract specific and signed by the Contractors's representative. Chip seal construction shall not proceed without Agency approval of the QCP and QC personnel present on the project. Failure to comply with these provisions will result in shutdown of the operations until such time as the Contractor's operations are in compliance.

2. Personnel

The QC staff shall include the following as a minimum:

a. QCP Administrator – The person with overall responsibility of the QCP
b. QCP Manager – The person responsible for the execution of the QCP and liaison with the Agency. This person shall be on the project, and have the authority to stop or suspend construction operations.

c. QC Technicians – The person(s) responsible for conductingQC tests and inspection to implement the QCP. QC technicians shall have Level 2 Aggregate Testing Certification from the American Concrete Institute (ACI) or other accrediting body approved by the Agency.
d. Certified Crew Members – Three crew members (job foreman, aggregate spreader operator and asphalt distributor operator), at a minimum, shall possess a valid chip seal certification and be on the project at all times the chip seal is being constructed. The chip seal certification is administered by the National Center for Pavement Preservation (NCPP) on behalf of AASHTO TSP[2] (Transportation Services Preservation Program).

3. Testing Facilities and Equipment

The Contractor shall provide the name of the laboratory conducting QC tests. The laboratory shall maintain accreditation by the AASHTO Accreditation Program (AAP) for all tests within the relevant scope of testing, or other accrediting body approved by the agency. Sampling, testing and measuring devices shall meet the requirements of the specified standards and test methods. The laboratory shall maintain records of the calibration and maintenance of all sampling, testing and measuring equipment.

4. Materials Testing

Chip seal aggregates and asphalt emulsion shall be tested for compliance with the specifications as follows:

Chip Seal Aggregate

a. Stockpile.
Test the aggregate gradation a minimum of once per day, or every 1500 tons, whichever is less in accordance with AASHTO T27 to determine compliance with Table 4 requirements. If the material is hauled from the production site to a temporary stockpile, test at the temporary stockpile.

b. Construction.
Test the aggregate gradation from the hopper of the chip spreader a minimum of once per day, or every 1500 tons, whichever is greater in accordance with AASHTO T27 to determine compliance with Table 4 requirements. The testing rate for quality values in Table 5 shall be once per source.

Emulsified asphalt

Only emulsified asphalt from certified or approved sources is allowed for use. Verify the emulsion(s) meet the specifications by obtaining certificates of compliance from the supplier.

Verify the application rate of the emulsified asphalt by dividing the volume of emulsified asphalt used by the area chip sealed each day. Allowable variation is +/- 5% of the application rate adjusted from the design quantity. Provide material certification and quality control test results for each batch of emulsified asphalt used on the project. Include the supplier name, plant location, emulsion grade, and batch number on all reports.

5. Calibration of Equipment and Workmanship

   Describe the equipment and methods used to calibrate the chip spreader and asphalt distributor and workmanship items including:

   a. Longitudinal application rates
   b. Transverse application rates
   c. Asphalt transverse application uniformity
   d. Transverse joint construction technique
   e. Monitoring method for application rates
   f. Rolling operations detailing the roller pattern and number of passes and coverages
   g. Sweeping operations and schedule
   h. Method of controlling traffic

6. Documentation

   Describe the documentation and reporting procedures for all QC activities. Include samples of all QC test forms, inspection and test reports.

7. Records and Documentation

   The Contractor shall maintain complete records of all QC tests and inspections. All QC test results shall be submitted to the Agency at the end of the contract. A material certification shall be submitted from each supplier for each batch of material delivered to the project, including test results.

   The QC records shall contain all test and inspection reports, forms and checklists, equipment calibrations, supplier material certificates, and non-conformance and corrective action reports. The QC records shall indicate the nature and number of observations made, the number and type of deficiencies found, the quantities conforming and non-conforming, and the nature of corrective action taken as appropriate for materials as well as workmanship. The QC records shall be available to the Agency at all times, and shall be retained by the contractor for the life of the contract. The Contractor's documentation procedures will be subject to approval by the Agency prior to the start of work, and to compliance checks by the Agency during the progress of the work.

8. Compliance with Specifications

The Contractor shall attest in writing to the Agency that the chip seal has been constructed in accordance with and meets the requirements of the specifications at the conclusion of the project.

R. Agency Acceptance

1. General
   The Agency will conduct acceptance sampling, testing, and inspection activities to ensure material quality, correct application rates, rolling, sweeping, and traffic control are within specification requirements. These activities will be done randomly by the Agency.

2. Acceptance Activities

   a. Materials Testing

      Aggregate

      Sample aggregate taken from the chip spreader hopper once per day. Samples will be stored and tested for gradation at the discretion of the Agency. If the results vary from the requirements of Tables 4 and 5, a price reduction will be applied per the Schedule of Price Reduction prepared by the owner agency.

      Emulsified asphalt

      Sample the first shipment and provide one sample for every 50,000 gallons (approximately 200 tons) thereafter. Testing of emulsions shall be in accordance with AASHTO M140, M208, M316, or Tables 1, 2 or 3 of this guide specification.

   b. Equipment
      All equipment to be used on the project shall be evaluated by the Agency to assure it is in acceptable operating condition, calibrated correctly and will provide the quantities of material specified.

   c. Final Inspection
      A final inspection will be done to assure that no bleeding or flushing, excessive chip loss or crushed aggregate has occurred. Longitudinal and transverse joints will be inspected to assure that no excessive overlap has occurred.

406.04 MEASUREMENT

The Engineer will measure work acceptably completed as specified in Subsection 109.01 of the AASHTO Construction Guide Specifications and as follows:

A. Emulsified asphalt

1. Measure the emulsified asphalt for chip seal by volume, at 60F.

B. Aggregate Chips

Aggregate chips will be measured based on the area of pavement surfaced.

Commentary
Chips can be paid for by the ton, as well. This is easier to verify, but results in an incentive to place more chips than necessary. Applying too many chips is poor practice and results in dislodgement of embedded chips. Also, paying by the ton will result in unnecessary additional cost.

406.05 PAYMENT

Payment for chip seals can be done by either paying for the materials in unit costs, or for the completed chip seal by area of pavement sealed.

Commentary

The advantage of payment by the square yard for a completed chip seal is simplicity if the area is easily defined. The disadvantage is that an incentive is created to reduce material quantities. Reduced asphalt emulsion quantities can lead to chip loss and vehicle damage.

A. Payment by Unit Price

The Agency will pay for accepted quantities at the contract price as follows:

1. Payment for the accepted quantity of emulsified asphalt and aggregate for chip seal (including any required additives) at the contract bid price of measure is compensation in full for all costs of furnishing and applying the material as specified.

2. Payment will be made in accordance with the schedule set forth below at the Contract bid price for the specified unit of measure.

Item No.	***Item***	***Unit***
State ##	Emulsified asphalt for chip seal……	Gallon
State ##	Aggregate for chip seal……	Tons
State ##	Diluted emulsion for fog seal, if used	Gallon

Such payment is full compensation for furnishing all materials, equipment, labor, and incidentals to complete the work as specified.

B. Payment for Completed Chip Seal

A. Payment for the accepted quantity of the chip seal at the Contract bid unit price of measure is compensation in full for all costs of furnishing and applying the material as specified, including cleaning the existing pavement, stationing, purchase of aggregate, delivery of aggregate, all labor, equipment, and materials necessary for the placement of the chip seal for full lane coverage, sweeping of any loose aggregate after construction and other requirements as specified.

B. Payment will be made in accordance with the schedule set forth below at the Contract bid price for the specified unit of measure.

Item No.	***Item***	***Unit***
State ##	Chip seal…….	Square Yard
State ##	Diluted emulsion for fog seal, if used	Gallon

Such payment is full compensation for furnishing all materials, equipment, labor, and incidentals to complete the work as specified.

ATTACHMENT 2 – CONSTRUCTION GUIDE SPECIFICATIONS FOR HOT ASPHALT CHIP SEALS

"*These Guide Specifications are the recommendation of the research for NCHRP Project 14-37 that was conducted by Shuler Consultants, LLC. The Guide Specifications have not been approved by NCHRP or any AASHTO committee; nor have they been formally accepted for the AASHTO specifications*".

SECTION 407
HOT APPLIED CHIP SEAL

407.01 Description

This guide specification is intended to provide information needed for owners or contractors to construct hot applied asphalt chip seals. A hot applied asphalt chip seal is the application of hot applied asphalt binder, followed immediately by an application of a single layer of pre-coated aggregate chips.

This guide specification refers to quality requirements for materials and a design method for chip seals available in other AASHTO documents. However, the main purpose is to provide guidance for the construction of hot applied asphalt chip seals applied in one layer.

Commentaries are included within the text of the Guide in places where added emphasis is needed to explain the section being discussed or when there are options to be considered by the user of the Guide, or, as sources of additional information. An example follows:

Commentary
This Guide covers construction of single application chip seals. If this process is repeated with another application of hot asphalt and another layer of cover aggregate, the process is known as a double chip seal. A triple chip seal would require yet another application of hot asphalt and cover aggregate. Other terms have been used referring to chip seals such as 'seal coat', 'surface treatment', 'surface seal', 'surface dressing', 'sprayed seal', and others. Sometimes, a fog seal is applied over the completed chip seal.

A. Referenced Documents

1. AASHTO Standards:
   - M 140, Emulsified Asphalt for fog seal
   - AASHTO M 320, Standard Specification for Performance-Graded Asphalt Binder.
   - M-332, Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test
   - T 27, Sieve Analysis of Fine and Coarse Aggregates
   - R-66, Sampling Bituminous Materials
   - T 96, Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine
   - T 301, Elastic Recovery Test of Asphalt Materials by Means of a Ductilometer
   - T 335, Standard Method of Test for Determining the Percentage of Fracture in Coarse Aggregate

2. ASTM Standards:
   - D 5624, Standard Practice for Determining the Transverse-Aggregate Spread Rate for Surface Treatment Applications
   - D 6114, Specification for Asphalt Rubber Binder
   - D 7564, Standard practice for Construction of Asphalt Rubber Cape Seal
   - D 7741, Standard Test Method of Apparent Viscosity of Asphalt Rubber or other Asphalt Binders by Using a Rotational Hand Held Viscometer

3. Other:
   - Federal Lands Highway, FLH T508, Flakiness Index Value

B. Terminology

Three broad classes of binders are used in hot applied chip seals. They include asphalt rubber, rubber modified asphalt, and performance graded binders. The latter two are PG graded.

1. Asphalt-Rubber Binder

a. a blend of coarse crumb rubber and an asphalt binder, meeting the requirements of ASTM D-6114. The binder must include at least 15% crumb rubber and can be as high as 22%.

2. Rubber Modified Asphalt

a. a blend of fine rubber and an asphalt binder mixed at an asphalt terminal. The binder may also include polymers. This product is also referred to as a terminal blend. This product includes a minimum of 5% crumb rubber, but can contain as much as 18%. There is no national specification for these products

3. Performance Graded Hot Applied Binders

a. these binders shall meet the requirements of AASHTO M 320. An unmodified or a modified binder could be used in a chip seal application.

4. Emulsions for fog seals, if used

a. CSS-1h – a cationic emulsified asphalt that is slow setting and has a residual binder residue with lower penetration than CSS-1.

b. SS-1h – an anionic emulsified asphalt that is slow setting and has a residual binder residue with lower penetration than SS-1.

407.02 MATERIAL

A. Asphalt Binder

1. Asphalt Rubber Binder– This shall meet all the requirements of ASTM D6114. It is a combination of: Asphalt binder, Asphalt modifier, and Crumb Rubber Modifier (CRM). If used, the asphalt modifier (or extender oil) shall be between 2.5 to 6.0 percent by weight of the asphalt binder in the asphalt-rubber binder.

   <u>Commentary</u>
   The California specification for CRM must be 76 ± 2 percent by weight scrap tire crumb rubber and 24 ± 2 percent by weight high natural crumb rubber (high nat.). The asphalt-rubber binder supplier determines the exact percentage of the extender oil and the CRM.

The asphalt binder (and if used the asphalt modifier) must be combined with the CRM at the asphalt-rubber binder production site. The asphalt binder and asphalt modifier blend must be from 350 to 425ºF when the CRM is added. Combined ingredients must be allowed to react at least 45 minutes at temperatures from 350 to 400º F except the temperature shall not be higher than 10ºF below the actual flashpoint of the asphalt-rubber binder. After reacting for at least 45 minutes, the asphalt-rubber binder must comply with the requirements shown in ASTM D 6114.

2. Rubber Modified Asphalt - This shall include PG asphalt with a minimum of 5-10% scrap tire rubber and 2% Styrene Butadiene Styrene (SBS) block copolymer blended at a terminal. The binder needs to meet the requirements of AASHTO M 320 and exhibit an elastic recovery greater than 60% when tested in accordance of AASHTO T 301. The actual PG grading of the rubberized asphalt would be per the design or as specified.

   Commentary
   In Arizona, Texas and California, this product is referred to as a terminal blend. The CRM content may vary from 5% to 18% or more.

3. *PG Asphalt -These binders shall meet the requirements of AASHTO M 320 or 322 with exhibit elastic recovery greater than or equal to 60% when tested in accordance with AASHTO T 301. The performance grade to be used shall be determined by the Engineer or Contractor.*

   Commentary
   Both polymer modified and unmodified binders can be used. Agencies shall designate the grade commonly used in their state.

i. Granulated Rubber

Crumb rubber shall be vulcanized rubber using an ambient temperature processing of scrap tires. Granulated rubber shall meet the gradations given in Table 1. Type I does not contain any extender oil or high natural rubber while Type II does contain extender oil.

Table 1- Granulated Rubber Gradations

Asphalt Rubber, Type I		**Asphalt Rubber, Type II**		**Rubber Modified Asphalt**
Sieve size	% passing	Scrap Tire	High Natural	% passing
#10	100	98-100	100	
#16	75-100	45-75	95-100	

#30	30-60	2-20	35-85	100
#50	5-30	0-2	10-30	
#200	0-5	0	0-1	0-10

The use of rubber from multiple sources is acceptable provided that the overall blend of rubber meets the specified gradation. Certification of the gradation and quality of the rubber shall be provided by the rubber supplier.

Commentary
The gradations used vary between states. These are guides that should be used if a state has not used hot applied chip seals. Type I is used in Arizona and Type II is used in California. Type II contains extender oils and contains 25% high natural and 75% scrap rubber.

ii. Aggregate

Chip seal aggregate shall be durable, uniform in quality and free from wood, bark, roots and other deleterious materials. Gradations and quality requirements are specified in Table 2 where all percentages are by weight. The aggregate size to be used will be as shown in the plans or other contract documents. Gradation A is for asphalt rubber while gradation B is for rubberized and performance grade asphalts. All aggregate retained on the 4.75 mm (No. 4) screen shall be crushed by mechanical means and meet the requirements shown in Table 3.

Table 2 – Chip Seal Aggregate Gradations

Sieve Size	A Asphalt Rubber	B Rubber Modified and PG Asphalts
¾”	100	
½”	95-100	100
3/8”	70-100	70-100
No. 4	0-15	0-15
No. 8	0-5	0-5
No. 16		
No. 30		
No. 50		
No. 200	0-1	0-1

Table 3 – Fracture and Abrasion Requirements

Property	Chip Seal Class*		
	I	II	III
Fracture, 1 Face,% min T335	70	85	95
Fracture, 2 Faces, % min T335	60	80	90
Los Angeles Abrasion, max. % loss, T 96	37	35	30
Flakiness Index, max. % FLH T508	25	20	17

* Class I is less than 500 AADT, II is 501 to 5000 AADT, III is greater than 5000 AADT

Prior to placing, the aggregate shall be uniformly pre-coated with a PG Grade Asphalt which meets the specification M 320 or 322 and is typically used by the agency based on climate. The pre-coating shall be accomplished by mixing at a central hot mix plant. The binder shall have a minimum temperature of 250º F at the time of pre-coating with approximately 0.40 to 0.80 percent asphalt cement, by weight of the aggregate. The end result shall be a dust free aggregate.

407.03 CONSTRUCTION

A. *Weather Limitations.* Construct chip seal per the following conditions:

1. Ambient or pavement surface temperatures shall be 50ºFand rising.
2. Suspend chip sealing if the pavement surface temperature exceeds 140F.
3. The road surface shall be dry and swept clean of dirt and debris.

B. *Mix Design*

1. Asphalt Rubber. Design of the rubberized asphalt chip seal surface treatment shall be the responsibility of the contractor. The application rate of the asphalt rubber shall be from 0.50 to 0.70 gallons per square yard. The application rate of the pre-coated cover aggregate shall be between 30 to 40 pounds per square yard. No later than two weeks before work commences, the contractor shall submit for the approval of the Engineer the chip seal design, specifying the additives for the asphalt rubber, the binder profile for the product showing the physical properties, application rate of the asphalt rubber, and the source, composition, and application rate of the cover aggregate. Samples of each material shall be included with the submittal. Once the materials and design are approved, no substitution will be permitted unless approved by the Engineer. The supplier of the binder shall certify the percent of granulated rubber in the blend and if the blend includes an extender oil. The temperature of the asphalt cement shall be between 350 and 425 F at the time the CRM is added. The components shall be mixed together in the blender and reacted for a minimum of 1 hour. The temperature of the binder shall be above 350F during the reaction period.

2. Rubber Modified Asphalt (aka terminal blends). The application rate of the binder will be 0.50 ± 0.10 gallons per square yard. The Engineer will specify the exact application rate based on the aggregate texture and absorption and the existing surface condition. Aggregate application rates shall range between 25-35 pounds per square yard.

3. Performance graded asphalts. The application rate of the binder will be 0.30 ± 0.10 gallons per square yard. The Engineer will specify the exact rate based on the surface and the characteristics of the aggregate material. Aggregate application rates shall be 20 to 30 pounds per square yard for conventional aggregates or as directed by the Engineer.

C. Preconstruction Meeting

Coordinate a preconstruction meeting prior to construction with the engineer to discuss the following topics:

1. construction process
2. quality control plan, required to be submitted
3. mix design, required to be submitted
4. materials control
5. materials measurement
6. equipment calibration, required to be submitted
7. traffic control plan
8. equipment/process overview
9. inspection
10. test strip
11. unique project conditions
12. project documentation
13. expectations

D. Road Surface Preparations

1. Cleaning Pavement

Clean the roadway surface by sweeping no more than 30 minutes prior to application of the hot asphalt and chips. However, this 30-minute window may be extended if authorized by the engineer in cases where extending the time does not jeopardize a clean surface prior to chip seal operations. Sweep the pavement with a motorized broom to remove loose material. Clean depressions not reached by the motorized broom with a hand broom. Clean the outer edges of the pavement to be sealed including an adjacent paved shoulder.

2. Protecting Accessories

Cover utility castings (manholes, gate valve covers, catch basins, sensors, etc.) to prevent coating with asphalt binder. Suitable covering includes plywood disks, Kraft paper, roofing felt or other approved methods. Remove the protective coverings before opening the road to traffic.

3. Stripe Removal

Thermoplastic pavement markings shall be removed by grinding or other approved methods prior to chip seal operations. Other pavement markings may be left in place.

E. Equipment

1. Blending Unit

A mechanical blender for proper proportioning and thorough mixing of the asphalt-cement and granulated rubber is required to produce the asphalt-rubber binder. This unit shall be equipped with: asphalt mass flow meter (gallons); a flow rate meter (gallons per minute); a positive displacement auger to feed the rubber properly to the mixing chamber at the specified rate; and a static motionless mixer or a blending tank with a high speed mixer. The blender shall have a separate asphalt binder feed pump and finished product pump to maximize production, and shall be capable of providing 100% proportional blend at any given time during the blending cycle; supporting documentation from the manufacturer shall be submitted to the Engineer.

A blending unit shall not be required for terminal blends.

2. Pressure Distributor

The pressure distributor shall be self-propelled with a ground speed control device interconnected with the asphalt pump such that the specified application rate will be supplied at any speed. The pressure distributor shall be capable of maintaining the asphalt binder at the specified temperature. For asphalt rubber applications, the pressure distributor shall be equipped with internal mixing capabilities. The spray bar nozzles shall produce a uniform triple lap application fan spray, and the shutoff shall be instantaneous, with no dripping. All nozzles shall be oriented at the same angle between 15° and 30° using the wrench supplied by the distributor manufacturer. Each pressure distributor shall be capable of maintaining the specified application rate within +/- 0.015 gal/yd^2 for each distributor load.

3. Aggregate Spreader

A variable width, self-propelled mechanical type aggregate spreader with a computerized spread control capable of distributing the aggregate uniformly to the required width and at the designed rate shall be used. The spreader shall be a self-propelled type mounted on pneumatic-tired wheels capable of an application width of 14 feet or greater.

4. Pneumatic-Tire Rollers

   A minimum of three (3) self- propelled pneumatic-tire rollers capable of ballast loading, either with water or sand to allow the weight of the machine to be varied from 6 to 12 tons to achieve a minimum contact pressure of 80 lbs /in^2 shall be used. The alignment of the axles shall be such the rear axle tires, when inflated to the proper pressure, can compact the voids untouched by the front-axle tire. All tires shall be as supplied by the roller manufacturer. Width of the rollers shall exceed 60 inches.

   Commentary
   Steel-wheel rollers have been used as the final roller on some chip seals with success. The advantage is a more even final elevation. This produces fewer prominent chip edges extruding above the surface which can be susceptible to snow plow damage. The disadvantage of steel-wheel rollers is the potential for crushing of aggregate chips that cannot withstand the high stress imparted at the steel roll-chip interface. Therefore, if used, steel rollers should be limited to 5 tons. Vibration shall not be used if the rollers are so equipped.

5. Brooms

   Motorized brooms with a positive means of controlling vertical pressure shall be used to clean the road surface prior to spraying the asphalt binder. Plastic bristle brooms are required to remove loose aggregate after chip sealing.

   Commentary
   Vacuum brooms are preferred in urban or residential areas, but push brooms are acceptable in rural areas where chips being scattered off the roadway do not pose a hazard to pedestrians or vehicles.

6. Trucks

   Asphalt Rubber Binder - All trucks for the asphalt rubber binder shall be equipped with internal agitation and heating capabilities. Trucks for the other binder types do not require these capabilities.

   Aggregate - Trucks for hauling cover aggregate shall be rear discharge equipped with a device to lock onto the hitch at the rear of the aggregate spreader to prevent spillage. Sufficient hauling vehicles shall be available to ensure continuous operations of the distributor and the aggregate spreader.

F. Equipment Calibration

The contractor shall provide proof of calibration of the pressure distributor and the aggregate spreader. Calibration shall be repeated once per week or after five full days of chip seal operations have been completed. The contractor shall submit the results of the calibration procedure to the Engineer.

Flow from each nozzle in the pressure distributor must be within +/- 10 percent of the average flow of all nozzles as measured by the procedure described below.

Uniformity of the aggregate applied transverse to the pavement centerline shall be judged using ASTM D5624, "Determining the Transverse Aggregate Spread Rate for Surface Treatment Applications". Tolerance for each pad tested for transverse spread rate shall be +/- 10 percent of the average of the total transverse rate.

Commentary
Calibration is very important to assure the quantity of asphalt and chips applied to the pavement is correct. Although many modern asphalt distributors and aggregate spreaders are computer controlled, calibration is required to tell the computer how much asphalt is being applied. This quantity must be checked prior to spraying asphalt and spreading chips and checked against the quantity the computer (if the distributor is so equipped) indicates is being applied.

1. Pressure Distributor
   All nozzles shall be the same size, provide the same flow rate, be oriented in the same direction, and be the same distance above the pavement.

   Commentary: The distributor truck applies emulsified asphalt to the pavement surface. This application must be done uniformly both transverse and longitudinal to the centerline of the pavement.

   When lower application rates are determined necessary or shown in the plans, smaller nozzles shall be inserted in the spray bar where the asphalt rate is reduced.

   Commentary: Due to minor rutting or heavy truck traffic, it may be desirable to reduce the asphalt application rate in the wheel paths.

   a. Nozzle Angle
   Nozzles shall be positioned at an angle of 15 to 30 degrees from the horizontal of the spray bar in accordance with the spray bar manufacturers recommendation. All nozzles shall spray a full fan except for the right and left edge nozzles. The right and left edge nozzle shall be adjusted to a half fan such that the spray stays to the inside of the spray bar.

   Commentary: The next step in calibrating the distributor is adjustment of the spray bar nozzle angles. Each nozzle has a slot cut across the face of the nozzle. When the nozzle

is threaded into the spray bar, the slot should all be positioned at an angle of 15 to 30 degrees to the direction of the spray bar as shown in Figure 1. This angle provides the best position for achieving uniformity in the spray and the triple overlap coverage. The angle should be adjusted using the wrench supplied with the distributor. This wrench is designed when used properly to set the correct angles for each nozzle. Any wrench that fits the hexagonal nozzle can adjust the nozzle angle but correctness of the angle would have to be visually verified.

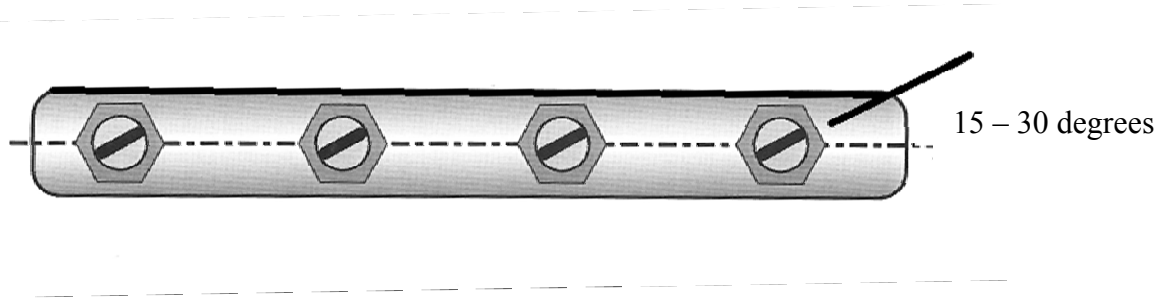

Figure 1- Spray Bar Nozzle Orientation in Spray Bar

The angle at which the nozzles are positioned shall be adjusted using the wrench supplied with the distributor.

However, in cases where this wrench is unavailable, a wrench that fits the hexagonal nozzle will suffice but the angle must be judged visually.
All nozzles fitted to the spray bar shall be full fan nozzles except for the right and left edge nozzles. These nozzles shall be half fan nozzles adjusted so the spray from the nozzle remains to the inside of the spray bar.

b. Spray Bar Height

The spray bar height must be adjusted so that the asphalt provides exactly two or three overlaps across the entire spray width.

Commentary
Streaking of the asphalt will occur if the spray bar is set too high or too low as shown in Figures 2 and 3.

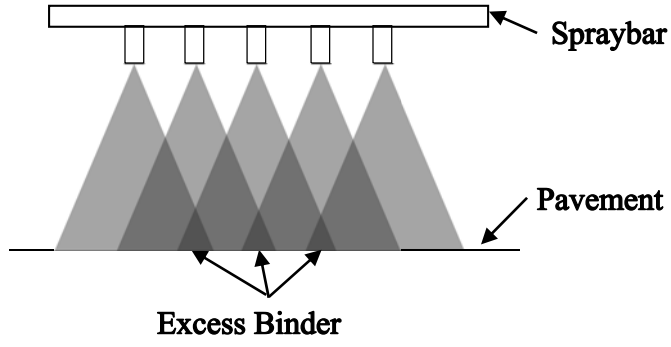

Figure 2- Streaks with Spray Bar Too High for Double Overlap

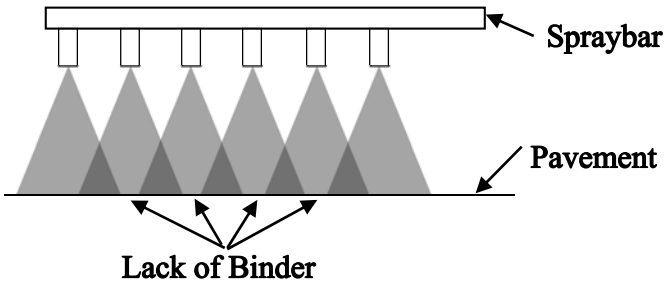

Figure 3 - Streaks With Spray Bar Too Low for Double Overlap

To avoid this streaking the bar must be adjusted to the correct height. This adjustment process is accomplished by shutting off nozzles to determine where the spray pattern contacts the pavement as shown in Figures 4 and 5.

Bar Height Adjustment to Achieve Double Lap
Every second nozzle shall be turned off when a double lap application is desired as shown in Figure 4. The distributor operator shall spray asphalt onto the pavement surface for as short an interval as possible while an observer watches where the asphalt hits the pavement from each nozzle left open. If there is overlap of asphalt from adjacent nozzles, the bar is too low. If there is a lack of asphalt from adjacent nozzles, the bar is too high.

Once it is confirmed the bar height is correct, the nozzles that were turned off can be turned back on and a double application of asphalt will result when spraying resumes.

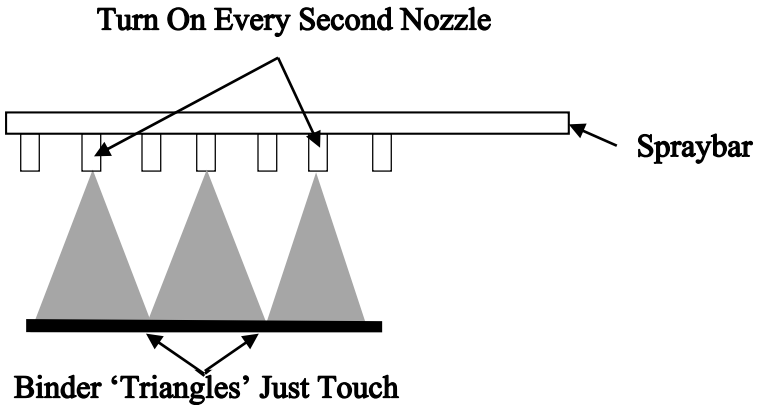

Figure 4 - Adjustment of Spray Bar Height for Double Overlap

<u>Triple Lap Application Bar Height Adjustment</u>
Every third nozzle shall be turned off when a triple lap application is desired as shown in Figure 5. The distributor operator shall spray asphalt onto the pavement surface for as short an interval as possible while an observer watches where the asphalt hits the pavement from each nozzle left open. If there is overlap of asphalt from adjacent nozzles, the bar is too low. If there is a lack of asphalt from adjacent nozzles, the bar is too high.

Once it is confirmed the bar height is correct, the nozzles that were turned off can be turned back on and a double application of asphalt will result when spraying resumes.

As the distributor empties during spraying, the bar height will rise. However, this is not usually enough to cause significant streaking worth adjustment of the spray bar.

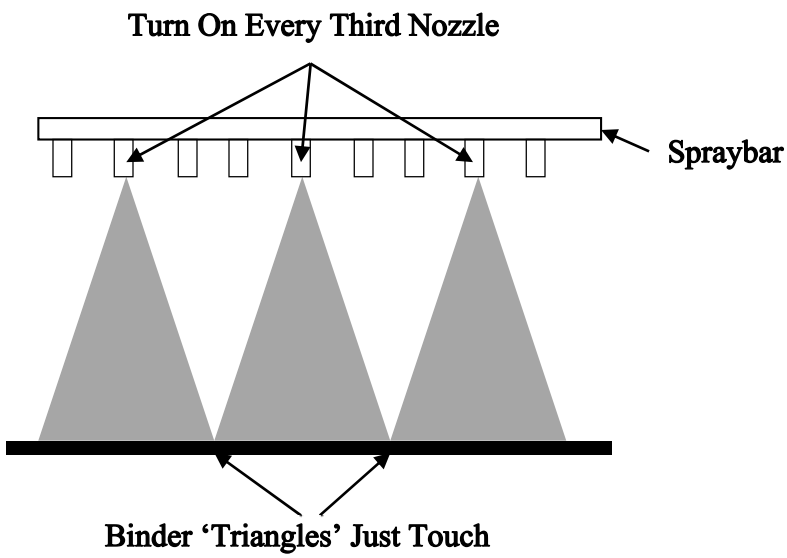

Figure 5 - Adjustment of Spray Bar Height for Triple Overlap

c. Transverse Flow Rate

The flow rate across the spray bar shall be uniform with each nozzle spraying within +/-10 percent of the average flow rate.

<u>Commentary</u>
This is done by measuring the width of the slot in the nozzle and by measuring the orifice diameter. Also, some nozzles are labeled by the manufacturer.

Manufacturers supply a list of nozzles in the owner's document describing which nozzles shall be used for various application rates or on a placard mounted on the equipment.

However, nozzles of the same apparent size have been measured with different flow rates. Therefore, it is recommended that all nozzles be checked for flow rate before chip seal operations begin. This is easily accomplished by fabricating a flow apparatus. This apparatus consists of a pipe to which each nozzle can be fitted, in turn, on one end and a water source can be fitted to the other end. The flow of water through each nozzle shall be measured by filling a one gallon container in a measured period. This shall be done for each nozzle to be used on the project. If the flow rate of any of the nozzles is greater than 10 percent of the average of all the nozzles to be used these nozzles shall be discarded, or modified to flow within the 10 percent tolerance.

Determination of uniform lateral flow from the spray bar is determined by collecting a measured volume of asphalt in containers placed under each nozzle. This process is practical using standard 6-inch by 12-inch concrete cylinder molds lined with one-gallon zip-lock freezer bags. The cylinder molds can be reused and the zip lock bags discarded appropriately with the contents.

d. Longitudinal Flow Rate

The longitudinal spray rate shall be accomplished by measuring the volume of asphalt in the distributor before and after spraying enough asphalt to reduce the volume of asphalt in the distributor by 70 to 90 percent.

Commentary

The longitudinal flow rate must be measured with all nozzles inserted in the distributor bar. First, the quantity of emulsified asphalt in the truck must be determined. Although there is a volume indicator on the rear of most modern distributors, these are not calibrated in small enough increments to be of use for longitudinal flow rate calibration and shall not be used for this purpose. Instead, the dip stick supplied with the distributor must be used. This dip stick is usually carried on the top of the tank near the inspection hatch. Prior to shooting asphalt, take a volume reading with the dip stick.

Pay attention to how the dipstick is used. Many dipsticks are not intended to be submerged in the asphalt, but instead, are inserted into the top of the tank only until the tip of the dipstick touches the surface of the asphalt. Then, the volume in the tank is read by indexing the top of the inspection cover to the reading on the dipstick.

Record this volume as 'beginning volume'. Set up the truck to shoot asphalt and shoot a minimum of 3000 feet by 12 feet of asphalt at the design rate using the gallon per minute pump flow volume and truck speed required by the

manufacturer to attain this flow rate. Take a second dip stick reading. Record this reading as 'ending volume'. Subtract 'ending volume' from 'beginning volume' and record this as 'volume used'. Determine the area of asphalt sprayed. Divide 'volume used' by the area sprayed in square yards. This is the gallons per square yard applied to the pavement. This value shall then be compared to the distributor computer, if equipped, to evaluate the accuracy of the computer. A correction factor may then be applied to the computer output, if needed, and used for the remainder of the day. This calibration shall be accomplished each day.

An example of this calibration is presented below:

Given:

1800-gallon capacity asphalt distributor
12-foot-wide spray width
Trial spray distance = 3630 feet
0.32 gallon/yd^2 design spray rate
Dipstick reading beginning of shot = 1765 gallons
Dipstick reading end of shot = 265 gallons

Calculations:

4. *Check to see if enough volume shot. 1765-265=1500 gallons*
5. *1500/1765 = 85 percent >70% and <90%. OK, enough applied to be valid*
6. *Calculate spray rate = 1500 gallons / (12 x 3630/3) = 0.31 gallons/yd^2*

Therefore, decrease distributor speed, or recalibrate computer and re-check.

3. Aggregate Chip Spreader

a. *Transverse Spread Rate*

<u>Commentary</u>
Various methods of calibrating this equipment have been used and the ASTM D5624 procedure can be effective. However, a visual assessment of the lateral distribution of chips is a good place to start the process since non-uniform distribution can easily be seen. The veil of chips deposited on the pavement from the spreader box can be viewed from behind with the spreader moving away from the observer or from the front. Either position for the observer is adequate for viewing how uniform the veil of chips is falling out of the spreader box. However, viewing from either front quarter affords the observer a better view of the entire spreader width and is, of course, safer than directly in front of the spreader. Any variation in light passing through the veil of chips indicates variation in application rate. More light means a lack of chips. Variation in light means the machine shall be stopped, the gates on the spreader contributing to the non-uniformity adjusted and the trial rerun. This procedure provides adjustment to

the transverse spread rate. Then, to obtain an objective means of measuring the amount of chips being deposited, ASTM D5624, "Determining the Transverse Aggregate Spread Rate for Surface Treatment Applications" is a good procedure to use.

b. Longitudinal Spread Rate

Commentary
Once the transverse spread rate is adjusted the longitudinal rate can be adjusted. This is also done visually, at first. Begin spreading chips into the fresh asphalt when a few chips cast by hand stick to the asphalt and do not roll over. This shall be done well before the asphalt begins to cool, but not immediately after spraying unless temperature and wind demand it.

The application rate of the chips shall be similar to the design rate. This is a rate where immediately upon dropping the chips, the appearance of the surface has some asphalt showing between the chips. In fact, the chip quantity should seem somewhat inadequate. The chip spread rate should not be low enough to cause pickup problems on rubber-tire rollers. However, the rate should be such that a small decrease in rate would cause pickup. Asphalt should be visible between the chips upon dropping the chips and before rolling. If all asphalt is covered before rolling, there is an excess of chips and the rate shall be reduced. It is the responsibility of the construction superintendent to achieve this application rate.

Evaluating the quantity of chips being placed is important after the rate is established. This provides a quantitative baseline for future work. The best method to accomplish this evaluation is by weighing the chip spreader before and after applying the chips and calculating the spread rate based on the area covered. This is often not practical. Therefore, a suitable alternative includes estimating the quantity of chips spread over a known area by knowing the weight of each transport truck supplying the spreader and dividing the estimated weight of chips spread by the area covered for that load.
An example follows:

Given:
Trucks loading the chip spreader are 12-ton capacity tandem dumps
12-foot-wide pavement
28 pounds per square yard design spread rate

Calculations:

6. Check Truck No. 1
a. Load = 23,803 lbs.
b. Spreader distance = 213 feet
c. Rate = 23,803/213x12/3 = 27.9 lbs./yd^2
7. Check Truck No. 2

a. Load = 23,921 lbs.
b. Spreader distance = 211 feet
c. Rate = 23,921/211 x 12/3 = 28.3 lbs./yd^2
8. Check Truck No. 3
a. Load = 23,848 lbs.
b. Spreader distance = 213 feet
c. Rate = 23,848/213 x 12/3 = 28.0 lbs./yd^2
9. Average Rate = (27.9 + 28.3 + 28.0) / 3 = 28.1 lbs./yd^2
10. No adjustment needed since measured rate is within 1 percent of design.

Compensation for moisture on chips must be considered when calibrating chip spreaders. The above example indicates no adjustment is needed since the measured spread rate is within 0.10 lbs/yd^2 of the design spread rate. However, if the chips above had contained as much as 1.02 percent moisture that was unaccounted for, the application rate would have been too low.

G. Test Strip

A test strip shall be constructed on or near the project site. Construct the test strip under similar placement conditions of time of day, temperature, and humidity as expected for the duration of the project. The test strip shall be a minimum of 300 feet in length and shall be constructed with the job mix proportions, materials, and equipment to be used on the project. Adjustments to the mixture formula shall be permitted provided they do not exceed the values stated in the mix design. The Agency shall evaluate the test strip to determine whether project specifications are met. If specifications are not met, additional test strips will be constructed until specifications are met, at no additional cost to the Agency.

H. Application of Asphalt Binder

Apply the asphalt binder at the rate determined by the design. This rate shall be within +/- 5% of the chip seal design rate. After applying the binder, place the cover aggregate at the design application rate. Adjust the rate of application, if necessary, so that some binder can be seen between the aggregate chips, but not so much that aggregate chips adhere to the pneumatic rollers. Inspect the aggregate in the wheel paths for proper embedment. Embedment shall be 50 to 60 percent after rolling. Make additional adjustments to the rate of application during the project, if needed.

The temperature of the binder asphalt at the time of application shall be as recommended by the contractor and approved by the Engineer. Recommendations for application temperatures are given in Table 4.

Table 4- Suggested Application Temperatures as a Function of Binder Type

Binder Type	Minimum Application Temperature, ^{O}F
Asphalt Rubber	375
Rubber Modified Asphalt	350
PG asphalt polymer modified	325
PG asphalt non-modified	275

Commentary
If the temperature is lower than 275 F, there is risk of less material will be applied than desired due to high viscosity.

The longitudinal construction joint for a single course chip seal must coincide with the painted lane line or at the outside edge of the shoulder. There shall be no overlap of the longitudinal construction joint for a single application chip seal.

I. Application of Cover Aggregate

Aggregates shall be applied immediately after applying the hot asphalt at the design rate using uniformly pre-coated aggregates heated to 175 to 225 F at the time of placement. The longitudinal spread rate shall be measured by placing one measuring pad in front of the spreader at 500 foot intervals for 1,500 feet.

The speed of the spreader shall be restricted to prevent the aggregates from rolling. Starting and stopping of the spreader shall be minimized. The edges of the aggregate application shall be sharply defined. Previously used aggregates from sweeping shall not be returned to the stockpile or the spreader for reuse

Commentary
Although a design was done to determine the chip application rate, adjustments are almost always needed in the field. This should be done during the first day of construction to make sure the chip quantity is correct. This is best done by observing the appearance of the chips after they have been dropped into the asphalt, but before rolling. Some asphalt should be visible between many of the chips. If asphalt cannot be seen between the chips, the chip rate is too high. Conversely, too much asphalt showing through between the chips will cause pickup on rubber tires.

J. Transverse Paper Joints

When beginning a new application of the chip seal transversely abutting the previously placed chip seal a transverse paper joint shall be used so excess asphalt and chips are not placed at the joint. The transverse paper joint shall be formed by placing 36-inch-wide Kraft paper on top of the previously applied chip seal so the edge of the paper aligns with the joint

that will be formed when the previously placed chip seal meets the newly applied chip seal. The asphalt distributor shall begin applying asphalt binder by starting the application on top of the Kraft paper. After the distributor moves forward and over the joint the paper shall be removed.

Commentary
Ideally, the paper should also be placed at the end of the distributor shot, as well. This creates a clean, edge with the correct asphalt and chip quantity at the joint. Where the paper should be placed is calculated based on the asphalt shot rate and the quantity of asphalt in the distributor. The distance the distributor travels before encountering the paper and turning off the bar should be approximately equivalent to 80 percent of the distributor tank volume. This assures the distributor does not spray until empty which can result in less asphalt applied than desired at the end of the shot.

K. Rolling Operations

Complete the first roller pass as soon as possible but not longer than two minutes after applying the aggregate. Proceed in a longitudinal direction at a speed less than or equal to 5 to 7 miles per hour. Three complete roller passes of the aggregate chips are required. One pass is defined as the roller moving over the aggregates in a single direction. Ensure the rolling is completed quickly enough to embed the aggregate, before the binder cools and no longer than 15 minutes after the binder is applied. Position the rollers in echelon so the entire width of the pavement lane is covered in one pass of the rollers.

Commentary
If desired, final rolling may be accomplished using the steel wheel roller in one pass

L. Sweeping

The removal of loose cover material shall commence after final rolling is completed such that the cover aggregate is not displaced and the asphalt surface is not damaged.

M. Traffic Control

The treated roadway shall not be used by the contractor or its agents until it has been established by the Engineer that the roadway will not be damaged or marred under the action of traffic. The contractor shall use signs or other traffic control devices to prevent traffic operating on the fresh chip seal. Any damage to the hot applied chip seal shall be repaired by the Contractor at no additional cost to the agency.

N. Protection of Motor Vehicles

The Contractor shall be responsible for claims of damage to vehicles until the roadways and shoulders have been swept free of loose aggregate and permanent markings have been applied. If permanent pavement markings are to be applied by Agency forces, the Contractor's responsibility ends after completion of the chip seal.

O. Fog Seal

If, in accordance with the plans, a fog seal is applied to the surface of the completed chip seal, spray the fog seal after sweeping and before placement of permanent pavement markings, but not sooner than 24 hours after final rolling. Refer to the AASHTO Construction Guide Specification for Fog Seals in the section for application over chip seals for specific requirements.

Commentary
Fog seals are applied to the surface of completed chip seals for two reasons: 1) The dark color provides more contrast to pavement markings, 2) the fog seal provides a slight increase in binder residue to increase chip retention.
A fog seal may also be applied to recent hot mix asphalt patches in the pavement to be chip sealed. These fresh hot mix patches can be more absorptive than the surrounding pavement due to higher air void content. The fog seal helps prevent the new chip seal asphalt from being absorbed into the substrate unevenly.

P. Sequence of Work

Construct the chip seal so that adjacent lanes are sealed on the same day when possible. If the adjacent lane(s) has not been sealed sweep all loose chips from the unsealed lane(s) before traffic is allowed on the surface without traffic control. The permanent pavement markings shall not be placed for three days after placing the fog seal for water borne pavement marking or ten days for other types of markings.

Commentary
The chip seal will usually cure within 24 hours under dry conditions and temperatures above 60F. The fog seal can be applied after the chip seal coat is cured. The fog seal will usually cure within 2 hours under dry conditions and temperatures above 60F. Interim pavement markings can be placed after the fog seal cures.

Q. Quality Control

1. General

The Contractor is responsible for quality control (QC) sampling and testing and shall submit a QC plan including materials and procedures for verifying the quality of the chip

seal aggregates and emulsified asphalt(s). The Contractor's QC plan shall include but is not limited to sampling, testing, inspection, monitoring, documentation, and corrective action procedures during transport, stockpiling and placement operations.

A written Quality Control Plan (QCP) shall be developed which details the Contractors' QC program that meets the requirements of these specifications. The QCP shall be contract specific and signed by the Contractors' representative. Chip seal construction shall not proceed without Agency approval of the QCP and QC personnel present on the project. Failure to comply with these provisions will result in shutdown of the operations until such time as the Contractor's operations are in compliance.

2. Personnel

The QC staff shall include the following as a minimum:

a. QCP Administrator – The person with overall responsibility of the QCP
b. QCP Manager – The person responsible for the execution of the QCP and liaison with the Agency. This person shall be on the project, and have the authority to stop or suspend construction operations.
c. QC Technicians – The person(s) responsible for conducting QC tests and inspection to implement the QCP. QC technicians shall have Level 2 Aggregate Testing Certification from the American Concrete Institute (ACI) or other accrediting body approved by the Agency.
d. Certified Crew Members – Three crew members (job foreman, aggregate spreader operator and asphalt distributor operator), at a minimum, shall possess a valid chip seal certification and be on the project at all times the chip seal is being constructed. The chip seal certification is administered by the National Center for Pavement Preservation (NCPP) on behalf of AASHTO TSP[2] (Transportation Services Preservation Program).

3. Testing Facilities and Equipment

The Contractor shall provide the name of the laboratory conducting QC tests. The laboratory shall maintain accreditation by the AASHTO Accreditation Program (AAP) for all tests within the relevant scope of testing, or other accrediting body approved by the agency. Sampling, testing and measuring devices shall meet the requirements of the specified standards and test methods. The laboratory shall maintain records of the calibration and maintenance of all sampling, testing and measuring equipment.

4. Materials Testing

Chip seal aggregates and asphalt binders shall be tested for compliance with the specifications. Only asphalt binders from certified or approved sources shall be allowed.

a. Asphalt Rubber

   i. Sampling shall be completed at the point of manufacture. Testing and reporting shall be completed on these samples. As a minimum, the following data shall be reported for all samples:

   ii. Total quantity of binder in tons

   iii. Tons and percentage of ground tire rubber based on total asphalt rubber binder

   iv. ASTM D-6114 certified test results

b. Rubberized asphalt.

   i. Only asphalt binder from a certified or approved source is allowed for use.

   ii. Verify the binder meets specifications by obtaining a certificate of compliance for each load provided

c. Performance Graded asphalts.

   i. Only asphalt binder from a certified or approved source is allowed for use.

   ii. Verify the binder meets specifications by obtaining a certificate of compliance for each load provided

d. Chip Seal Aggregate

   i. Stockpile.
   Test the aggregate gradation a minimum of once per day, or every 1500 tons, whichever is less in accordance with AASHTO T27 to determine compliance with Table 4 requirements. If the material is hauled from the production site to a temporary stockpile, test at the temporary stockpile.

   ii. Construction.
   Test the aggregate gradation from the hopper of the chip spreader a minimum of once per day, or every 1500 tons, whichever is less in accordance with AASHTO T27 to determine compliance with Table 4 requirements. The testing rate for quality values in Table 5 shall be once per source.

e. Emulsified asphalt for fog seal

   Only emulsified asphalt from certified or approved sources is allowed for use. Verify the asphalt(s) meet the specifications by obtaining certificates of compliance from the supplier.

   Verify the application rate of the emulsified asphalt by dividing the volume of emulsified asphalt used by the area chip sealed each day. Allowable variation is +/- 5% of the application rate adjusted from the design quantity. Provide material certification and quality control test results for each batch of emulsified asphalt used

on the project. Include the supplier name, plant location, asphalt grade, and batch number on all reports.

5. Calibration of Equipment and Workmanship

   Describe the equipment and methods used to calibrate the chip spreader and asphalt distributor including:
   a. Longitudinal application rates
   b. Transverse application rates

   Describe the process to be used to ensure
   a. Good workmanship including; asphalt transverse application uniformity
   b. Transverse joint construction technique
   c. Longitudinal and transverse joints construction techniques
   d. Monitoring methods for application rates to minimize bleeding, rock loss and streaking
   e. Rolling operations detailing rolling pattern and number of passes or coverages
   f. Sweeping operations and schedule
   g. Method of controlling traffic

6. Documentation

   Describe the documentation and reporting procedures for all QC activities. Include samples of all QC test forms, inspection and test reports.

7. Records and Documentation

   The Contractor shall maintain complete records of all QC tests and inspections. All QC test results shall be submitted to the Agency at the end of the contract. A material certification shall be submitted from each supplier for each batch of material delivered to the project, including test results.

   The QC records shall contain all test and inspection reports, forms and checklists, equipment calibrations, supplier material certificates, and non-conformance and corrective action reports. The QC records shall indicate the nature and number of observations made, the number and type of deficiencies found, the quantities conforming and non-conforming, and the nature of corrective action taken as appropriate for materials as well as workmanship. The QC records shall be available to the Agency at all times, and shall be retained by the contractor for the life of the contract. The Contractor's documentation procedures will be subject to approval by the Agency prior to the start of work, and to compliance checks by the Agency during the progress of the work.

8. Compliance with Specifications

The Contractor shall attest in writing to the Agency that the chip seal has been constructed in accordance with and meets the requirements of the specifications at the conclusion of the project.

R. Agency Acceptance

1. General

The Agency will conduct acceptance sampling, testing, and inspection activities to ensure material quality, correct application rates, rolling, sweeping, and traffic control are within specification requirements. These activities will be done randomly by the Agency.

2. Acceptance Activities

a. Materials Testing

i. Asphalt Binders.

Sample the first shipment and provide one sample for every 50,000 gallons (approximately 200 tons) thereafter. Testing of the binders shall be in accordance with AASHTO M320 or 322.

ii. Aggregate

Sample aggregate taken from the chip spreader hopper once per day. Samples shall be stored and tested for gradation at the discretion of the Agency. If the results vary from the requirements of Tables 2 and 3, a price reduction shall be applied per the Schedule of Price Reduction prepared by the owner agency. Price adjustments are not included in this guide since most agencies do not use them for this type of treatment.

iii. Fog Seal Emulsion

Sample the first shipment and provide one sample for every 50,000 gallons (approximately 200 tons) thereafter. Testing of emulsions shall be in accordance with AASHTO M140, M208, and M316.

b. Equipment

All equipment to be used on the project shall be evaluated by the Agency to assure it is in acceptable operating condition, calibrated correctly and shall provide the quantities of material specified.

c. Final Inspection

A final inspection shall be done to assure that no bleeding or flushing, excessive chip loss or crushed aggregate has occurred. Longitudinal and transverse joints shall be inspected to assure that no excessive overlap has occurred.

407.04 MEASUREMENT

The Engineer shall measure work acceptably completed as specified in Subsection 109.01 of the AASHTO Construction Guide Specifications and as follows:

A. When Payment is by Unit Price

1. Asphalt Binders
   Measure the asphalt binder used for the for chip seal by volume, at 60F.

2. Aggregate Chips
   Aggregate chips will be measured by the area of pavement surfaced.

   Commentary
   Chips can be paid for by the ton, as well. This is easier to verify, but results in an incentive to place more chips than necessary. Applying too many chips is poor practice and results in dislodgement of embedded chips. Also, paying by the ton will result in unnecessary additional cost.

407.05 PAYMENT

Payment for chip seals can be done by either paying for the materials in unit costs, or for the completed chip seal by area of pavement sealed.

Commentary

The advantage of payment by the square yard for a completed chip seal is simplicity if the area is easily defined. The disadvantage is that an incentive is created to reduce material quantities. Reduced asphalt quantities can lead to chip loss and vehicle damage.

A. Payment by Unit Price

The Agency shall pay for accepted quantities at the contract price as follows:

1. Payment for the accepted quantity of emulsified asphalt and aggregate for chip seal (including any required additives) at the contract bid price of measure is compensation in full for all costs of furnishing and applying the material as specified.

2. Payment shall be made in accordance with the schedule set forth below at the Contract bid price for the specified unit of measure.

Item No.	***Item***	***Unit***
State ##	Hot asphalt for chip seal……	Gallon
State ##	Aggregate for chip seal……...	Tons
State ##	Diluted emulsion for fog seal, if used.....	Gallon

Such payment is full compensation for furnishing all materials, equipment, labor, and incidentals to complete the work as specified.

B. Payment for Completed Chip Seal

1. Payment for the accepted quantity of the chip seal at the Contract bid unit price of measure is compensation in full for all costs of furnishing and applying the material as specified, including cleaning the existing pavement, stationing, purchase of aggregate, delivery of aggregate, all labor, equipment, and materials necessary for the placement of the chip seal for full lane coverage, sweeping of any loose aggregate after construction and other requirements as specified.

2. Payment shall be made in accordance with the schedule set forth below at the Contract bid price for the specified unit of measure.

Item No.	***Item***	***Unit***
State ##	Chip seal…….....	Square Yard
State ##	Diluted emulsion for fog seal, if used.....	Gallon

Such payment is full compensation for furnishing all materials, equipment, labor, and incidentals to complete the work as specified.

ATTACHMENT 3 – CONSTRUCTION GUIDE SPECIFICATIONS FOR MICROSURFACING

"*These Guide Specifications are the recommendation of the research for NCHRP Project 14-37 that was conducted by Shuler Consultants, LLC. The Guide Specifications have not been approved by NCHRP or any AASHTO committee; nor have they been formally accepted for the AASHTO specifications*".

SECTION 408
MICROSURFACING

408.01 DESCRIPTION

This guide specification is intended to provide information needed for owners or contractors to construct microsurfacing. A microsurfacing is the application of a mixture containing polymer modified emulsified asphalt, mineral aggregate, mineral filler, water, and other additives that are properly proportioned, mixed, and spread on a paved surface. Microsurfacing shall be constructed on a prepared surface.

This guide specification refers to quality requirements for materials and a design method for microsurfacing available in other AASHTO documents. However, the main purpose of this specification is to provide guidance for the construction of microsurfacing.

Commentaries are included in this Guide in places where added emphasis is needed to explain the section being discussed or when there are options to be considered by the user of the Guide, or, as sources of additional information.

A. Referenced Documents

1. AASHTO Standards

- MP 28, Materials for Microsurfacing
- M 140, Emulsified Asphalt
- M 208, Cationic Emulsified Asphalt
- M 316, Polymer-Modified Cationic Emulsified Asphalt
- PP 83, Microsurfacing Design
- T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27, Sieve Analysis of Fine and Coarse Aggregates

2. Other:

- Gransberg, D. 2010. "Microsurfacing – A Synthesis of Highway Practice." NCHRP Synthesis 411, Transportation Research Board, Washington, D.C., 2010

B. Terminology

1. CQS-1P – a cationic quick setting polymer modified emulsified asphalt.

2. CQS-1hP – a cationic quick setting polymer modified emulsified asphalt with a harder asphalt residue.

408.02 MATERIAL

A. Emulsified Asphalt

Emulsified asphalt for microsurfacing shall meet the requirements of AASHTO MP 28. The emulsified asphalt properties are determined by the Owner Agency utilizing regional climatic and traffic conditions. Only emulsified asphalt from certified or approved sources is allowed. Each load of emulsified asphalt shall have a certificate of compliance/analysis which is to be submitted to the Agency daily.

Commentary

The base asphalt used for microsurfacing emulsion might be a PG 64-22 which is acceptable in moderate to warm climates whereas in colder climates a PG 58-28 might be more appropriate.

B. Aggregate

Mineral aggregates for microsurfacing shall meet the requirements of AASHTO MP 28.

Commentary

The Type II gradation is used mainly on roads and streets to correct moderate surface defects, fill surface voids, and for wearing surfaces for medium to heavy traffic. The Type III gradation is used on collectors, arterials, and major highways to improve friction and durability. The Type II gradation is a better choice if traffic noise is a concern.

C. Mineral Filler

Mineral filler for microsurfacing shall meet the requirements of AASHTO MP 28.

Commentary

Portland cement or aluminum sulfate are the typical mineral fillers used in microsurfacing. The amount to be used is determined by the requirements of the mix design.

D. Water

Water for microsurfacing shall meet the requirements of AASHTO MP 28.

Commentary

The amount of water used in microsurfacing is based on the requirements of the mix design. If the placement conditions are very warm, additional water may be added to the mix based upon field conditions, however, excess water negatively affect the consistency of the mix.

E. Additives

Additives used in microsurfacing shall meet the requirements of AASHTO MP 28.

Commentary

Additives to control the set of the mixture are applied during placement and are designed to perform with the emulsions that the supplier furnishes. It is typically used when placement conditions are very warm.

408.03 CONSTRUCTION

A. Weather Limitations

Microsurfacing shall not be applied if either the pavement temperature or the air temperature is below 50F and falling. No material shall be applied when rain is expected before the mix is cured. No material is to be applied if temperatures below 32F are expected within 24 hours.

B. Mix Design

The mix design shall be prepared by an AASHTO accredited laboratory following the AASHTO PP 83 and must be submitted to the owner agency prior to beginning the work. Field adjustments to the design are permitted if they are within the overall tolerances set forth in the job mix formula.

C. Preconstruction Meeting

Coordinate a preconstruction meeting prior to construction between the agency and the contractor to discuss the following topics:

1. the construction process
2. the quality control plan
3. mix design

4. materials control
5. materials measurement
6. equipment calibration
7. traffic control plan
8. equipment/process overview
9. inspection
10. test strip
11. unique project conditions
12. project documentation
13. expectations
14. schedule

D. Road Surface Preparation

Clean the pavement surface of all loose material, vegetation, removal of lane stripping and thermoplastic pavement markings, base repairs, structural leveling and other objectionable materials immediately before applying the microsurfacing. Allow all pavement surface cracks to dry thoroughly, if water is used, before applying the microsurfacing mixture. Cover service entrances (i.e., manhole covers, valve boxes) with an approved method. Eliminate aggregate, either spilled from the mixing machine or existing on the pavement surface.

Allow crack sealant material to cure for a minimum of 30 days on pavement surfaces that have been crack sealed before application of the microsurfacing. Waive this requirement if a compatible crack sealant is used that does not require a cure time.

Apply a tack coat, if required by the Agency, using an emulsified asphalt meeting the requirements of AASHTO M 140, M 208, or M 316. Dilute the emulsified asphalt one-part emulsion to one-part water at the plant or the project site as approved by the engineer. Apply the diluted tack coat at the rate of 0.05 to 0.10 gallons/yd^2. Allow the tack to cure sufficiently before the application of the microsurfacing.

Commentary

Additional surface preparation items to include are removal of raised reflectorized pavement markings, herbicide treatment, oil spot removal and shoulder clippings. Cracks 0.25 inch or wider shall be sealed. Overbands on the surface shall not exceed 4 inches in width and shall not be greater than 1/8 inch thick. Tack coat is not typically used prior to microsurfacing. But if it is specified in the design, it is applied to an existing surface that is moderately raveled or if there is concern the microsurfacing will not properly bond to the existing surface.

E. Equipment

1. Mixing Equipment

Mix materials in a specifically designed paver, either truck mounted or continuous run machines, as required by the Agency. The paver shall be a continuous-flow mixing unit able to accurately proportion and deliver the aggregate, emulsified asphalt, mineral filler, water, and additives, to a continuous flow mixing chamber. The machine shall have sufficient storage capacity for all the mixture ingredients to maintain an adequate supply to the mixing chamber.
If a continuous run machine is required by the Agency to reduce construction joints, use a machine capable of loading materials while continuing to apply microsurfacing.

Figure 1 - Continuous front-loaded self-propelled (left) and truck-mounted (right) microsurfacing mixing machines (Gransberg, 2010).

<u>*Commentary*</u>

Truck mounted machines are generally used for residential streets and locations where construction joints are not undesirable. Continuous machines are used for highways and airfield applications.

2. Proportioning Devices

The machine shall have controls to meter each individual material into the mixing chamber. The rates of the emulsified asphalt and mineral filler addition shall be interconnected or linked to the aggregate delivery system such that the ratios of these materials remain fixed to the Job Mix Formula during the project.

<u>*Commentary*</u>

This is generally accomplished during the calibration of the machine and is conducted in the presence of the Agency representative.

3. Spreading Equipment

A spreader box shall be equipped with spiral augers that are permanently fixed to the box. The spreader box shall be equipped with a front seal to eliminate any loss of the mixture and an adjustable rear seal to control the application rate of the material. The spreader box and rear seal shall be designed to ensure the delivery of a uniform mixture to the secondary strike-off. The box shall be capable of shifting laterally to compensate for variability in the geometry of the pavement.

4. Secondary Strike-off

The spreading equipment shall be equipped with a secondary strike-off with the same leveling adjustment capabilities as the spreader box to provide a satisfactory surface texture.

5. Rut Filling

A rut box specifically designed and manufactured to fill ruts shall be provided for each designated wheel track. Rut boxes are used when filling ruts 0.5 inch or more in depth. Ruts deeper than 1 inch may require multiple lifts.

The rut boxes shall be 5-6 feet wide with a dual chamber and an inner "V" configuration of augers to channel the large aggregate toward the center of the rut and the fines to the edges of the rut fill pass. The box shall be equipped with a dual strike-off plate to control the width and depth of the rut fill.

6. Brooms

Motorized brooms shall have a positive means of controlling vertical pressure and be capable of cleaning the road surface prior to placing microsurfacing.

7. Rolling

Where required by the Agency, a self-propelled, 10 ton (maximum) pneumatic tire roller equipped with a water spray system shall be used. All tires shall be inflated per the manufacture's specifications.

Commentary

Rolling of microsurfacing is typically not required except for airfield applications and parking lots. When required, the minimum tire pressure of 90 psi unless otherwise recommended by the equipment manufacturer.

F. Mix Paver Calibration

Calibrate the mix paver to be used for the placement of microsurfacing in the presence of the representative from the specifying agency according to the method recommended by the mix paver manufacturer.

Each unit shall be calibrated prior to the beginning of each project for each aggregate type, or as required by the agency. The calibration procedure shall include a metered verification for each material used. No machine will be permitted to work until the calibration has been completed or accepted.

G. Test Strip

A test strip shall be constructed on or near the project site. If near the site, the pavement conditions must be very similar. Construct the test strip under similar placement conditions of time of day, temperature, and humidity as expected for the duration of the project. The test strip shall be a minimum of 300 feet in length and shall be constructed, after completion of the calibration, with the job mix proportions, materials, and equipment to be used on the project. Adjustments to the mixture formula shall be permitted provided they do not exceed the values stated in the mix design. The test strip shall be evaluated by the Agency to determine whether project specifications are met. If specifications are not met, additional test strips will be constructed until specifications are met, at no additional cost to the Agency.

H. Application of Mixture

For mix consistency and performance, adjustments to the job mix formula are allowed and must remain within the tolerances set forth in the mix design.

Wet the surface of the pavement by fogging a fine mist of water ahead of the spreader box, when necessary. The rate of application shall not result in pooling of water on the surface to be paved.

In irregular areas, not accessible to the spreader box, use hand tools to provide a complete and uniform coverage. These areas shall be cleaned and lightly dampened before placing the mix. The finished texture shall be uniform and have a neat appearance.

Where required in the plans, use the rut box to fill ruts and depressions equal to or greater than 0.5 inch. For ruts of less than 0.5 inch, a full width scratch course using the conventional spreader box is acceptable. Where ruts exceed 1 inch, multiple passes with the rut box may be necessary.

All rut filling shall be allowed to cure under traffic for at least 24 hours before the final surface course is placed. Mixtures for filling ruts shall meet the requirements of

Type III in AASHTO MP 28. The mixture must meet the longitudinal and transverse profile noted in the project plans.

When required in the plans, roll pavement surfaces with a minimum of two full coverage passes after the mixture has cured to the point where it will not be damaged by the roller following the requirements of Section 408.03.E7 above.

All areas including service entrances, gutters, and intersections shall be cleaned of any debris associated with the placement of the microsurfacing on a daily basis. At the direction of the engineer, sweep raveled aggregate.

I. Aggregate Stockpiling, Testing and Moisture Control

The gradation of the aggregate stockpile shall not vary by more than the stockpile tolerance from the mix formula while also remaining within the specification grading band. Sampling and testing of the aggregate shall be a minimum of one per each 500 tons with a sample consisting of three test portions tested in accordance with AASHTO T 27 and T 11.

Stockpile moisture can vary due to weather conditions and the contractor shall take the necessary precautions to protect the aggregate stockpiles and, if necessary, re-work the stockpiles to reach an acceptable moisture content contained in the mix design.

Commentary

For example, the gradation of the minus 8 sieve for Type III microsurfacing aggregate is 45-70 % passing with a +/- 5 % stockpile tolerance. If the mix design for Type III aggregate for the amount of material passing the minus 8 sieve from the stockpile gradation is 62%, the allowable variation is 57-67% passing. If the % passing is 67%, the allowable variation is 62-70%.

J. Application of Aggregate and Emulsified Asphalt

Verify the application rate of the aggregate and emulsified asphalt using the paver's calibration records. Provide material certification and quality control test results for each load of emulsified asphalt used on the project. Include the supplier name, plant location, emulsion grade, and batch number on all reports.

K. Workmanship

When placing microsurfacing, the longitudinal and transverse joints shall be uniform, neat in appearance, and shall not contain material build-up or uncovered areas.

Longitudinal joints shall be placed on lane lines, edge lines, or shoulder lines and shall have a maximum overlap of 3 inches. Longitudinal joints shall be straight in appearance along the centerline, lane lines, shoulder lines, and edge lines.

Longitudinal lines at intersections, curbs, shoulders, and street ends shall be straight to provide a good appearance. Longitudinal edge lines shall not vary by more than ± 2 inches in 100 linear feet.

The finished surface shall have a uniform texture free from excessive surface defects, ripples, or drag marks. A single drag mark exceeding 0.5 inch in width and 6 inches in length or a total of four drag marks within 100 linear feet in a single pass are considered to be excessive.

The contractor shall produce neat and uniform longitudinal and transverse joints. Transverse joints shall be constructed as butt-type joints. Joints are acceptable if there is no more than 0.25 inch vertical space for longitudinal joints, and no more than 0.25 inch for a transverse joint between the pavement surface and a 10-foot straightedge placed perpendicular to the joint.

If these criteria are exceeded, the contractor shall stop work and correct them.

L. Opening to Traffic

Do not allow traffic on the newly completed surface course until the mix has set sufficiently to prevent pick-up as determined by the contractor. Stopping and starting traffic will require additional curing time. Construct the microsurfacing so that adjacent lanes are placed on the same day when possible. Barricades, signage and traffic control shall follow the current MUTCD standards.

Place temporary pavement markings after the microsurfacing cures. The permanent pavement markings shall not be placed for 10-14 days for water borne pavement markings or per manufacturer's recommendations for other types.

M. Project Documentation

The contractor shall supply daily documentation to the Agency that includes the following:

1. Aggregate used, tons (dry)
2. Microsurfacing emulsified asphalt used, tons
3. Emulsified asphalt for tack coat used, if specified, tons
4. Mineral filler used, pounds
5. Water used in mixture, gallons
6. Additive used in mixture, gallons
7. Surface area completed, square yards
8. Surface area application rate, dry pounds of aggregate per square yard
9. Percentage of emulsified asphalt based on dry aggregate

N. Quality Control

1. General

The Contractor is responsible for quality control (QC) sampling and testing and shall submit a QC plan including materials and procedures for verifying the quality of the microsurfacing aggregates and emulsified asphalt(s). The Contractor's QC plan shall include but is not limited to sampling, testing, inspection, monitoring, documentation, and corrective action procedures during transport, stockpiling and placement operations. The plan shall include, as a minimum, the following:

1. Sampling and testing procedures for in accordance with AASHTO MP 28.
2. Sampling and testing procedures for asphalt emulsion.
3. Sampling and testing procedures for residual binder content.
4. Actions the contractor will take to correct any deficiencies and who will be responsible to the make corrections.

A written Quality Control Plan (QCP) shall be developed which details the Contractors's QC program that meets the requirements of these specifications. The QCP shall be contract specific and signed by the Contractors's representative. Microsurfacing construction shall not proceed without Agency approval of the QCP and QC personnel present on the project. Failure to comply with these provisions will result in shutdown of the operations until such time as the Contractor's operations are in compliance.

2. Personnel

The QC staff shall include the following as a minimum:

a. QCP Administrator – The person with overall responsibility of the QCP
b. QCP Manager – The person responsible for the execution of the QCP and liaison with the Agency. This person shall be on the project, and have the authority to stop or suspend construction operations.
c. QC Technicians – The person(s) responsible for conducting QC tests and inspection to implement the QCP. QC technicians shall have Level 2 Aggregate Testing Certification from the American Concrete Institute (ACI) or other accrediting body approved by the Agency.
d. Certified Crew Members – Three crew members (job foreman, aggregate spreader operator and asphalt distributor operator), at a minimum, shall possess a valid microsurfacing certification and be on the project at all times the microsurfacing is being constructed. The microsurfacing certification is administered by the National Center for Pavement Preservation (NCPP) on behalf of AASHTO TSP^2 (Transportation System Preservation Program).

3. Testing Facilities and Equipment

The Contractor shall provide the name of the laboratory conducting QC tests. The laboratory shall maintain accreditation by the AASHTO Accreditation Program (AAP) for all tests within the relevant scope of testing, or other accrediting body approved by the agency. Sampling, testing and measuring devices shall meet the requirements of the specified standards and test methods. The laboratory shall maintain records of the calibration and maintenance of all sampling, testing and measuring equipment.

4. Materials Testing

Aggregates and asphalt emulsion shall be tested for compliance with the specifications as follows:

A. Aggregate

a. Stockpile.
Test the aggregate gradation a minimum of once per day, or every 1500 tons, whichever is less in accordance with AASHTO MP 28. If the material is hauled from the production site to a temporary stockpile, test at the temporary stockpile.

b. Construction.
Test the aggregate gradation from the delivery vehicle a minimum of once per day, or every 1500 tons, whichever is less in accordance with AASHTO MP 28.

B. Emulsified Asphalt

Provide material certification and quality control test results for each batch of emulsified asphalt used on the project. Include the supplier name, plant location, emulsion grade, and batch number on all reports.

5. Records and Documentation

The Contractor shall maintain complete records of all QC tests and inspections. All QC test results shall be submitted to the Agency within 24 hours. A material certification shall be submitted from each supplier for each batch of material delivered to the project, including test results.

The QC records shall contain all test and inspection reports, forms and checklists, equipment calibrations, supplier material certificates, and non-conformance and corrective action reports. The QC records shall indicate the nature and number of observations made, the number and type of deficiencies found, the quantities conforming and non-conforming, and the nature of corrective action taken as appropriate for materials as well as workmanship. All the QC records shall be given

to the Agency at the end of the contract. The Contractor's documentation procedures will be subject to approval by the Agency prior to the start of work, and to compliance checks by the Agency during the progress of the work.

6. Compliance with Specifications

The Contractor shall attest in writing to the Agency that the microsurfacing has been constructed in accordance with and meets the requirements of the specifications at the conclusion of the project.

A. Agency Acceptance

The Agency will conduct acceptance sampling, testing, and inspection activities to ensure material quality, correct application rates, rolling, sweeping, and traffic control are within specification requirements. These activities will be done randomly by the Agency.

1. Materials Testing

a. Aggregate

Sample aggregate taken from the delivery vehicle or stockpile once per day. Samples will be stored and tested for gradation at the discretion of the Agency. If the results vary from AASHTO MP 28, acceptance or removal will be based on the Agency's specification.

b. Emulsified asphalt

Sample the first shipment and provide one sample for every 50,000 gallons (approximately 200 tons) thereafter. Testing of emulsions shall be in accordance with AASHTO MP 28.

c. Residual Binder Content

A State Agency Representative shall obtain a sample of the completed microsurfacing mixture to determine the residual binder content.

2. Equipment

All equipment to be used on the project shall be evaluated by the Agency to assure it is in acceptable operating condition, calibrated correctly and will provide the quantities of material specified. If the equipment is operating outside of calibration, the project will be shut down immediately and the equipment shall be recalibrated.

a. Final Inspection

A final inspection will be done to assure that no bleeding, flushing or dragmarks have occurred. Longitudinal and transverse joints will be inspected to assure that no excessive overlap has occurred.

408.04 MEASUREMENT

The Engineer will measure work acceptably completed as specified in Subsection 109.01 of the AASHTO Construction Guide Specifications.

The engineer shall not measure mix water or water used to pre-wet the pavement surface.

408.05 PAYMENT

The Agency will pay for accepted quantities at the contract price as follows:

A. Payment will be made in accordance with the schedule set forth below at the contract bid price for the specified unit of measure.

Item No.	Item	Unit
State ##	Aggregate for Microsurfacing……	ton
State ##	Polymer modified emulsified asphalt for microsurfacing……..	ton, gal
State ##	Diluted emulsified asphalt for tack coat…….	ton, gal
State ##	Filler……...	ton

Such payment is full compensation for furnishing all materials, equipment, labor, and incidentals necessary to complete the work as specified. If the materials placed on the project fail to meet the specification requirements, they shall be repaired, or replaced, by the contractor to the satisfaction of the Agency at no additional cost to the Agency.

Commentary

Some current specifications require the basis of payment be by the square yard of material placed because it is easy to measure. If the application rate specified is not verified by the agency inspector, it is possible they can get an application that is deficient in thickness or low in binder content. Some agencies measure the placement by the amount of material placed by the ton but they must monitor the materials by using the measurements provided by the mixing machine.

ATTACHMENT 4– CONSTRUCTION GUIDE SPECIFICATIONS FOR EMULSIFIED ASPHALT FOG SEAL

"*These Guide Specifications are the recommendation of the research for NCHRP Project 14-37 that was conducted by Shuler Consultants, LLC. The Guide Specifications have not been approved by NCHRP or any AASHTO committee; nor have they been formally accepted for the AASHTO specifications*".

SECTION 410
EMULSIFIED ASPHALT FOG SEAL

410.01 Description

This guide specification is intended to provide information needed for owners or contractors to construct emulsified asphalt fog seals. An emulsified asphalt fog seal is the application of emulsified asphalt, either diluted or undiluted, to a prepared pavement surface and may be followed immediately by a light application of blotter sand. Fog seals are intended as a barrier to air and water infiltration of a pavement surface, to arrest low severity raveling or to create color contrast between traffic markings and the paved surface.

This guide specification refers to quality requirements for materials and methods used to construct fog seals.

Commentaries are included in this Guide in places where added emphasis is needed to explain the section being discussed or when there are options to be considered by the user of the Guide, or, as sources of additional information.

A. Referenced Documents

1. AASHTO Standards:

   - M 140, Emulsified Asphalt
   - M 208, Cationic Emulsified Asphalt
   - T 27, Sieve Analysis of Fine and Coarse Aggregates
   - T 304, Standard Method of Test for Determining the Uncompacted Void Content of Fine Aggregate

2. ASTM Standards:

   - D 5624-13, Standard Practice for Determining the Transverse-Aggregate Spread Rate for Surface Treatment Applications

3. Other:

- Shuler, S. 1991, High Traffic Chip-Seal Construction: The Tulsa Test Road, *Transportation Research Record No. 1300*, National Academy of Sciences, pp 116-124.

B. Terminology

1. *CSS-1h* – a cationic emulsified asphalt that is slow setting and has a residual binder residue with lower penetration than CSS-1.

2. *SS-1h* – an anionic emulsified asphalt that is slow setting and has a residual binder residue with lower penetration than SS-1.

410.02 MATERIAL

A. Emulsified Asphalt

Emulsified asphalt for fog seals shall meet the requirements of AASHTO M140 or M208. Fog seal emulsified asphalt may be diluted 50:50 with water prior to application, but the residual asphalt content shall not be less than 50 percent by weight of the total mixture.

B. Aggregate

When blotter aggregate is used in fog seals, the aggregate shall meet the requirements of AASHTO T27. The aggregate size to be used will be as shown in the plans or other contract documents or the requirements shown in Table 1. Aggregate shall be crushed by mechanical means and shall have a minimum angularity of 45 as determined by AASHTO T 304.

Table 1 – Fog Seal Aggregate

Sieve Size, T27	Passing, %
No. 8	100
No. 16	50-85
No. 30	25-60
No. 50	5-30
No. 200	0-10

Commentary

Blotter aggregate is sometimes used to absorb any excess asphalt emulsion that may occur on the pavement surface due to over application or because of pooling in low areas of the pavement.

410.03 CONSTRUCTION

A. Weather Limitations

Construct fog seal per the following conditions:

1. Ambient or pavement surface temperatures shall be 60F (15C) and rising.
2. Application of the fog seal shall be only during daylight hours.
3. The road surface shall be dry
4. Suspend fog seal operations when rain is expected before the fog seal emulsion can set.
5. Temperatures below 40F are not anticipated for at least 24 hours after application.
6. Sustained winds are less than or equal to 10 miles (16 kilometers) per hour; and
7. Application is completed at least 2 hours before sunset.

B. Application Rate

The asphalt emulsion application rate for the fog seal shall be between 0.015 to 0.039 gal/yd^2 of residual asphalt binder. Target rates are shown in Table 2 for four types of typical pavement surfaces. The actual rate used for a specific pavement shall be determined using a test strip or by the ring test described below.

Table 2—Initial Target Fog Seal Application Rate

Surface Type	Residual Rate Gal/yd^2	Undiluted Gal/yd^{2*}	Diluted 1:1 Gal/yd^2
Dense-Graded Asphalt Mixture	0.015-0.021	0.025-0.035	0.05-0.07
Open-Graded Asphalt mixture	0.021-0.027	0.035-0.045	0.07-0.09
Chip Seal (<1/2 in. top agg size)	0.027-0.033	0.045-0.055	0.09-0.11
Chip Seal (≥1/2 in. top agg size)	0.033-0.039	0.055-0.065	0.11-0.13

**This assumes an emulsion residual binder content of 60% and a water content of 40%*

Ring Test:

1. Sweep the section of road to be fog sealed clean of debris and dust.
2. Draw three 6-in. diameter circles on the swept pavement.
3. Select three target application rates and translate them to the required volume of emulsified asphalt from Table 2.
4. Label each circle with its application rate.
5. Use a 10-ml graduated cylinder to pour the required amount of emulsified asphalt into the center of each circle. Evenly distribute the material within the circle.
6. The ideal application rate will evenly and completely cover the pavement within the circle, with no emulsified asphalt draining outside.
7. Record the optimal application rate.

Table 3—Amount of Emulsified Asphalt for Ring Test

gal/yd^2	ml (6-in. Circle)
0.05	4.2
0.06	5.0
0.07	5.8
0.08	6.6
0.09	7.4
0.10	8.3
0.11	9.1
0.12	10.0
0.13	12.8

All design work will be carried out using the emulsified asphalt to be used on the job site or from equivalent material from the same source and having substantially the same material properties.

Commentary

The ring test is especially recommended when the pavement surface to be fog sealed is tight and dense and excess emulsion could result.

C. *Preconstruction Meeting*

Coordinate a preconstruction meeting prior to construction with the engineer to discuss the following topics:

i. construction process
ii. quality control plan, required to be submitted
iii. mix design, required to be submitted

iv. materials control
v. materials measurement
vi. equipment calibration, required to be submitted
vii. traffic control plan
viii. equipment/process overview
ix. inspection
x. test strip
xi. unique project conditions
xii. project documentation
xiii. expectations

D. Road Surface Preparations

1. Cleaning Pavement

   Clean the roadway surface by sweeping no more than 30 minutes prior to application of the asphalt emulsion fog seal. However, this 30-minute window may be extended if authorized by the engineer in cases where extending the time does not jeopardize a clean surface prior to fog seal operations. Sweep the pavement with a motorized broom to remove loose material. Clean depressions not reached by the motorized broom with a hand broom. Clean the outer edges of the pavement to be sealed including an adjacent paved shoulder.

2. Protecting Accessories

   Cover utility castings (manholes, gate valve covers, catch basins, sensors, etc.) to prevent coating with emulsified asphalt. Suitable covering includes plywood disks, Kraft paper, roofing felt or other approved methods. Remove the protective coverings before opening the road to traffic.

E. Equipment

1. Pressure Distributor

   The pressure distributor shall have a ground speed control device interconnected with the emulsified asphalt pump such that the specified application rate will be supplied at any speed. The pressure distributor shall be capable of maintaining the emulsified asphalt at the specified temperature. The spray bar nozzles shall produce a uniform double lap application fan spray, and the shutoff shall be instantaneous, with no dripping. All nozzles shall be oriented at the same angle between 15° and 30° using the wrench supplied by the distributor manufacturer and as described below in Equipment Calibration.

2. Blotter Sand Spreader

   If used, a self-propelled mechanical type aggregate spreader with a computerized spread control, capable of distributing the aggregate uniformly to the required width and at the designed rate shall be used. The spreader shall be a self-propelled type mounted on pneumatic-tired wheels.

3. Brooms

   Motorized brooms with a positive means of controlling vertical pressure shall be used to clean the road surface prior to spraying emulsified asphalt.

   Commentary

   Vacuum brooms are preferred in urban or residential areas, but push brooms are acceptable in rural areas where debris scattered off the roadway does not pose a hazard to pedestrians or vehicles.

4. Trucks

   Unless otherwise approved, use trucks of uniform capacity to deliver the aggregate.

F. Equipment Calibration

The contractor shall provide proof of calibration of the pressure distributor and the aggregate spreader if aggregate is applied to the fog seal. Calibration shall be repeated once per week or after every five full days of operations. The contractor shall submit the results of the calibration procedure to the Engineer.

Flow from each nozzle in the pressure distributor must be within +/-10 percent of the average flow of all nozzles as measured by the procedure described below.

Uniformity of the aggregate applied transverse to the pavement centerline in accordance with ASTM D5624, "Determining the Transverse Aggregate Spread Rate for Surface Treatment Applications". Tolerance for each pad tested for transverse spread rate shall be +/-10 percent of the average of the total transverse rate.

Commentary

Calibration is very important to assure the quantity of emulsion and blotter sand applied to the pavement is correct. Although many modern asphalt distributors and aggregate spreaders are computer controlled, calibration is required to tell the computer how much emulsion is being applied. This quantity must be checked prior to spraying emulsion and spreading blotter sand and checked against the quantity the computer (if the distributor is so equipped) indicates is being applied.

4. Pressure Distributor

All nozzles shall be the same size, provide the same flow rate, be oriented in the same direction, and be the same distance above the pavement.

Commentary: The distributor truck applies emulsified asphalt to the pavement surface. This application must be done uniformly both transverse and longitudinal to the centerline of the pavement.

When lower application rates are determined necessary or shown in the plans, smaller nozzles shall be inserted in the spray bar where the emulsion rate is reduced.

Commentary: Due to minor rutting or heavy truck traffic, it may be desirable to reduce the emulsion application rate in the wheel paths.

b. Nozzle Angle

Nozzles shall be positioned at an angle of 15 to 30 degrees from the horizontal of the spray bar in accordance with the spray bar manufacturers recommendation. All nozzles shall spray a full fan except for the right and left edge nozzles. The right and left edge nozzle shall be adjusted to a half fan such that the spray stays to the inside of the spray bar.

Commentary: The next step in calibrating the distributor is adjustment of the spray bar nozzle angles. Each nozzle has a slot cut across the face of the nozzle. When the nozzle is threaded into the spray bar, the slot should all be positioned at an angle of 15 to 30 degrees to the direction of the spray bar as shown in Figure 1. This angle provides the best position for achieving uniformity in the spray and the triple overlap coverage. The angle should be adjusted using the wrench supplied with the distributor. This wrench is designed when used properly to set the correct angles for each nozzle. Any wrench that fits the hexagonal nozzle can adjust the nozzle angle but correctness of the angle would have to be visually verified.

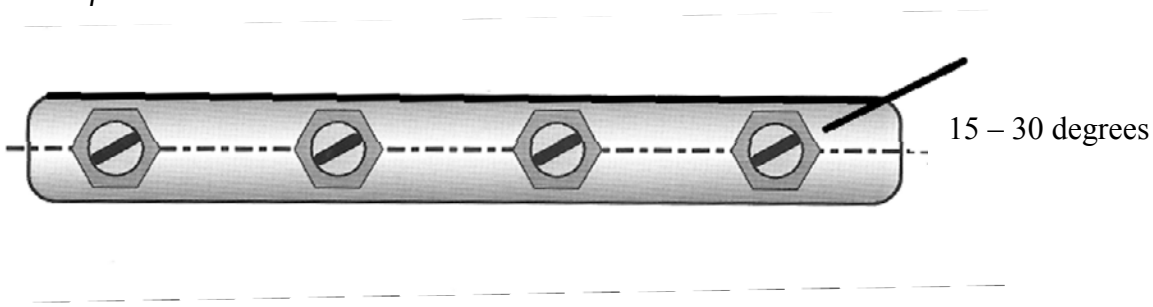

Figure 1- Spray Bar Nozzle Orientation in Spray Bar

The angle at which the nozzles are positioned shall be adjusted using the wrench supplied with the distributor.

However, in cases where this wrench is unavailable, a wrench that fits the hexagonal nozzle will suffice but the angle must be judged visually.
All nozzles fitted to the spray bar shall be full fan nozzles except for the right and left edge nozzles. These nozzles shall be half fan nozzles adjusted so the spray from the nozzle remains to the inside of the spray bar.

e. Spray Bar Height

The spray bar height must be adjusted so that the emulsion provides exactly two or three overlaps across the entire spray width.

Commentary
Streaking of the emulsion will occur if the spray bar is set too high or too low as shown in Figures 2 and 3.

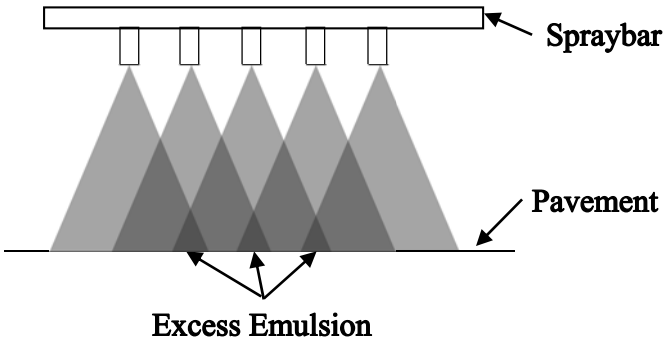

Figure 2- Streaks with Spray Bar Too High for Double Overlap

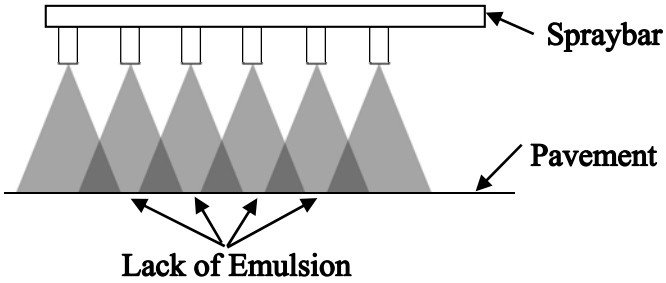

Figure 3 - Streaks With Spray Bar Too Low for Double Overlap

To avoid this streaking the bar must be adjusted to the correct height. This adjustment process is accomplished by shutting off nozzles to determine where the spray pattern contacts the pavement as shown in Figures 4 and 5.

Bar Height Adjustment to Achieve Double Lap

Every second nozzle shall be turned off when a double lap application is desired as shown in Figure 4. The distributor operator shall spray emulsion onto the pavement surface for as short an interval as possible while an observer watches where the emulsion hits the pavement from each nozzle left open. If there is overlap of emulsion from adjacent nozzles, the bar is too low. If there is a lack of emulsion from adjacent nozzles, the bar is too high.

Once it is confirmed the bar height is correct, the nozzles that were turned off can be turned back on and a double application of emulsion will result when spraying resumes.

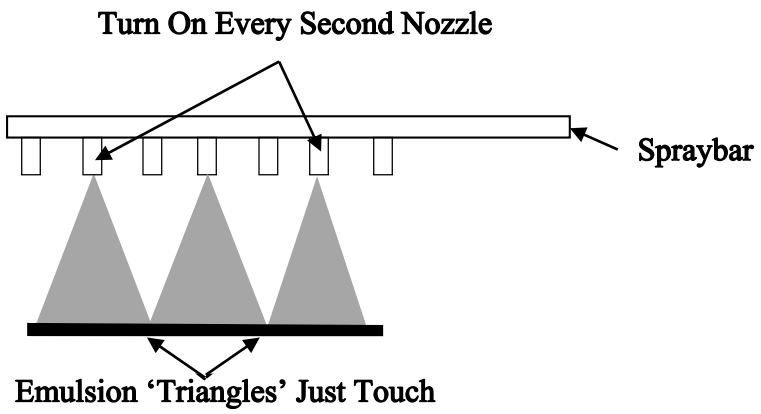

Figure 4 - Adjustment of Spray Bar Height for Double Overlap

<u>Triple Lap Application Bar Height Adjustment</u>
Every third nozzle shall be turned off when a triple lap application is desired as shown in Figure 5. The distributor operator shall spray emulsion onto the pavement surface for as short an interval as possible while an observer watches where the emulsion hits the pavement from each nozzle left open. If there is overlap of emulsion from adjacent nozzles, the bar is too low. If there is a lack of emulsion from adjacent nozzles, the bar is too high.

Once it is confirmed the bar height is correct, the nozzles that were turned off can be turned back on and a double application of emulsion will result when spraying resumes.

As the distributor empties during spraying, the bar height will rise. However, this is not usually enough to cause significant streaking worth adjustment of the spray bar.

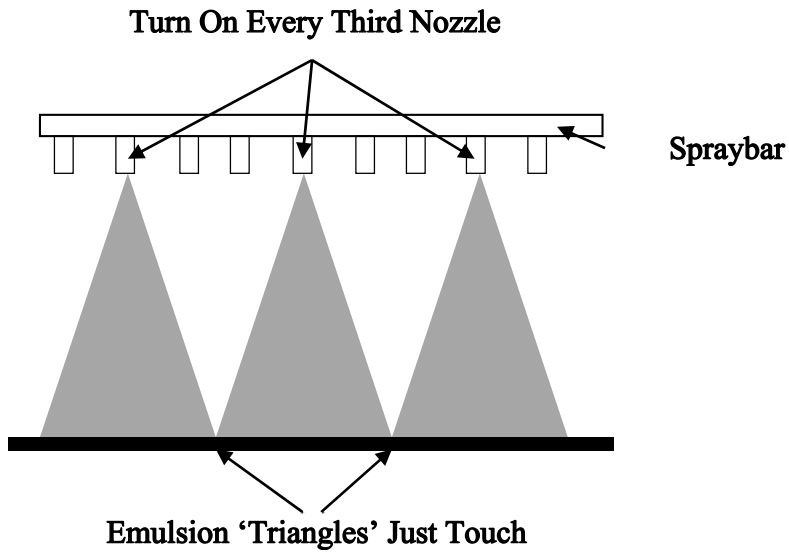

Figure 5 - Adjustment of Spray Bar Height for Triple Overlap

f. Transverse Flow Rate

The flow rate across the spray bar shall be uniform with each nozzle spraying within +/-10 percent of the average flow rate.

Commentary
This is done by measuring the width of the slot in the nozzle and by measuring the orifice diameter. Also, some nozzles are labeled by the manufacturer. Manufacturers supply a list of nozzles in the owner's document describing which nozzles shall be used for various application rates or on a placard mounted on the equipment.

However, nozzles of the same apparent size have been measured with different flow rates. Therefore, it is recommended that all nozzles be checked for flow rate before fog seal operations begin. This is easily accomplished by fabricating a flow apparatus. This apparatus consists of a pipe to which each nozzle can be fitted, in turn, on one end and a water source can be fitted to the other end. The flow of water through each nozzle shall be measured by filling a one gallon container in a measured period. This shall be done for each nozzle to be used on the project. If the flow rate of any of the nozzles is greater than 10 percent of the average of all the nozzles to be used these nozzles shall be discarded, or modified to flow within the 10 percent tolerance.

Determination of uniform lateral flow from the spray bar is determined by collecting a measured volume of emulsion in containers placed under each nozzle. This process is practical using standard 6-inch by 12-inch concrete cylinder

molds lined with one-gallon zip-lock freezer bags. The cylinder molds can be reused and the zip lock bags discarded appropriately with the contents.

g. Longitudinal Flow Rate

The longitudinal spray rate shall be accomplished by measuring the volume of emulsion in the distributor before and after spraying enough emulsion to reduce the volume of emulsion in the distributor by 70 to 90 percent.

Commentary
The longitudinal flow rate must be measured with all nozzles inserted in the distributor bar. First, the quantity of emulsified asphalt in the truck must be determined. Although there is a volume indicator on the rear of most modern distributors, these are not calibrated in small enough increments to be of use for longitudinal flow rate calibration and shall not be used for this purpose. Instead, the dip stick supplied with the distributor must be used. This dip stick is usually carried on the top of the tank near the inspection hatch. Prior to shooting emulsion, take a volume reading with the dip stick.

Pay attention to how the dipstick is used. Many dipsticks are not intended to be submerged in the emulsion, but instead, are inserted into the top of the tank only until the tip of the dipstick touches the surface of the emulsion. Then, the volume in the tank is read by indexing the top of the inspection cover to the reading on the dipstick.

Record this volume as 'beginning volume'. Set up the truck to shoot emulsion and shoot a minimum of 3000 feet by 12 feet of emulsion at the design rate using the gallon per minute pump flow volume and truck speed required by the manufacturer to attain this flow rate. Take a second dip stick reading. Record this reading as 'ending volume'. Subtract 'ending volume' from 'beginning volume' and record this as 'volume used'. Determine the area of emulsion sprayed. Divide 'volume used' by the area sprayed in square yards. This is the gallons per square yard applied to the pavement. This value shall then be compared to the distributor computer, if equipped, to evaluate the accuracy of the computer. A correction factor may then be applied to the computer output, if needed, and used for the remainder of the day. This calibration shall be accomplished each day.

An example of this calibration is presented below:

Given:

1800-gallon capacity asphalt distributor
12-foot-wide spray width
Trial spray distance = 3630 feet
0.32 gallon/yd^2 design spray rate
Dipstick reading beginning of shot = 1765 gallons

Dipstick reading end of shot = 265 gallons

Calculations:

7. *Check to see if enough volume shot. 1765-265=1500 gallons*
8. *1500/1765 = 85 percent >70% and <90%. OK, enough applied to be valid*
9. *Calculate spray rate = 1500 gallons / (12 x 3630/3) = 0.31 gallons/yd^2*

Therefore, decrease distributor speed, or recalibrate computer and re-check.

5. Blotter Sand Spreader

c. *Transverse Spread Rate*

<u>Commentary</u>
Various methods of calibrating this equipment have been used and the ASTM D5624 procedure can be effective. However, a visual assessment of the lateral distribution of sand is a good place to start the process since non-uniform distribution can easily be seen. The veil of sand deposited on the pavement from the spreader box can be viewed from behind with the spreader moving away from the observer or from the front. Either position for the observer is adequate for viewing how uniform the veil of sand is falling out of the spreader box. However, viewing from either front quarter affords the observer a better view of the entire spreader width and is, of course, safer than directly in front of the spreader. Any variation in light passing through the veil of sand indicates variation in application rate. More light means a lack of sand. Variation in light means the machine shall be stopped, the gates on the spreader contributing to the non-uniformity adjusted and the trial rerun. This procedure provides adjustment to the transverse spread rate. Then, to obtain an objective means of measuring the amount of sand being deposited, ASTM D5624, "Determining the Transverse Aggregate Spread Rate for Surface Treatment Applications" is a good procedure to use.

d. *Longitudinal Spread Rate*

Once the transverse spread rate is adjusted the longitudinal rate can be adjusted. This is also done visually, at first. This shall be done well before the emulsion begins to 'break' or 'set', but not immediately after spraying unless temperature, wind, or high demulsibility demand it.

The application rate of the sand shall be similar to the design rate. This is a rate where immediately upon dropping the sand, the appearance of the surface has some emulsion showing between the sand. In fact, the chip quantity should seem somewhat inadequate. The chip spread rate should not be low enough to cause pickup problems on rubber-tire rollers. However, the rate should be such that a small decrease in rate would cause pickup. Emulsion should be visible between

the sand upon dropping the sand and before rolling. It is the responsibility of the construction superintendent to achieve this application rate.

Evaluating the quantity of sand being placed is important after the rate is established. This provides a quantitative baseline for future work. The best method to accomplish this evaluation is by weighing the sand spreader before and after applying the sand and calculating the spread rate based on the area covered. This is often not practical. Therefore, a suitable alternative includes estimating the quantity of sand spread over a known area by knowing the weight of each transport truck supplying the spreader and dividing the estimated weight of sand spread by the area covered for that load.
An example follows:

Given:
Trucks loading the chip spreader are 12-ton capacity tandem dumps
12-foot-wide pavement
28 pounds per square yard design spread rate

Calculations:

11. Check Truck No. 1
a. Load = 23,803 lbs.
b. Spreader distance = 213 feet
c. Rate = 23,803/213x12/3 = 27.9 lbs./yd^2
12. Check Truck No. 2
a. Load = 23,921 lbs.
b. Spreader distance = 211 feet
c. Rate = 23,921/211 x 12/3 = 28.3 lbs./yd^2
13. Check Truck No. 3
a. Load = 23,848 lbs.
b. Spreader distance = 213 feet
c. Rate = 23,848/213 x 12/3 = 28.0 lbs./yd^2
14. Average Rate = (27.9 + 28.3 + 28.0) / 3 = 28.1 lbs./yd^2
15. No adjustment needed since measured rate is within 1 percent of design.

Compensation for moisture on sand must be considered when calibrating spreaders. The above example indicates no adjustment is needed since the measured spread rate is within 0.10 lbs/yd^2 of the design spread rate. However, if the sand above had contained as much as 1.02 percent moisture that was unaccounted for, the application rate would have been too low.

G. Test Strip:

Construct a 100-ft test strip and adjust the application rate as needed to assure a uniform application of the fog seal emulsified asphalt is applied with no streaking. Apply the fog

seal to minimize the amount of overspray and do not allow traffic on the fog seal until it has cured. The application rate shall not result in an excess of asphalt emulsion that could run off the pavement area to be sealed.

Commentary

Care should be taken to ensure the fog seal application rate does not cause a significant reduction in the surface texture of the pavement.

H. Application of Emulsified Asphalt

Apply the asphalt emulsion at the rate determined by the test strip or the ring test within +/-5 %. After applying the emulsified asphalt, place the cover aggregate at an application rate that just covers the emulsified asphalt or is sufficient to blot excess emulsion.

The temperature of the emulsified asphalt at the time of application shall be above 120F.

Commentary

If the temperature is lower than 120F there is risk of less material being applied than desired due to high viscosity.

The longitudinal construction joint for a fog seal must coincide with the painted lane line or at the outside edge of shoulder. There shall be no overlap of the longitudinal construction joint.

Allow the fog seal to cure undisturbed for at least 2 hours or until the emulsified asphalt breaks and is substantially tack free.

Cover unabsorbed asphalt with blotter aggregate to protect traffic or minimize rain damage.

Remove excess blotter aggregate after the asphalt is absorbed by sweeping.

I. Application of Cover/Blotter Aggregate

Cover or blotter aggregate shall be used for two purposes: 1) to blot excess asphalt emulsion prior to opening to traffic, and 2) to provide friction. After the emulsified asphalt has been sprayed and has begun to set, apply the aggregates. Aggregates shall be applied by the aggregate spreader if uniform application transverse and longitudinal to the pavement is required. Aggregates may be applied by hand when localized areas requiring blotting of excess emulsion are present.

J. Transverse Paper Joints

When beginning a new application of the fog seal transversely abutting the previously placed fog seal a transverse paper joint shall be used so excess asphalt and aggregates are not placed at the joint. The transverse paper joint shall be formed by placing 36-inch-wide Kraft paper on top of the previously applied fog seal so the edge of the paper aligns with the joint that will be formed when the previously placed fog seal meets the newly applied fog seal. The asphalt distributor shall begin applying asphalt emulsion by starting the application on top of the Kraft paper. After the distributor moves forward and over the joint the paper shall be removed.

Commentary

Ideally, the paper should also be placed at the end of the distributor shot, as well. This creates a clean, edge with the correct emulsion and fog quantity at the joint. Where the paper should be placed is calculated based on the emulsion shot rate and the quantity of emulsion in the distributor. The distance the distributor travels before encountering the paper and turning off the bar should be approximately equivalent to 80 percent of the distributor tank volume. This assures the distributor does not spray until empty which can result in less emulsion applied than desired at the end of the shot.

K. Traffic Control

Traffic may be allowed onto the fresh fog seal after the emulsion has completely set and after aggregates have been applied, if used.

L. Protection of Motor Vehicles

The Contractor is responsible for claims of damage to vehicles until the roadways and shoulders have been swept free of loose aggregate and permanent pavement markings have been applied. If permanent pavement markings are to be applied by Agency forces, the Contractor's responsibility ends after completion of the fog seal and placement of temporary pavement markings.

M. Sequence of Work

Construct the fog seal so that adjacent lanes are sealed on the same day when possible. If the adjacent lane(s) has not been sealed sweep all loose aggregates from the unsealed lane(s) before traffic is allowed on the surface without traffic control.

The permanent pavement markings shall not be placed for three days after placing the fog seal for water borne pavement marking or ten days for other types.

If fog sealing a new chip seal, the fog seal can be applied after the chip seal coat is cured, typically 1-2 days after construction.

Permanent pavement markings shall not be placed for three days after placing the fog seal.

Commentary

The fog seal will usually cure, or set, within 2 hours under dry conditions and temperatures above 60F. Interim pavement markings can be placed after the fog seal cures.

N. Quality Control

1. General

The Contractor is responsible for quality control (QC) sampling and testing and shall submit a QC plan including materials and procedures for verifying the quality of the fog seal aggregates and emulsified asphalt(s). The Contractor's QC plan shall include but is not limited to sampling, testing, inspection, monitoring, documentation, and corrective action procedures during transport, stockpiling and placement operations.

A written Quality Control Plan (QCP) shall be developed which details the Contractors's QC program that meets the requirements of these specificaitions. The QCP shall be contract specific and signed by the Contractors's representative. Fog seal construction shall not proceed without Agency approval of the QCP and QC personnel present on the project. Failure to comply with these provisions will result in shutdown of the operationsuntil such time as the Contractor's operations are in compliance.

2. Personnel

The QC staff shall include the following as a minimum:

a. QCP Administrator – The person with overall responsibility of the QCP

b. QCP Manager – The person responsible for the execution of the QCP and liaison with the Agency. This person shall be on the project, and have the authority to stop or suspend construction operations.
c. QC Technicians – The person(s) responsible for conductingQC tests and inspection to implement the QCP. QC technicians shall have Level 2 Aggregate Testing Certification from the American Concrete Institute (ACI) or other accrediting body approved by the Agency.
d. Certified Crew Members – Three crew members (job foreman, aggregate spreader operator and asphalt distributor operator), at a minimum, shall possess a valid fog seal certification and be on the project at all times the fog seal is being constructed. The fog seal certification is administered by the National Center for Pavement Preservation (NCPP) on behalf of AASHTO TSP[2] (Transportation Services Preservation Program).

3. Testing Facilities and Equipment

The Contractor shall provide the name of the laboratory conducting QC tests. The laboratory shall maintain accreditation by the AASHTO Accreditation Program (AAP) for all tests within the relavent scope of testing, or other accrediting body approved by the agency. Sampling, testing and measuring devices shall meet the requirements of the specified standards and test methods. The laboratory shall maintain records of the calibration and maintenance of all sampling, testing and measuring equipment.

4. Materials Testing

Fog seal aggregates and asphalt emulsion shall be tested for compliance with the specifications as follows:

Aggregate

a. Stockpile.
Test the aggregate gradation a minimum of once per day, or every 1500 tons, whichever is greater in accordance with AASHTO T27 to determine compliance with Table 1 requirements. If the material is hauled from the production site to a temporary stockpile, test at the temporary stockpile.

b. Construction.
Test the aggregate gradation from the hopper of the fog spreader a minimum of once per day, or every 1500 tons, whichever is greater in accordance with AASHTO T27 to determine compliance with Table 1 requirements. The testing rate for quality values in Table 5 shall be once per source.

Emulsified Asphalt

Only emulsified asphalt from certified or approved sources is allowed for use. Verify the emulsion(s) meet the specifications by obtaining certificates of compliance from the supplier.

Verify the application rate of the emulsified asphalt by dividing the volume of emulsified asphalt used by the area fog sealed each day. Allowable variation is +/- 5% of the application rate adjusted from the design quantity. Provide material certification and quality control test results for each batch of emulsified asphalt used on the project. Include the supplier name, plant location, emulsion grade, and batch number on all reports.

5. Calibration of Equipment and Workmanship

Describe the equipment and methods used for equipment calibration and workmanship as follows:

a. Longitudinal application rates
b. Transverse application rates
c. Asphalt transverse application uniformity
d. Transverse joint construction technique
e. Monitoring method for application rates
f. Sweeping operations and schedule, if aggregate is applied
g. Method of controlling traffic

6. Documentation

Describe the documentation and reporting procedures for all QC activities. Include samples of all QC test forms, inspection and test reports.

7. Records and Documentation

The Contractor shall maintain complete records of all QC tests and inspections. All QC test results shall be submitted to the Agency at the end of the contract. A material certification shall be submitted from each supplier for each batch of material delivered to the project, including test results.

The QC records shall contain all test and inspection reports, forms and checklists, equipment calibrations, supplier material certificates, and non-conformance and corrective action reports. The QC records shall indicate the nature and number of observations made, the number and type of deficiencies found, the quantities conforming and non-conforming, and the nature of corrective action taken as appropriate for materials as well as workmanship. The QC records shall be available to the Agency at all times, and shall be retained by the contractor for the life of the contract. The Contractor's documentation procedures will be subject to approval by the Agency prior to the start of work, and to compliance checks by the Agency during the progress of the work.

8. Compliance with Specifications

   The Contractor shall attest in writing to the Agency that the fog seal has been constructed in accordance with and meets the requirements of the specifications at the conclusion of the project.

O. Agency Acceptance

1. General
   The Agency will conduct acceptance sampling, testing, and inspection activities to ensure material quality, correct application rates, sweeping, and traffic control are within specification requirements. These activities will be done randomly by the Agency.
2. Acceptance Activities
   i. Materials Testing

      Aggregate (if used)

      Sample aggregate taken from the aggregate spreader hopper once per day. Samples will be stored and tested for gradation at the discretion of the Agency. If the results vary from the requirements of Table 1, a price reduction will be applied per the Schedule of Price Reduction prepared by the owner agency.

      Emulsified asphalt

      Sample the first shipment and provide one sample for every 50,000 gallons (approximately 200 tons) thereafter. Testing of emulsions shall be in accordance with AASHTO M140, M208, and M316.
3. Equipment

   All equipment to be used on the project shall be evaluated by the Agency to assure it is in acceptable operating condition, calibrated correctly and will provide the quantities of material specified.
4. Final Inspection

   A final inspection will be done to assure that no bleeding or flushing, excessive fog loss or crushed aggregate has occurred. Longitudinal and transverse joints will be inspected to assure that no excessive overlap has occurred.

410.04 MEASUREMENT

The Engineer will measure the acceptably completed fog seal as specified in Subsection 109.01 of the AASHTO Construction Guide Specifications or as follows:

A. Emulsified asphalt

Measure the undiluted emulsified asphalt by volume, at 60F.

B. Aggregate

Aggregate will be paid for by the area of pavement surfaced.

410.05 PAYMENT

Payment for fog seals can be done by either paying for the materials as unit costs, or for the completed fog seal by area of pavement sealed.

Commentary

The advantage of payment by the square yard for a completed fog seal is simplicity if the area is easily defined. The disadvantage is that an incentive is created to reduce material quantities. Reduced asphalt emulsion quantities can lead to chip loss and vehicle damage.

A. Payment by Unit Price

The Agency will pay for accepted quantities at the contract price as follows:

1. Payment for the accepted quantity of emulsified asphalt and aggregate for fog seal (including any required additives) at the contract bid price of measure is compensation in full for all costs of furnishing and applying the material as specified.

2. Payment will be made in accordance with the schedule set forth below at the Contract bid price for the specified unit of measure.

Item No.	***Item***	***Unit***
State ##	Emulsified asphalt for fog seal……	Gallon
State ##	Aggregate for fog seal……	Tons
State ##	Diluted emulsion for fog seal, if used.....	Gallon

Such payment is full compensation for furnishing all materials, equipment, labor, and incidentals to complete the work as specified.

B. Payment for Completed Fog Seal

1. Payment for the accepted quantity of the fog seal at the Contract bid unit price of measure is compensation in full for all costs of furnishing and applying the material as specified, including cleaning the existing pavement, stationing, purchase of

aggregate, delivery of aggregate, all labor, equipment, and materials necessary for the placement of the chip seal for full lane coverage, sweeping of any loose aggregate after construction and other requirements as specified.

2. Payment will be made in accordance with the schedule set forth below at the Contract bid price for the specified unit of measure.

Item No.	***Item***	***Unit***
State ##	Fog seal…….	Square Yard
State ##	Diluted emulsion for fog seal, if used.....	Gallon

Such payment is full compensation for furnishing all materials, equipment, labor, and incidentals to complete the work as specified.

Commentary

The advantage of payment by the square yard for a completed fog seal is simplicity if the area is easily defined. The disadvantage is that an incentive is created to reduce material quantities.