Development of a Specification for Quality Acceptance of Chip Seal Using a Laser Texture Scanner

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DEVELOPMENT OF A SPECIFICATION FOR QUALITY ACCEPTANCE OF CHIP SEAL USING A LASER TEXTURE SCANNER

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16. ABSTRACT

Chip seal applications are widely used in Washington state as a cost-effective pavement surfacing method; however, variations in performance and premature failures have been observed. Currently, chip seal construction and its acceptance (except for materials) are largely based on the experiences of contractors and inspectors. The goal of this study was to develop a quality acceptance specification based on a laser texture scanner. Data were collected with laser scanners during and after the construction of several WSDOT chip seal projects. Experimental sections were also included in the field to study modified chip gradation and compaction patterns. It was found that the rut depth in existing pavement strongly correlates with the percent embedment of chips. It was also found that emulsion and its asphalt residue migrate to rutted wheel paths even after construction, which increases the chip seal's bleeding potential. It is critical to address rutting (> ¼ in.) in existing pavement before chip seal placement. When the chip seal is placed on new hot mix asphalt (HMA) inlay, the emulsion can drain into the new HMA if an inadequate fog seal has been applied on top of the HMA, which may lead to raveling (or loss of chips) of the chip seal. An oscillatory roller crushes chips and is not recommended for chip compaction. A combination roller, which consists of pneumatic tires and a steel drum, may be effective in compacting chips in the wheel paths and between the wheel paths. Sharp curves were also found to increase susceptibility to a loss of chips. The mean profile depth (MPD) measured by the laser scanner, which is inversely related to the percent embedment of chips, is a good indicator of chip seal performance. A draft quality acceptance specification in terms of MPD was developed. A program was also developed to determine the lower limit of the MPD, based on a formula developed in this study. An upper MPD limit of 170 mils (0.170") was proposed. A laser scanner test protocol was developed as part of this study. Recommendations for further studies were provided.

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LIST OF ABBREVIATIONS

ADT	Average daily traffic
ALD	Average least dimension
BST	Bituminous surface treatment
COV	Coefficient of variation
CTM	Circular track meter
DFT	Dynamic friction tester
DOT	Department of transportation
ETD	Estimated texture depth
HMA	Hot mix asphalt
LSL	Lower specification limit
LTS	Laser texture scanner
MPD	Mean profile depth
MTD	Mean texture depth
NMAS	Nominal maximum aggregate size
PCR	Pavement condition rating
SPWL	Simple percentage within limits
WSDOT	Washington State Department of Transportation

EXECUTIVE SUMMARY

Chip seal, commonly known as bituminous surface treatment (BST), plays a crucial role in pavement preservation and maintenance on Washington state routes. This cost-effective surface treatment enhances road surface durability and extends pavement service life. However, currently, other than materials, the quality assurance of chip seal construction is largely based on the experiences of contractors and inspectors. Based on field projects, this study conducted a comprehensive evaluation of chip seal performance based on mean profile depth (MPD) measured by a laser texture scanner. This parameter has been identified to be closely correlated with the embedment percentage of chip aggregates, which accounts for emulsion application rate, compaction efforts, pavement substrate conditions, and more.

This study produced the following findings:

1. As determined by a literature review and industry survey, chip seal construction is traditionally subject to visual inspections to assess their performance during construction. Recent methodologies have introduced some objectivity into the process, including measurements relating to surface texture, such as those by the Wyoming Department of Transportation and New Zealand. Graded chips, instead of single-size chips, are the most commonly used for chip seal. Regarding emulsion types, CRS-2P is predominant. Agencies primarily use pneumatic rollers for compaction, with variations in the required number of passes, while some agencies also use steel rollers for specific compaction needs. Common issues such as loss of chips and bleeding highlight the

importance of these quality controls to maintain the effectiveness and durability of chip seal surfaces.

2. Field program evaluations encompassed diverse factors, including different climatic conditions, construction methods, traffic, and chip aggregate gradation (such as ½ in. - No. 4, 3/8 in. - No. 4, and modified 3/8 in. gradation). The chip seal construction projects that were included in this study covered all Washington State Department of Transportation (WSDOT) regions. The macrotextures of these projects were measured in terms of mean profile depth (MPD) during construction in the summer of 2022 and after one year in service in the summer of 2023. In addition, measurements were taken in WSDOT's Eastern Region projects in fall 2022, winter 2022, and/or fall 2023. Limited laboratory experiments were also conducted to evaluate several issues arising during the construction and monitoring stages.
3. On the basis of field samples or field measurements, a relationship between MPD and percent embedment of chips was developed. This relationship is based on realistic field conditions for the chip seal, which is believed to be more representative of such a relationship than that developed on the basis of laboratory conditions in previous studies.
4. The modified gradation of chips and different compaction patterns that were experimented with in test sections did not manifest performance that was distinct from that of regular gradations and construction patterns in current practices. The researchers believe that the modified gradation is close to the regular gradation of chips. The oscillatory roller was found to crush chips and

is therefore not recommended for rolling chips. However, the combination roller, which comprises pneumatic tires and a steel drum, seems to be effective for compaction in both wheelpaths and between wheelpaths and is recommended for final rolling.

5. When chip seal is placed on new hot mix asphalt (HMA) inlay, significant drainage of emulsion can occur, despite the application of a fog seal on the HMA. It is recommended that a higher emulsion application rate be used compensate for the “lost” emulsion, and/or that a higher rate of fog seal be used on the new HMA inlay/overlay before the chip seal is placed. Alternatively, HMA can be placed significantly earlier (e.g., six months or longer) before chip seal construction to allow the HMA texture to be closed by traffic.
6. A strong correlation was found between rut depth in existing pavement and MPD. Higher rut depth correlated with lower MPD or a higher percent embedment of chips, which indicates a greater degree of bleeding in the field. Laboratory experiments showed that emulsion and its asphalt residue can migrate between chips to rutted areas in the wheelpaths, even after compaction of the chips, thereby increasing the bleeding potential in the wheelpaths. This finding is significant and highlights the importance of removing excessive rutting (e.g., >¼ in.) in existing pavement before chip seal placement. Additionally, selecting an appropriate emulsion type with lower fluidity at higher temperatures warrants further study.
7. After one year of service, it was found that an MPD of 0.065 in. or higher in the wheelpath indicates good chip seal performance, while lower values

suggest that bleeding has occurred. Therefore, it is recommended that a one-year MPD of 0.065 in. is used as a performance threshold.

8. A model was developed to relate MPD after one year of service to factors that affect chip seal performance, such as initial MPD between wheelpaths immediately after brooming, truck traffic, rut depth in existing pavement, substrate condition, and shade. On the basis of the 0.065-in. for one-year performance threshold, a draft specification was created to use initial MPD between wheelpaths immediately after brooming as a quality assurance measure, according to the model developed in this study. An upper limit of 0.170 in. was proposed in the draft specification, based on raveling in the field.
9. Further studies are recommended to verify the model with longer field performance, e.g., three to four years or longer, instead of one year. A study and implementation of chip seal mix design are also recommended to determine appropriate application rates of emulsion and chips, before chip seal construction, based on specific site conditions.

Chapter 1 INTRODUCTION

1.1 Background and Problem Statement

Chip seal, a cost-effective pavement surfacing method, is widely used by state and local governments in Washington state. Approximately 7,000 miles of Washington State Department of Transportation (WSDOT) roadway are designated as chip seal routes (Pierce and Kebede, 2015), although chip seal often has been placed on roads that are not necessarily designated as chip seal routes. The appeal of chip seals lies in their lower cost in comparison to that of hot mix asphalt projects and their ability to extend the life of asphalt pavements. However, unlike hot mix asphalt (HMA), which undergoes rigorous mix design, mix verification, and construction quality control/acceptance measures, chip seal construction acceptance relies on the experience and visual observations of field engineers and inspectors. This reliance, as well as programming decisions, has led to significant variations in chip seal performance, with some projects experiencing premature failures that reduce their average lifespan (Pierce and Kebede, 2015).

One critical factor contributing to these premature failures is the percentage of the chips embedded in the asphalt (Boz et al., 2019), analogous to density of HMA in the field. Percent embedment can be related to chip dimension, emulsion application rate, pavement substrate, compaction, etc. Inadequate embedment leads to chip loss, while excessive embedment causes bleeding due to exposed asphalt on the surface. This not only shortens the chip seal life but also poses safety issues, such as hydroplaning and reduced skid resistance (Boz et al., 2019). Currently, there are no data-driven measures to determine the percentage of chip embedment during construction, hindering quality control.

The lack of measurement and control of percent embedment significantly contributes to the variation in chip seal performance and premature failures. As the WSDOT faces stringent budgets, chip seal projects are considered a viable approach to maintaining pavements in good condition (minimal rutting and cracking). However, without improvements and specific construction specifications, contractors are not easily held accountable for failures, often causing WSDOT to have to assume repair costs.

Laser technology has already been successfully utilized to measure the macrotexture of chip seal projects, showing potential for use in determining the percent embedment of chips. Incorporating the laser scanner into the acceptance process for chip seal projects can offer valuable data-driven insights for quality control and performance assessment. This can address the current lack of measurement and control and potentially reduce premature failures in Washington state's chip seal projects.

1.2 Objectives

The main objective of this project was to develop a specification for chip seal construction that would enhance their quality and effectiveness. The specific objectives were as follows:

- Evaluate the performance of the automated laser scanner in determining percent embedment and correlate it with the field performance of chip seals.
- Provide practical recommendations for the potential inclusion of chip seal specifications and acceptance criteria.

1.3 Report Organization

This report consists of five chapters. Chapter 1 provides an overview of chip seals, highlights the main issues, and sets out the study objectives. Chapter 2 offers an extensive review of chip seal literature, focusing on chip seal materials, design methods, construction and performance assessment, and a summary of a survey of state highway agencies. Chapter 3 details the field experiment program to evaluate chip seal performance during and after construction. Chapter 4 presents the results and analysis of the field experiments. Chapter 5 presents the study conclusions and offers recommendations for implementations, as well as recommendations for further studies.

Chapter 2 LITERATURE REVIEW AND SURVEY

Chip seal, a bituminous surface treatment (BST), is made up of a combination of a layer of asphalt emulsion or hot binder, covered by one or more layers of aggregates (i.e., chips and/or choke), followed by rolling, brooming, and if needed, a thin fog seal layer. Chip seal is effective in conserving the existing asphalt pavement and is designed primarily to retard pavement deterioration (seal minor cracks) while improving surface characteristics (Galehouse et al., 2003), though chip seal has also been used on new asphalt paving for pavement preservation. Chip seals can increase skid resistance, prevent the infiltration of water, and slow the growth of distresses (Gransberg and James, 2005). WSDOT applies chip seals throughout Washington state (Pierce and Kebede, 2015). Research has shown that chip seal treatment, when applied correctly and at the right stage, can extend the service life of the pavement by four to six years on average (Pierce and Kebede, 2015), and possibly even longer.

2.1 Factors Affecting Chip Seal Performance

2.1.1 Chip Seal Materials and Properties

The performance of the chip seal depends on the interaction between aggregate and emulsion and their capability to bond and hold properly. Chip seal consists of two primary materials: cover stone aggregates (i.e., chips) and asphalt, which can be either hot-applied asphalt binder or asphalt emulsion (Rahman et al., 2012).

2.1.1.1 Aggregate Properties

Chip seal performance is affected by the properties of the aggregate, as discussed below.

Aggregate Size and Gradation

Chip seal performance depends on particle gradation, which affects void quantity and embedment (Hanson, 1934; Shuler et al., 2011). The coefficient of uniformity (C_u) is used to assess gradation, and a lower presence of fine particles enhances adhesion between asphalt and particles (Kim et al., 2012). Aggregates with uniform gradations improve tire-surface contact, leading to enhanced skid resistance (Tighe et al., 2000). However, a single-size gradation can increase traffic noise (Wood et al., 2006).

Particle Shape, and Flakiness

Particle shape significantly influences chip seal microtexture and macrotexture (Gransberg and James, 2005). Cubic particles need less emulsion for embedding than flat and elongated ones (Buss et al., 2016). Under traffic, flat and elongated particles tend to have bleeding, leading to premature chip seal failure (Gransberg and James, 2005).

Toughness, Soundness, and Cleanliness

Aggregates must resist both polishing and abrasion (Shuler et al., 2011), which are evaluated by using tests such as the Los Angeles Abrasion Test (AASHTO T96) and the Micro Deval Test (AASHTO T327) (Shuler et al., 2011). Soundness tests measure material degradation from weathering, limiting aggregate mass loss (Shuler et al., 2011). Cleanliness is also crucial for chip seal performance, as excessive fine particles can compromise adhesion (Estakhri and Senadheera, 2003).

2.1.1.2 Asphalt Emulsion

Emulsion requires lower placement temperatures (e.g., 140°F to 180°F) than hot-applied asphalt binder (e.g., minimum 275°F) and therefore is more often used (Wood et al., 2006). Emulsion provides an embedding layer where the aggregate will be embedded and retained. An asphalt emulsion is composed of asphalt, water, and emulsifier additives

(McHattie, 2001). Asphalt content in asphalt emulsion ranges from 50 percent to 75 percent, with classifications including anionic, cationic, and nonionic types (McHattie, 2001). Climate, aggregate moisture, and dust influence emulsion performance (McHattie, 2001), and faster settings emulsion is recommended for chip seal applications to minimize traffic interruptions (Shuler et al., 2010; Buss et al., 2016).

The breaking of an emulsion depends on chemical composition and charge type. Anionic emulsions, such as HFMS-2, have a negative charge and a prolonged breaking time, whereas cationic emulsions, such as CVRS-2P, have a positive charge and break quickly, which allows for rapid initial bonding and minimizes traffic disruptions (McHattie, 2001). While cationic emulsions break and settle to allow water to evaporate, anionic emulsions experience simultaneous asphalt setting with water evaporation (McHattie, 2001). Figure 2-1 illustrates how the breaking of emulsion, as well as the curing, occurs in the field (CalTrans Division of Maintenance, 2003).

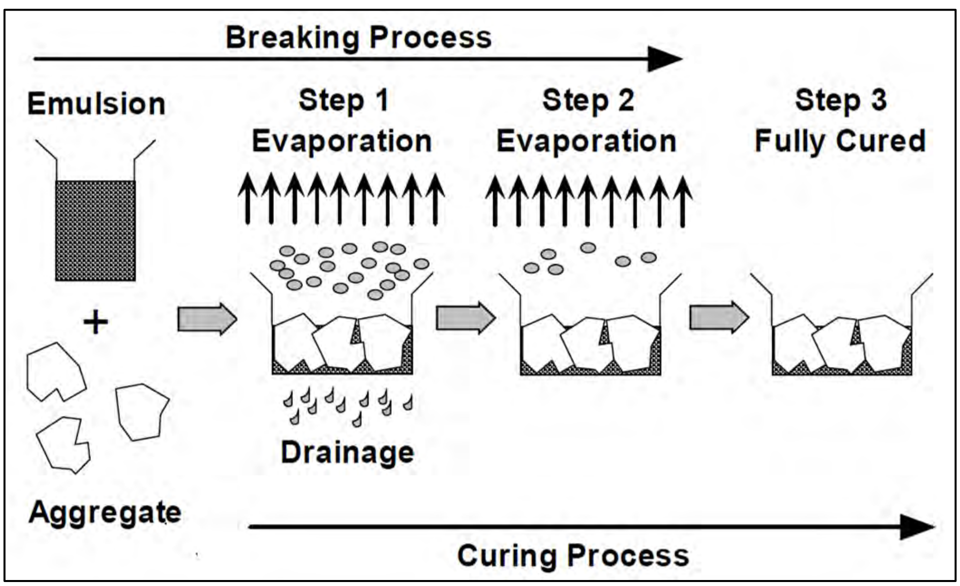


Figure 2-1. Photo. Breaking and Curing Process of Emulsion
(Source: CalTrans Division of Maintenance, 2003)

Curing is the second process that occurs in emulsion chemistry. Once the breaking starts, the water begins to evaporate, causing the asphalt on the bottom of the surface to firm up. This process should result in 60 to 70 percent of the aggregate depth being covered by the emulsion after breaking and curing. Figure 2-2 illustrates the emulsion curing process and settlement (Wood et al., 2006). Factors such as wind, humidity, temperatures (high and low), and the season influence the curing process. For instance, drizzle can lead to premature failure of the chip seal treatment in some instances (Buss et al., 2016).

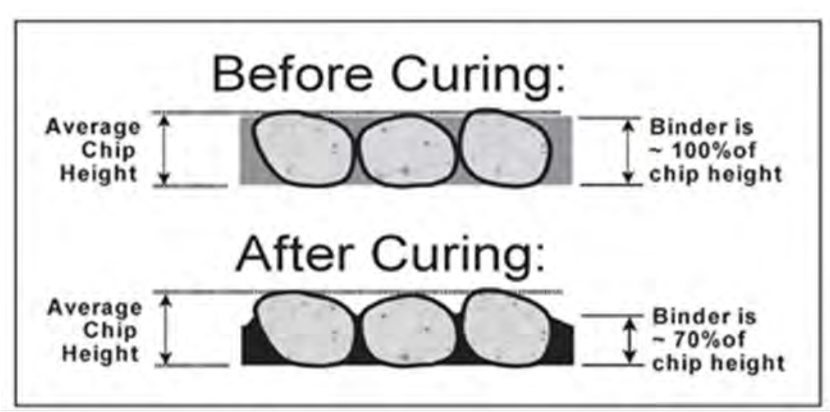


Figure 2-2. Photo. Curing Process and Settlement (Wood et al., 2006)

2.1.3 Chip Seal Design Methods

The performance of chip seal also depends on the materials and their application rates used for its construction and the construction process itself. However, application rates often rely on the experience of contractors or emulsion suppliers. The design of a chip seal can provide valuable information to guide the construction and is specific to the section of the road on which it is applied (Gransberg and James, 2005). Different design methods have been developed from empirical data (Gransberg and James, 2005). The McLeod and Kearby methods are the most common chip seal design methods in the United States.

On the other hand, some methods have been developed in different countries such as Road Note 39 (United Kingdom), Road Note 3 (tropical regions, i.e., Malaysia), Austroads Provisional Sprayed Seal Design Method (Australia), and Technical Recommendations for Highways, Surfacing Seals for Rural and Urban Roads or TRH3 (South Africa) (Gransberg and James, 2005). Furthermore, to accommodate the different conditions of roads and countries, many departments of transportation (DOTs) have developed their own design methods, often based on the Mcleod Method (Gransberg and James, 2005).

However, these design methods have not been widely applied in practice in the U.S., and chip seal design and construction are still largely based on experience.

2.1.4 Site Conditions

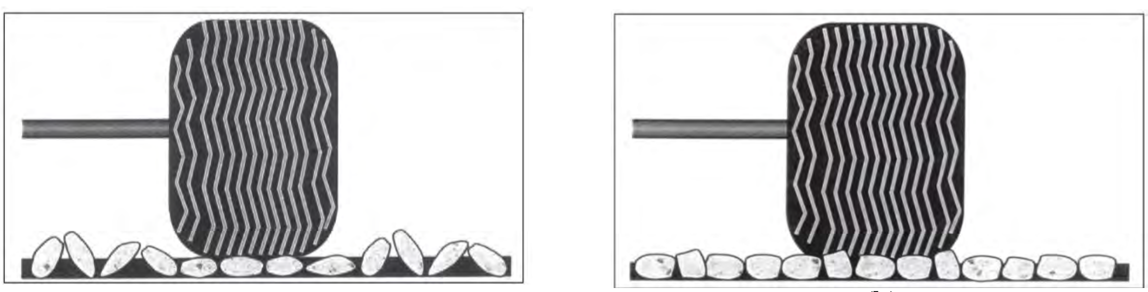
The performance of chip seals is influenced by existing pavement condition parameters such as distress levels, substrate surface type, friction condition, and pavement geometry (Shuler et al., 2010; Lee et al., 2011). Maintenance activities such as crack sealing and pavement repair are essential before chip seal application (Buss et al., 2016). Pavements with high-stress levels may experience emulsion loss, affecting embedment (Peshkin et al., 2004; Shuler et al., 2011). Applying a fog seal treatment before chip seal application on highly porous surfaces is preferred to improve adhesion and performance (Shuler et al., 2010).

Pavements with cracks and significant deflections may affect chip seal performance, as high deflections in the pavement structure can lead to fatigue in the pavement layers and surface, including chip seal (South African National Roads Agency, 2007). Soft substrates and rutting presence increase chip penetration and cause distresses such as bleeding and flushing (Shuler et al., 2010). Maintaining surface uniformity is crucial for proper emulsion placement (Shuler et al., 2011).

Pavements with low skid resistance (i.e., smooth surfaces), may lead to a reduction in emulsion adhesion. Smooth surfaces also result in inadequate embedment of aggregate chips into a substrate, which can cause early raveling and poor chip seal performance (Shuler et al., 2011). For instance, if the surface is smooth and lacks sufficient roughness, then it is typically advised to reduce the emulsion rate to avoid flushing. On the other hand, for rougher surfaces, a higher emulsion application rate may be necessary to ensure that the aggregate stays in place. Various tests, such as the dynamic friction tester (DFT) (Buss et al., 2016), and circular texture meter (Shuler et al., 2010) help assess surface texture and friction. Rough textures are generally beneficial, but excessive texture may require adjustments in emulsion application rate (Shuler et al., 2010).

The performance of chip seals is significantly influenced by pavement geometry, including factors such as the number of lanes, curves, intersections, and slopes (Shuler et al., 2011; Buss et al., 2016). Roads with steep grades and fewer lanes may experience premature bleeding, where the aggregate may dislodge or experience shear moment. This can lead to excess binder on the surface, or chip loss, particularly in areas with positive slopes where vehicles face increased friction from tires (Buss et al., 2016; Mahoney et al., 2014). At intersections and turns, the setting of the aggregate can be disrupted if the emulsion has not fully cured or if traffic conditions (e.g., high speeds) prevent proper bonding. This may contribute to both bleeding and chip loss (Shuler et al., 2010; Mahoney et al., 2014; Buss et al., 2016). Additionally, the presence of curves in the pavement geometry can exacerbate chip loss, particularly if the road lacks adequate traffic calming measures or lane width adjustments to accommodate vehicles navigating the curves (Buss et al., 2016). Pavement sections with slopes and gradients not exceeding 15 percent are recommended (Mahoney et al., 2014).

The behavior of traffic on chip seals is a critical consideration for their performance. Slower vehicle movement, as observed by Shuler (1991), aids in the compaction of the treatment, ensuring better embedment. Conversely, if traffic is allowed on the surface too soon at high speeds during construction, it can disrupt embedment, leading to increased chip loss and an uneven distribution of aggregate (McHattie, 2001). Furthermore, factors such as the timing of opening to traffic, the type of traffic vehicle, and its volume significantly impact seal effectiveness (Testa and Hossain, 2014). The shape of aggregates, e.g., cubic and tetrahedral vs. flat and elongated, plays a crucial role in how they interact under traffic loading, as illustrated in Figure 2-3 (Wood et al., 2006).



(a) (b)

Figure 2-3. Photo. Behavior of Particles under Traffic Loading (a) Flat and Elongated Particles Behavior, (b) Cubical Particles Behavior (Source: Wood et al., 2006)

2.1.5 Construction Effects on Chip Seal Performance

Chip seal construction involves four steps: emulsion spreading, aggregate spreading, rolling for proper embedment, and sweeping (Gransberg and James, 2005).

Successful construction practices focus on materials evaluation, correct application of emulsion and aggregate, and adherence to construction steps (Gransberg, 2006). Proper rolling ensures initial embedment and aggregate orientation within the emulsion layer (Gransberg and James, 2005). Compaction patterns and roller types significantly influence chip seal performance (Kim and Lee, 2008). However, construction of chip seal is less regulated and is more based on experiences than materials, for which sampling and testing in the laboratory are often specified.

2.2 Field Performance Measurement of Chip Seals and Agency Practices

2.2.1 Performance Measures of Chip Seals

Traditionally, field assessment of chip seals has relied heavily on visual inspections by pulling chips, which can be subjective. The sand patch test, also known as the volumetric technique (ASTM E965), evaluates pavement macro-texture. This can be used to correlate with surface voids and offer insights into chip seal performance (Gransberg and James, 2005; Ozdemir et al., 2018). However, recent developments in technologies, such as the laser texture scanner, provide more objective evaluation methods. Mean texture depth (MTD) and mean profile depth (MPD) from a laser scanner have emerged as key indicators of chip seal quality and durability, providing more objective measures (Pierce and Kebede, 2015).

2.2.1.1 Conventional Methods

The sand patch test, also known as the volumetric technique (ASTM E965), evaluates pavement macro-texture (Gransberg and James, 2005). By employing a fixed sand volume and observing the spread in a circular shape in the field, this method estimates chip seal macrotexture (Ozdemir et al., 2018).

Equation (1) calculates MTD from sand volume and spread area (ASTM , 2019)

$$\mathrm{MTD} = \frac{4 \times \mathrm{V}}{\pi \times \mathrm{D}^2} \qquad \text{(Equation 1)}$$

where

MTD= Mean texture depth, which can be expressed in mm, or in.

V= volume of sand expressed as mm^3 or in^3;

D= average diameter of the sand circle expressed as mm or in.

Equation (2) can be used to determine the embedment percentage based on the sand patch method (Shuler et al., 2011). This equation calculates the percentage of chip embedment by using the average least dimension (ALD) of the chips, along with the weight and unit weight of glass beads (or sand) used to cover the chip seal surface (Shuler et al., 2011).

$$\text{Embedment \%} = 100 \times \frac{\left[\mathrm{ALD} - \left(\frac{W_{bb}}{\gamma_b \times A}\right)\right]}{\mathrm{ALD}} \qquad \text{(Equation 2)}$$

where

ALD = average least dimension;

W_{bb} = weight of beads between the binder surface and the top of the chip;

γ_b = unit weight of beads; and

A = area of glass bead circle.

2.2.1.2 Laser Profiler Method

Mean profile depth is a critical parameter for evaluating pavement macrotexture, calculated as the average of the highest peak and the second-highest peak levels on the surface profile (Flintsch et al., 2003). Zhao et al. (2019) emphasized MPD's significance in chip seal performance and road safety assessment, particularly concerning pavement friction. Laser technologies, such as the laser texture scanner (LTS) and the circular track meter (CTM), provide field measurements of MPD (Zúñiga Garcia, 2017). Equation (3) is the calculation of MPD:

$$\text{MPD} = \frac{(1^{st}\text{Peak level} + 2^{nd}\text{Peak level})}{2} \qquad \text{(Equation 3)}$$

where the "1st Peak level" refers to the highest peak level; the "2nd Peak level" refers to the second highest peak level. The "Average level" in Figure 2-4 refers to the averages of all the profile depths to the solids' border in the area (not just the valley) where the measurements are taken. MTD, on the other hand, refers to the average depth of the valley, shown in Figure 2-4.

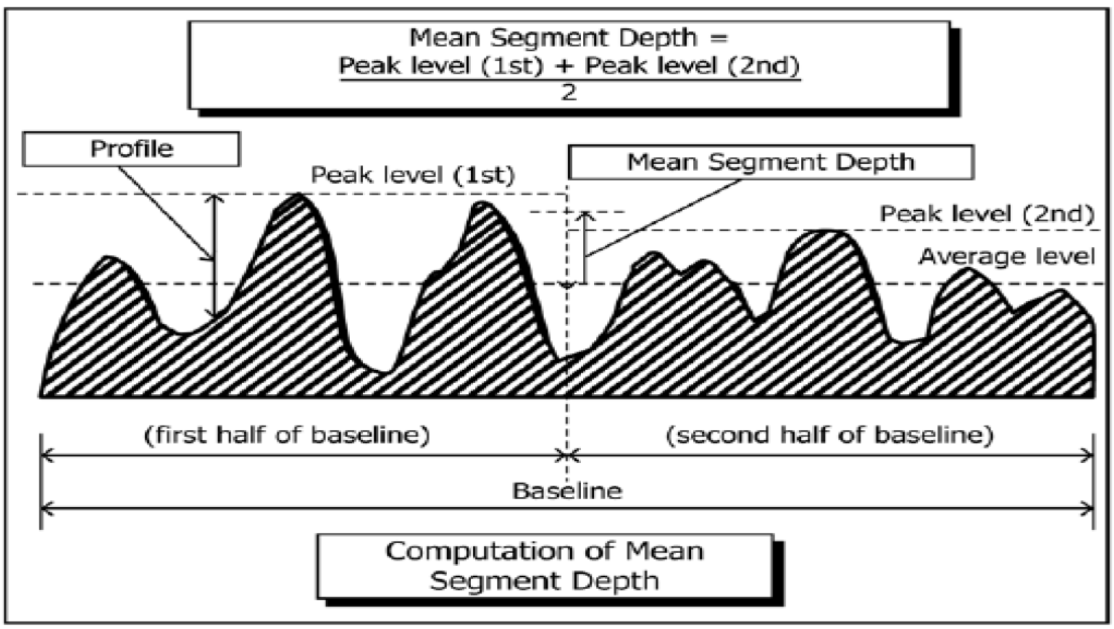


Figure 2-4. Photo. Computation of Mean Segment Depth (Source: ASTM, 2015)

LTS and CTM utilize laser sensors for texture depth measurement, which can be used to determine estimated texture depth (ETD), based on Equation (4) (Zúñiga Garcia, 2017). LTS scans the pavement surface with high precision, covering an area approximately 3 inches wide and 4 inches long, whereas CTM utilizes circular measurements with an 11.2-inch diameter (Zúñiga Garcia, 2017). Figure 2-5 displays a laser texture scanner.

$$\mathrm{ETD} = 0.2 + 0.8 \times \mathrm{MPD} \qquad \text{(Equation 4)}$$

Figure 2-5. Photo. AMES Laser Texture Scanner Model 9300 (Source: Zuniga Garcia, 2017)

The CTM, depicted in Figure 2-6, performs measurements by segments, providing a mean profile depth by circular area. Studies have demonstrated a strong correlation between CTM measurements and conventional tests such as the sand patch test (Flintsch et al., 2003) as shown in Figure 2-7, although laser scanning is more repeatable and expedient.

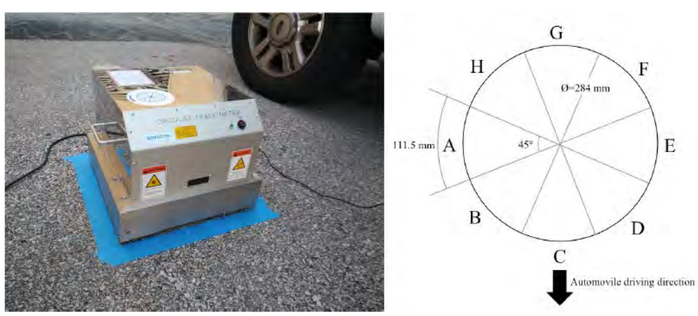


Figure 2-6. Photo. Circular Track Meter and Measurement Process
(Source: Zúñiga Garcia, 2017)

Flintsch et al. (2003) further reinforced the effectiveness of automated macrotexture measurement techniques, showing their potential to replace manual testing by improving reproducibility and reducing technicians' exposure to traffic. Furthermore, Zúñiga García (2017) suggested that advanced texture characterization techniques could be extended to skid resistance assessment, providing a fast and inexpensive tool for road maintenance.

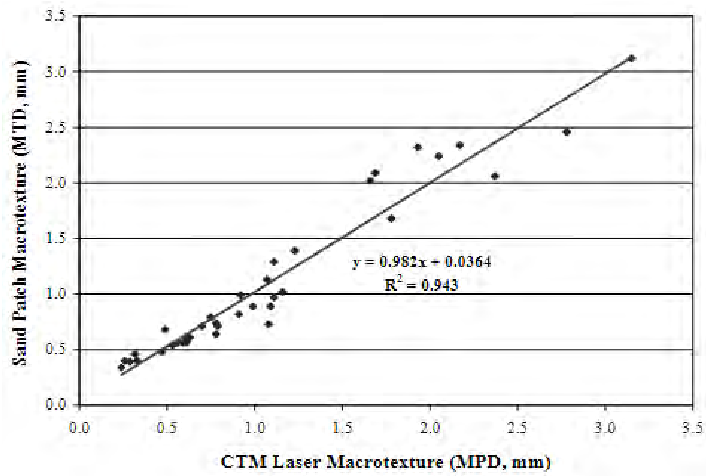


Figure 2-7. Graph. Sand Patch Test (MTD) vs CTM Test (MPD) (Source: Flintsch et al., 2003)

2.2.1.3 Image Processing Analysis

The study conducted by Kutay and Ozdemir (2016) focused on the development of a method to determine percent embedment based on image analysis. The chip seals were evaluated by using image analysis to determine the aggregate embedment depth and the percentage of voids filled with binder (Kutay and Ozdemir, 2016).

Kutay and Ozdemir (2016) and Ozdemir et al. (2018) analyzed chip seal surfaces by using digital imaging techniques to improve pavement macrotexture assessment. Their studies demonstrated that image-based methods could correlate the information content of images with physical texture measurements, such as the sand patch test, which has been traditionally used in pavement assessments (Kutay and Ozdemir, 2016; Ozdemir et al., 2018). However, some challenges remain in the practical application of large-scale imaging methods

2.2.2. Agencies' Quality Acceptance

The New Zealand Department of Transport has refined chip seal assessment by introducing models such as Equation (5), which estimates texture depth at one year, aiding in the establishment of quality control protocols (Gransberg, 2007).

$$\mathrm{Td}_1 = 0.07 \times \mathrm{ALD} \times \mathrm{Log}(\mathrm{Y_d}) + 0.9 \qquad \text{(Equation 5)}$$

where Td_1 refers to the target texture depth at one year (mm); Y_d refers to the design year (years); and ALD refers to the average least dimension of the aggregate in use (mm) (Gransberg, 2007). New Zealand defines a failure as a texture depth of less than 0.028 in. (0.7 mm) for speeds below 44 miles per hour (MPH) (70 km/hr), or less than 0.035 in. (0.9 mm) for speeds above 43.5 MPH. The contractors are paid on the basis of the measured texture. The Texas Department of Transportation also applied the New Zealand method for chip seal projects in San Antonio (Gransberg, 2007).

Similarly, Buss et al. (2016) proposed to Oregon Department of Transportation (ODOT) to use Equation (6) to determine the target texture depth based on aggregate dimensions and traffic levels.

$$\mathrm{Y_d} = 4.916 + 1.68\,(\mathrm{ALD}) - (1.03 + 0.219(\mathrm{ALD})) \times \mathrm{Log}(\mathrm{elv}) \qquad \text{(Equation 6)}$$

where Y_d represents years of design life, elv signifies equivalent light vehicles, and ALD denotes the average least dimension of the aggregate used.

The South African Design Manual (TRH3) also specifies texture depth, providing guidelines based on aggregate dimensions and traffic intensity (South African National Roads Agency, 2007).

In a study for the North Carolina Department of Transportation (NCDOT), Kim et al. (2012) utilized 3-D laser profilers and scanners to assess chip seal quality, as shown in Figure 2-8.

Figure 2-8. Photo. 3-D Laser Profiler (Source: Kim et al., 2012).

2.3. Survey of State Highway Agencies

A questionnaire was sent to all highway agencies in the United States to collect their practices. A total of 28 state DOTs responded. Appendix A contains the survey questionnaire used in this study. Below is a summary of the results of the survey. Note that some of the respondents did not answer all questions or provided more than one answer to some questions. Because many states share the same initial letters, the State Abbreviations recognized by the U.S. Postal Service are used herein.

2.3.1. Use of Chip Seal by State Agencies

As shown in Figure 2-9, 14 agencies indicated using chip seal for proactive preservation. Two agencies (AK and IN) reported utilizing chip seals for maintenance (reactive and temporary). Only one agency (DC) mentioned employing chip seals for rehabilitation (reactive and long-term), and two agencies (DE and MS) employed chip seal for low-volume road surfacing only. Finally, seven agencies chose to use chip seal for multiple purposes including maintenance, low-volume roads, and preservation.

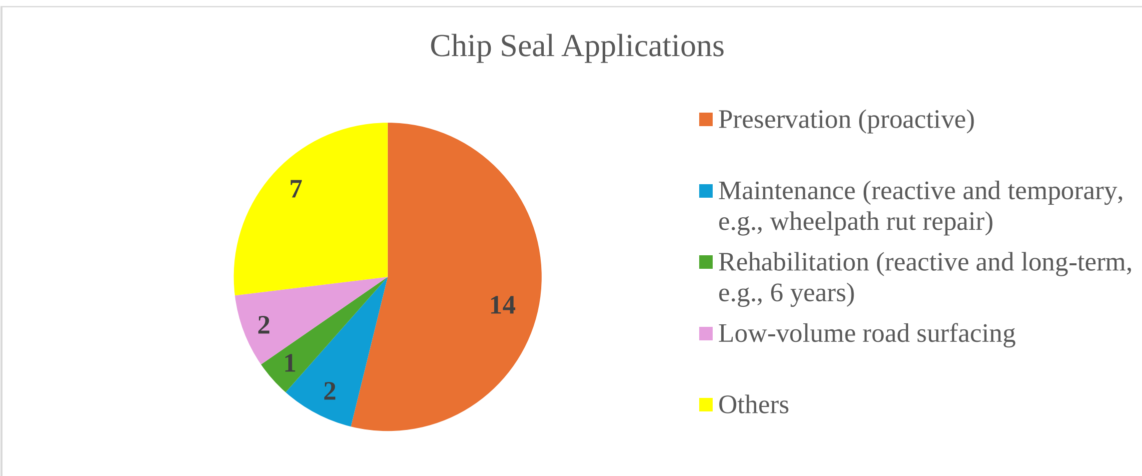


Figure 2-9. Chart. State Transportation Agencies' Use of Chip Seal

2.3.2 Timing of Chip Seal Placement after HMA Overlay or Reconstruction

The timing for placing chip seal after an HMA overlay or reconstruction varied among different agencies (Figure 2-10). Twelve agencies indicated that chip seal was applied "whenever needed," with no specific timeframe mentioned. Eight agencies reported the application of chip seal during different periods: TN DOT reported that the application could occur within the first five years of service, while MI DOT reported between five and seven years. On the other hand, MN DOT established the application of chip seal depending on the district, ranging from 0~1 year and from 5~7 years, but generally after five years, similar to AR DOT. OH DOT did not report having a specific period, but the decision to apply chip seal over overlays was based on factors such as budget, pavement condition rating (PCR), and traffic volume, usually when the PCR was between 65 and 80.

Three agencies reported periods of 0~1 year, namely DE, UT, and WY. Meanwhile, two agencies (SD and ND) reported between 1~3 years. Only one agency (RI) reported a period of 3~5 years.

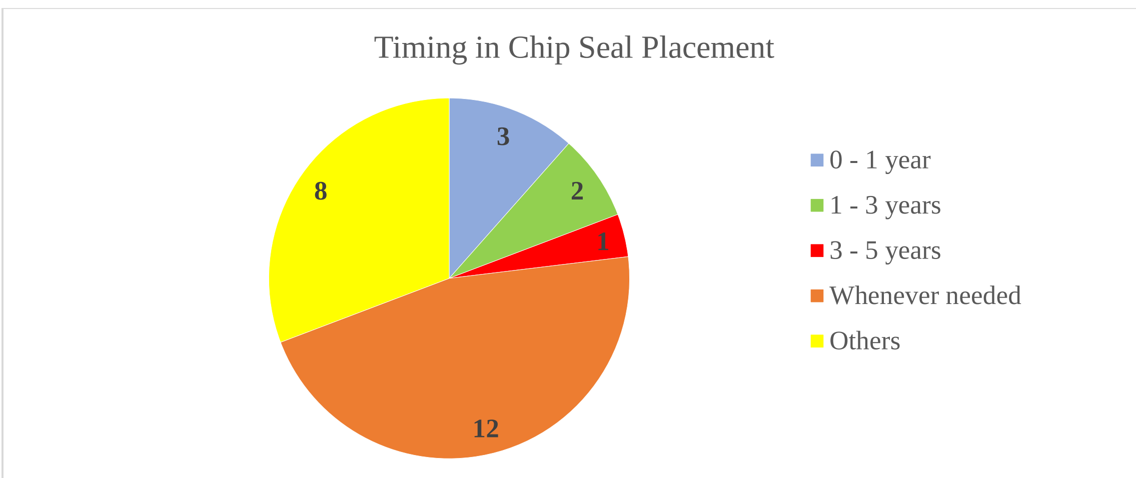


Figure 2-10. Chart. Timing of Chip Seal Placement by State Transportation Agencies

2.3.3 Candidate Projects for Chip Seal Placement

As shown in Figure 2-11, 11 agencies reported applying chip seal to candidate pavements in various conditions. Nine agencies reported applying chip seals to HMA pavements in good condition as a preservation method. Additionally, three agencies (AL, IN, TN) indicated using chip seal on HMA pavements in poor condition, while another three agencies (DE, MS, TX) reported applying chip seal over existing chip seal surfaces.

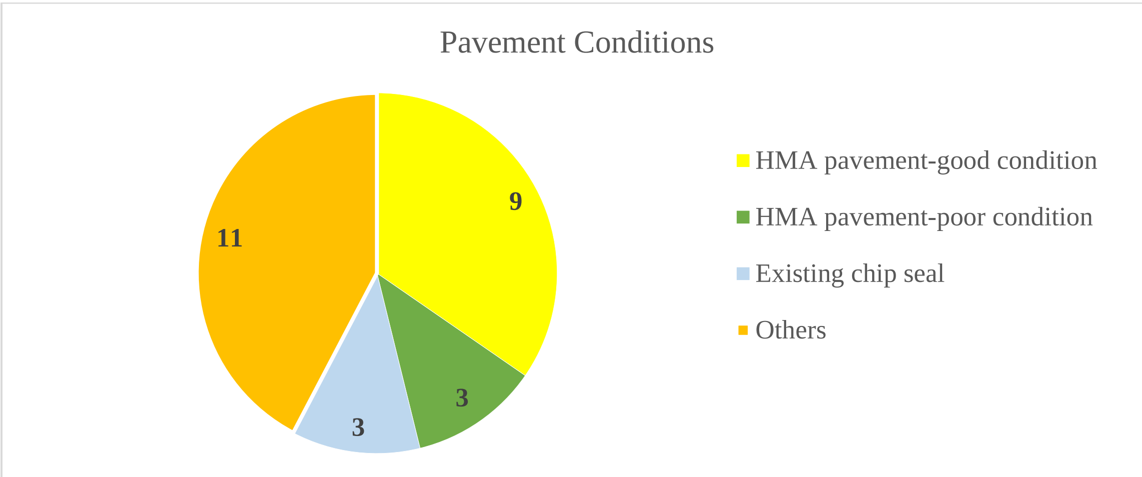


Figure 2-11. Chart. State Transportation Agencies' Practices and Approaches

2.3.4 Types of Chip Seal Used

Figure 2-12 shows that, out of the 26 agencies that responded, 22 indicated that the most commonly used type of chip seal was a single layer chip. One agency (NC DOT) reported using a double-chip seal in combination with a fog seal. Only one other agency (VA DOT) used chip seals with choke. Additionally, two agencies reported using different types of chip seals; for instance, MA DOT used rubber chip seals, and IA DOT applied sand seals.

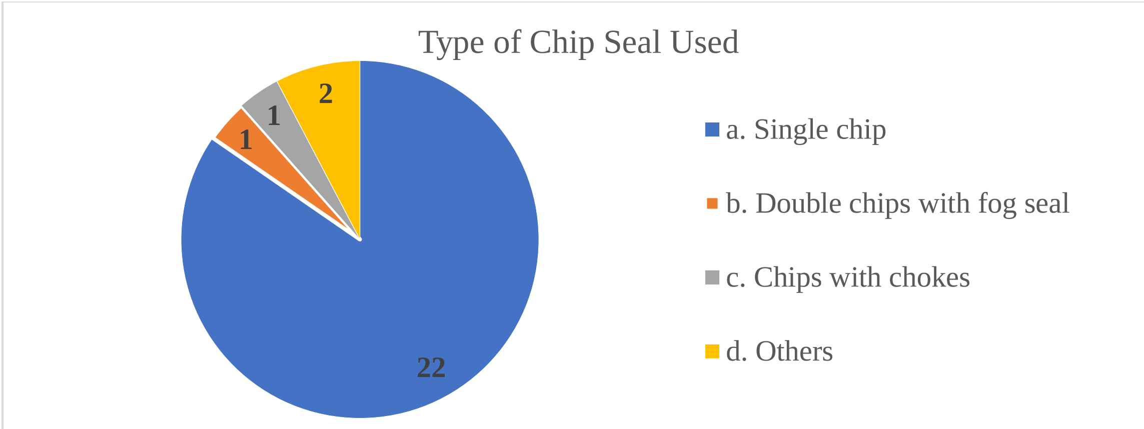


Figure 2-12. Chart. Types of Chip Seal Used by State Transportation Agencies

2.3.5 Average Daily Traffic (ADT) for Chip Seal Projects

As shown in Figure 2-13, seven agencies indicated an ADT of less than 3,000, including AK, AL, IA, MI, ND, and SC, while four agencies (DE, IN, TN, and VA) reported applying chip seal to roads with an ADT of less than 1,000. Five other agencies (CA, NC, OH, RI, and PA) preferred roads with an ADT of less than 5,000. Six agencies, including AR, DC, MA, MN, TX, and UT, applied chip seals to roads with an ADT of less than 10,000.

Additionally, three agencies indicated that there were ADT ranges not covered by the predefined options. KS DOT applied chip seal on roads with varying traffic volumes, including high-traffic roads like I-70, but primarily on lower-traffic roads with fewer than 3,000 vehicles per day. Meanwhile, MT DOT considered all traffic levels for chip seal application. SD DOT applied chip seal on most non-Interstate routes with varying ADT. Additionally, PA DOT occasionally applied chip seal on low-speed routes with high traffic volumes, ranging from 10,000 to 20,000 vehicles per day.

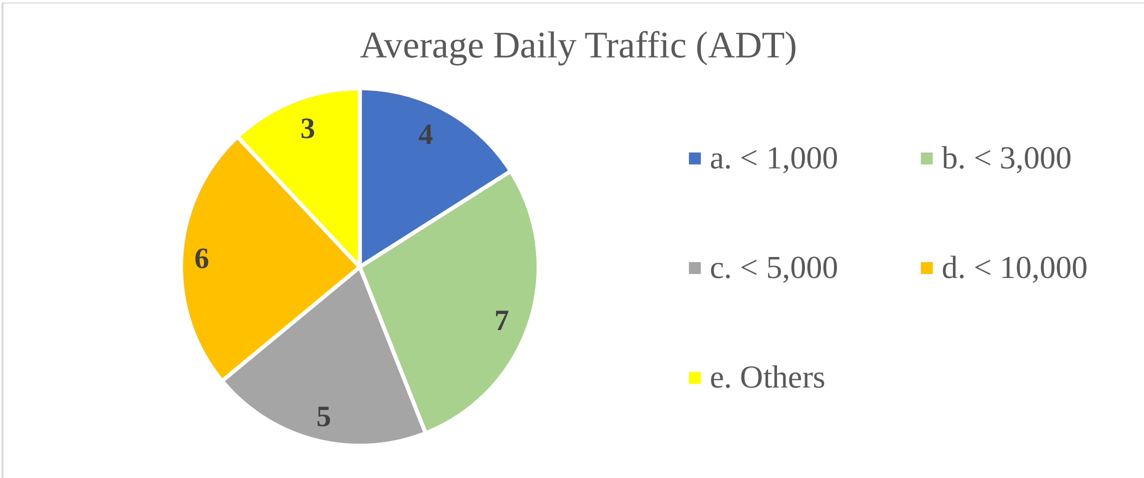


Figure 2-13. Chart. ADT for Chip Seal Projects

2.3.6 Minimum Air Temperature for Chip Seal Construction

Figure 2-14 shows that of the 25 agencies that responded, ten agencies (CA, DE, IN, KS, MN, ND, PE, SC, VA, and WY) required a minimum air temperature of 60°F for chip seal application. Another five agencies (AK, MA, MI, NC, and RI) reported a minimum temperature of 50°F. Only two agencies (MS and OH) reported the use of temperatures of 70°F. AL DOT considered construction during the summer season without a specific minimum temperature.

Seven agencies (AR, DC, IA, MT, SD, TX, and UT) mentioned restrictions regarding the temperature range for chip seal application. Montana DOT followed the supplier's recommended temperatures.

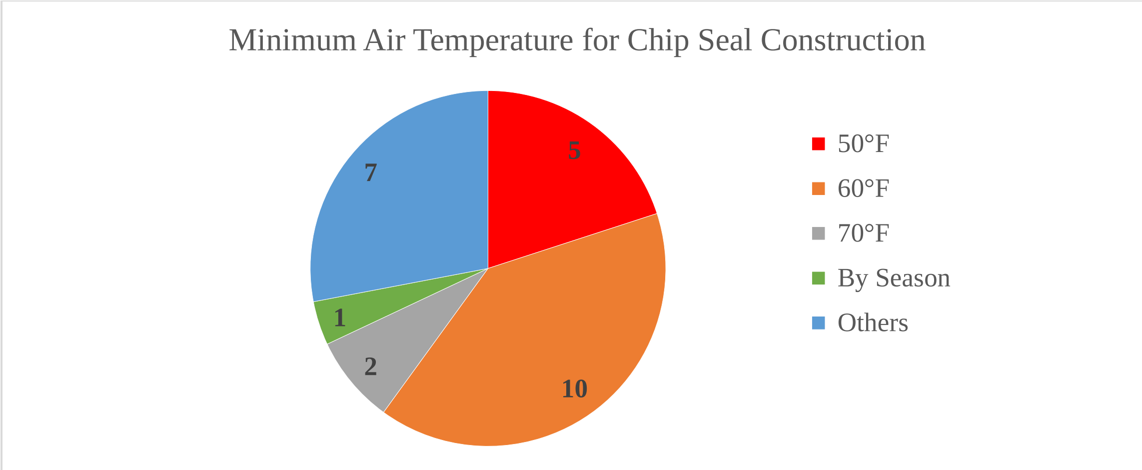


Figure 2-14. Chart. Minimum Air Temperature for Chip Seal Construction

2.3.7 Maximum Air Temperature in Chip Seal Construction

Eighteen agencies reported that no maximum air temperature was specified. However, seven agencies reported having different limits. Five of those seven agencies provided specific maximum air temperature requirements: 110°F (CA and UT), 95°F (DE), and 98°F (NC), while one provided a pavement temperature of 140°F (OH). In addition, KS DOT specified that bituminous material suppliers typically recommended temperatures.

2.3.8 Project Site Elevation Considerations for Chip Seal Construction

Only one agency (CA) specified a maximum elevation of 3,000 feet for chip seal application, while the rest of the respondents (24) indicated that they had no elevation limitation for chip seal construction.

2.3.9 Rut Filling prior to Chip Seal Application

Among the 25 agencies that responded to this question, only 12 addressed the issue of filling rut depth for chip seal application. Of those, six agencies reported filling ruts in the same year as chip seal construction, while one agency (TX DOT) noted that rut filling could be addressed either eight months ahead or during chip seal construction. None of the agencies reported filling ruts two years in advance. Thirteen agencies reported that rut depth was not filled before chip seal application.

MI DOT addressed rut depths greater than 1/2 in.; AL DOT specified a minimum of 1/4 inches for rut fill; and DE DOT reported depths of greater than 1 inch. UT DOT suggested that minor rutting (less than 1/4 in.) might not require filling.

2.3.10. Crack Sealing Activities and Timing

Out of the 25 agencies that responded to this question, 15 indicated that cracks be sealed before the chip seal was applied, typically for cracks larger than 3 mm and smaller than 25 mm wide. Of 15 responses, five agencies (CA, MA, MI, MT, and OH) reported sealing the cracks the same year as the chip seal construction. Another five agencies (MN, SD, TX, UT, and WY) reported sealing cracks one year before the construction. None of the agencies reported sealing cracks two years before the chip seal construction. The remaining five agencies provided various approaches. For instance, IA DOT's crack sealing timing varied, occurring several months to one year before the chip seal; and PA DOT sealed cracks from 1/4 in. to 1 in. the same year as construction or one year before.

The most mentioned crack widths needing sealing included those less than 1 in. (MI DOT), greater than 1/4 in. (CA DOT), less than 3/4 in. (SD DOT), greater than 1/8 in. (WY and MT DOTs), and from 1/4 in. to 1 in. (PA DOT). Additionally, RI DOT required sealing for all widths greater than 1/16 in.

2.3.11. Pavement Repairs prior to Chip Seal Application

The DOTs of AK, AL, IN, MN, MT, ND, RI, SD, and WY did not repair existing pavement with patches before the chip seal. Fifteen agencies indicated that existing pavement was repaired with patches before a chip seal. Of the 15 agencies that did repair the roads with patches, 13 of them carried out the patching during the same year of construction, whereas only two agencies (TX and PA) repaired with patches one year before the construction of the chip seal. NCDOT indicated that the repairs depended on pavement condition and traffic level.

2.3.12. Chip Seal Design Method

Figure 2-15 shows that none of the agencies reported using the Kearby or Modified Kearby methods. Only three DOTs used specific design methods such as the McLeod (DE, MN, and RI), two used the Modified McLeod (MI and SD), and one used AASHTO PP82 (MS). In contrast, 17 agencies reported using various other methods and tests for chip seal design.

While MA DOT adhered to an existing standard without a particular design process, Indiana DOT used Indiana Testing technique 579. This used small test strips with different emulsion shot rates to determine the shot rate that gave target percent embedment of 65 to 75 percent. Wyoming DOT used the NCHRP Report 680 method to determine the aggregate and emulsion application rate based on factors such as the aggregate particle size, shape, and binder absorption. Ohio DOT required test strips with a chip embedment of two-thirds. Montana DOT assigned duty to contractors with a warranty standard.

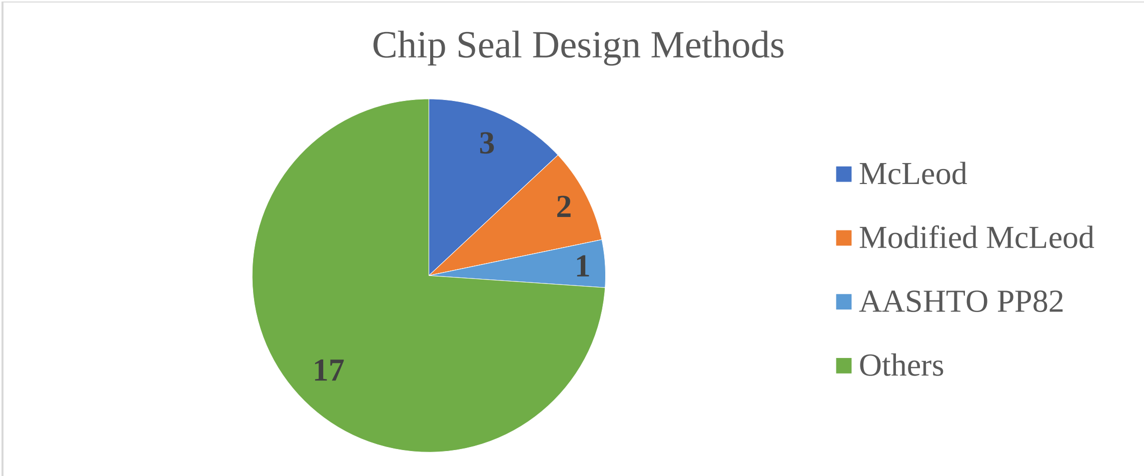


Figure 2-15. Chart. Chip Seal Design Methods by State Transportation Agencies**.**

2.3.13 Calibration or Verification of Emulsion and Chip Application Rates

In terms of calibration and verification, the majority of agencies (21) reported implementing calibration or verification processes for emulsion and chip application rates. Eighteen required calibration and testing for asphalt distributors. For example, MA DOT mandated this annually in accordance with ASTM D2995.

2.3.14. Chip Size and The Application Conditions of Sites

Thirteen agencies reported that they preferred a chip size of 3/8 in. as the most common, while only eight agencies commonly used ½-in. chip seals. No agencies reported using ¾-in. chips.

Twenty-four DOTs responded to chip gradation options. Seven agencies used single sizes without specifying a chip size, including IN, MN, OH, RI, SD, and TX, whereas only RI DOT specified a 3/8-in. size. The agencies that chose graded chips and provided specific gradation details are listed in Table 2-1.

Table 2-1. Chip Seal Gradation (Percent Passing) by DOTs.

Sieve Size	AK	MA	MI	MN	UT	ND	MS	WY
1/2"	90-100%	90-100%	85-100%	100%	100-98%	-	90-100%	-
3/8"	40-75%	25-60%	-	100%	69-91%	100%	90-100%	80-100%
1/4"	-	-	85-100%	0-80%	-	-	-	-
#4	0-15%	0-8%	0-15%	0-50%	0-11%	0-70%	20-55%	0-10%
#8	0-5%	0-4%	0-15%	0-12%	0-6%	0-17%	0-10%	0-5%
#10	-	-	-	-	-	-	-	-
#16	-	-	-	0-5%	-	-	0-10%	-
No. 200	0-1.0%	0-2%	-	0-1.0%	0-1.5%	0-1.5%	<1.5%	0-2%

Note: (-) indicates that no specification is provided for that sieve size by the corresponding state.

2.3.15. Use of Choke Stones on Chips

Of the 24 responses regarding the use of choke stones or sand on top of chips, only three agencies used choke stones, including the DOTs of AK, IA, and VA. AK DOT specified the use of concrete sand, and VA DOT used sand with a nominal maximum aggregate size (NMAS) of sieve #9. MT DOT reported the use of blotter, which could be applied as needed.

2.3.16. Type of Emulsions and Conditions

Table 2-2 shows the emulsions and asphalt binders most commonly used in chip seals by the responding DOTs. Note that several agencies used multiple types of emulsions as well as hot asphalt binders. Of all the emulsions mentioned, CRS-2P and CRS-2 were the most commonly preferred by agencies. Of the 23 respondents, 16 agencies reported using CRS-2P among their emulsion types. Among those, only four agencies used exclusively CRS-2P: OH, DE, MS, and IA. DOTs such as SD DOT preferred CRS-2P for clean aggregates and AE150S for dirty aggregates. SC DOT used CRS-2P and CRS-2L, but CRS-2 only for granite and reclamation. RI DOT and MD DOT mentioned rubber asphalt as the most commonly used binder.

Table 2-2. Types of Emulsions and Binders Used by State Transportation Agencies

Agency	Emulsion Preference 1	Emulsion Preference 2	Hot Asphalt Binder
AK DOT	CRS-2P and CSS-1	HFMS-2h	PG 58-34
AL DOT	CRS-1H	CRS-2P	PG67-22
CA DOT	-	-	Crumb Rubber Modified
DC DOT	HF 150 and HF 150P	HF 100 and HF 100P	-
DE DOT	CRS-2P		-
IA DOT	-	CRS-2P	-
IN DOT	AE-90S and CRS-2P	-	-
KS DOT	CRS-1HP	-	-
MI DOT	CSEA	CRS-2M	-
MN DOT	CRS-2P	CRS-2	58-28 and 64-28; Crumb Rubber Modified
MS DOT	CRS-2P	-	-
MT DOT	CRS-2P	CHFRS-2P	-
NC DOT	CRS2-L	CRS-2P	-
ND DOT	CRS-2P	CRSHF	-
OH DOT	CRS-2P	-	-
PA DOT	RS-2PM and CRS-2PM	RS-2 and CRS-2	
RI DOT	-	-	Crumb Rubber Modified
SC DOT	CRS-2P and CRS-2L	CRS-2	-
SD DOT	CRS-2P	AE150S	-
TX DOT	HFRS-2, MS-2, CRS-2, CRS-2H, HFRS-2P, CRS-2P, CHFRS-2P	RS-1P, CRS-1P	AC-20-5TR
UT DOT	CRS-2P	LMCRS	-
VA DOT	CRS-2L	-	-

Note: (-) indicates that no data was provided for the corresponding state.

2.3.17. Rolling Requirements for Chip Seal Application

Of the 25 respondents, 15 reported the exclusive use of pneumatic rollers, while another five reported the combined use of pneumatic and steel rollers (AR, CA, MA, TX, and VA). On the other hand, only two agencies (MA and NC) reported the combined use of rubber and steel rollers. For instance, NC DOT required at least three passes with a pneumatic roller and one pass with a steel roller, while MA DOT required two passes of a pneumatic roller and one pass of a steel roller. However, TxDOT recommended the use of pneumatic rollers for sealing and surface treatment work, avoiding steel rollers.

2.3.18. Fog Seal Application

Of the 26 DOTs evaluated, 11 agencies applied a fog seal after chip seal, while 15 did not. Regarding the time of application, three DOTs (CA, IN and ND) applied fog seal immediately after brooming, whereas the DOTs of MN, SD, and UT applied it one day later. The DOTs of DE, MI, NC, OH, WY waited more than two days before applying a fog seal. The types of emulsions used included CSS, SS, QS, RS, CRS-2Pd, CQS and non-tracking tack, while CA DOT used a flush coat followed by sand. The dilution ratios varied, with 1:1 used by the DOTs of CA, ND, and WY; 2:1 used by UT DOT; and a 30 percent emulsion used by MN DOT. The application rates ranged from 0.05 to 0.20 gal/yd^2. In addition, PA DOT used a fog seal when aggregate embedment was less than 50 percent one day after completion.

2.3.19. Inspection of Chip Embedment during and after Chip Seal Construction

Of the 26 DOT agencies, 15 inspected chip embedment during or after construction. Most of these DOTs used visual inspection methods, with specific thresholds such as 2/3 aggregate embedment (OH), 50 percent before rolling and 70 percent after (UT), and 40 percent embedment after rolling (TX). WY DOT used macrotexture from a sand patch test to ensure 65 to 75 percent embedment, while PA DOT employed both visual and manual depth checks with a threshold of over 50 percent stone embedment. CA DOT specified test strips of different emulsion application rates to reach a target percent embedment of 50 to 70 percent.

2.3.20. Quality Acceptance Specification of Chip Seal Construction

Of the 26 agencies, 16 agencies reported having quality acceptance specifications for chip seal construction, based on material sampling, macro texture, and visual inspections. For instance, the DOTs of MS and MI both referred to quality control-based visual inspection. Ohio DOT emphasized the importance of inspecting areas with limited tears, conducting daily emulsion sampling, and ensuring a minimum embedment of 2/3 of the chip height. Indiana DOT measured micro-texture profiles as part of its friction requirements. Additionally, the BC DOT followed criteria based on materials control and construction practices; and KS DOT set a 30-day observation period after seal completion.

2.3.21. Major Distress in Chip Seal during Construction

In total, 26 agencies responded about the major distresses in chip seal during construction. Of those, ten DOTs reported "loss of chips" as the major distress during construction, including AL, IA, MT, ND, PA, SC, UT, VA, and WY DOTs. Eight agencies reported having both a loss of chips and bleeding problems during construction as the main issues. AR DOT stated that distresses were not common during construction and bleeding might happen in service at intersections.

2.3.22. Common Issues after Construction

Nine agencies reported both bleeding and loss of chips as common issues after construction. Seven agencies indicated a loss of chips as the major distress, and two reported bleeding.

In summary, unlike HMA, chip seal design and construction have been largely based on experience. There is no well-established quality acceptance criteria for chip seal construction among DOTs. Visual inspection remains the primary inspection method.

Chapter 3 FIELD EXPERIMENT PROGRAM

To develop a data-driven draft quality acceptance specification, the team monitored chip seal projects to collect data during chip seal construction in 2022 and after. The chip seal program encompassed several WSDOT regions, including the Eastern, North Central, Northwest, Southwest, South Central, and Olympic regions. Field experiments were designed to explore various possibilities for enhancing the performance of chip seal construction. Among the key considerations established for the selection of projects to be included in this research were the average daily traffic (ADT), climate, chip sizes and gradations, type of emulsion, construction process, and site conditions. These variables were considered to allow for a comprehensive comparison among different chip seal projects and their performance.

3.1 Chip Seal Projects

The chip seal projects include construction on SR 26, SR 127, SR 27, US 195, and SR 261 in the Eastern Region (ER); SR 410 in the South Central Region (SCR); SR 20 in the Northwest Region (NWR); SR 17 in the North Central Region (NCR); SR 142 in the Southwest Region (SWR); and SR 106 in the Olympic Region (OR). Figure 3-1 illustrates the locations of these projects.

Figure 3-1. Photo. Project Location Map.

Table 3-1 provides specific project information, including locations, ADT, and truck percentage (T). The ADT levels ranged from 436 for SR 261 to 9,083 for SR 17. Additionally, the truck percentages for SR 127 and SR 26 were high, 26.9 and 19.4 percent, respectively, in comparison to other projects. Note that SR 20 in the NW Region and SR 410 in the SC Region are located in high-elevation and heavily canopied areas.

Table 3-1. Chip Seal Project Summary**.**

Region	Routes	Project Locations	ADT (2019)	T%	Mileposts
ER	SR 26	Lacrosse - Airport Rd to Dusty	1882	19.4	102.76-116.74
ER	SR 127	Big Alkali Rd to Dusty	783	7.8	19.45-27.05
ER	SR 27	Garfield to Rockford	945	26.9	24.76-68.73
ER	US 195	Colton to Jct SR 27	5228	13.7	8.61-19.96
ER	SR 261	Snake River to SR 260	436	13.0	15.2-29.39
NWR	SR 20	Rocky Creek to Granite Creek	1606	7.2	102.09-148.12
SCR	SR 410	288th Ave Se Vic to Crystal Mountain Blvd Vic	2021	8.0	26.02-58.29
NCR	SR 17	Lind Coulee Br to Vic I-90	9083	14.9	43-50.4
SWR	SR 142	Lyle to Goldendale	723	14.2	0-33.54
OR	SR106	MP 0.00 to MP 19.96	1244	5.3	0-19.96

3.2 Field Chip Seal Materials

Table 3-2 summarizes the emulsion types and aggregate top sizes, as well as choke, used in these chip seal projects. The ER and NCR regions used CVRS-2P, and other regions used CRS-2P. In terms of maximum aggregate sizes, the NWR, SCR, and OR regions used ½-in. chips, and other regions used 3/8-in. chips. All regions used choke on chips, except in environmentally sensitive areas, such as SR 142 within the city limits of Lyle, Washington, where dust was a concern to the residents.

Table 3-2. Chip Seal Materials Project Summary.

Region	Route No.	Emulsion	Aggregate Size	Choke
ER	SR 26	CVRS-2P	3/8" - # 4 & modified	Yes
ER	SR 127	CVRS-2P	3/8" - # 4 & modified	Yes
ER	SR 27	CVRS-2P	3/8" - # 4 & modified	Yes
ER	US 195	CVRS-2P	3/8" - # 4	Yes
ER	SR 261	CVRS-2P	3/8" - #. 4	Yes
NWR	SR 20	CRS-2P	½" - # 4	Yes
SCR	SR 410	CRS-2P	½" - # 4	Yes
NCR	SR 17	CVRS-2P	3/8" - # 4	Yes
SWR	SR 142	CRS-2P	3/8" - # 4	Yes, except within the City of Lyle
OR	SR106	CRS-2P	½" - # 4	Yes

Chips from a few chip seal construction sites were sampled to determine the gradations in accordance with AASHTO T27. Figures 3-2 and 3-3 show the gradations of chips along with WSDOT specification limits. Table 3-3 summarizes the percent passing for different sieving sizes for the chip gradations used in the study, aligned with the WSDOT specifications. Note that the gradations, except for modified gradation, were close to each other, regardless of ½ in. - #4, or 3/8 in. - #4.

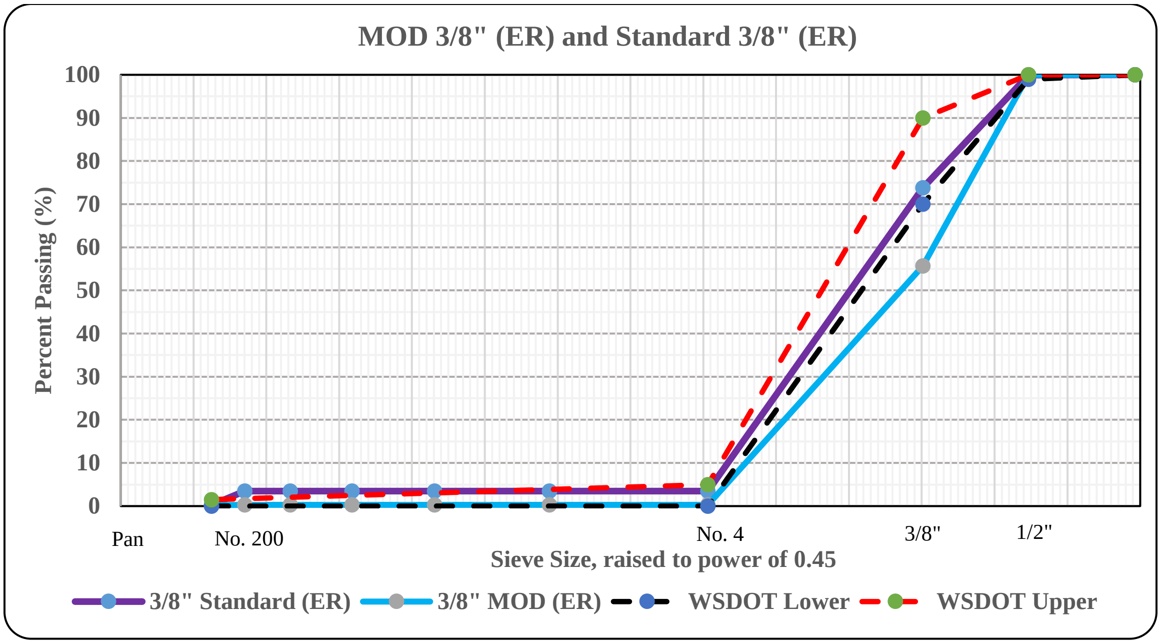


Figure 3-2. Graph. 3/8-in. Chip Gradations of the Eastern Region.

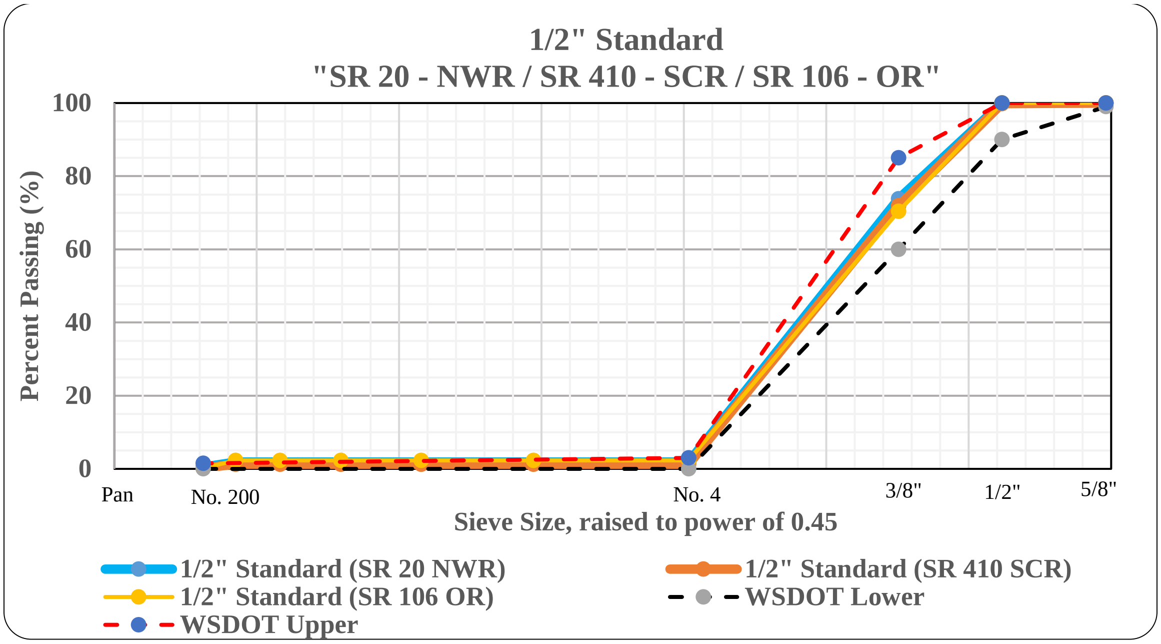


Figure 3-3. Graph. ½-in. Chip Gradations of the Northwest and South Central Regions.

Table 3-3. Chip Gradation Percentage Passing for Studied Sections.

Sieving size (No.)	3/8" Standard (ER)	3/8" MOD (ER)	1/2" Standard (SR 106 OR)	1/2" Standard (SR 20 NWR)	1/2" Standard (SR 410 SCR)
5/8"	100.0	100.0	100.0	100.0	100.0
1/2"	99.9	100.0	100.0	100.0	99.8
3/8"	73.8	55.7	70.4	73.8	71.9
#4	3.5	0.3	2.3	1.8	1.2
#200	0.3	0.2	0.2	0.5	0.2

WSDOT specifies graded chips as cover aggregates. The literature review and agency survey indicated that single-sized chips may perform better than graded chips. However, single-sized chips may be more expensive than graded chips. To study the effects of chip gradation on chip seal performance, e.g., graded vs. single-sized, a small laboratory study was conducted to determine optimal chip gradations. Hot mix asphalt samples were prepared, and the emulsion was applied at 0.45 gal/yard² on the HMA samples. The 3/8-in. chips of different gradations (primarily percentage passing the 3/8-in. sieve) were placed on the emulsion and compacted in a Superpave Gyratory Compactor. After cooling and sweeping, Cantabro tests were conducted, and the loss of chips was determined. For detailed testing procedures, refer to Umutoniwase (2022).

The test results shown in Figure 3-4 indicate that when the percentage passing 3/8-in. was reduced (or approached single-sized), the loss of chips decreased drastically from 73 percent to 60 percent and remained relatively constant until 40 percent. Therefore, for the modified 3/8-in. chips, the researchers decided to reduce the current WSDOT specifications on percentage passing 3/8-in. from 70 to 90 percent to 40 to 60 percent for the test sections. However, Figures 3-2 and 3-3 show that for standard 3/8-in. chips, the contractor used a percentage passing 3/8-in. close to the lower limit (70 percent). For modified chips, the contractor used a percentage passing 3/8-in. close to the upper limit (60 percent), thus rendering the difference between modified chips and regular chips to be less significant than expected.

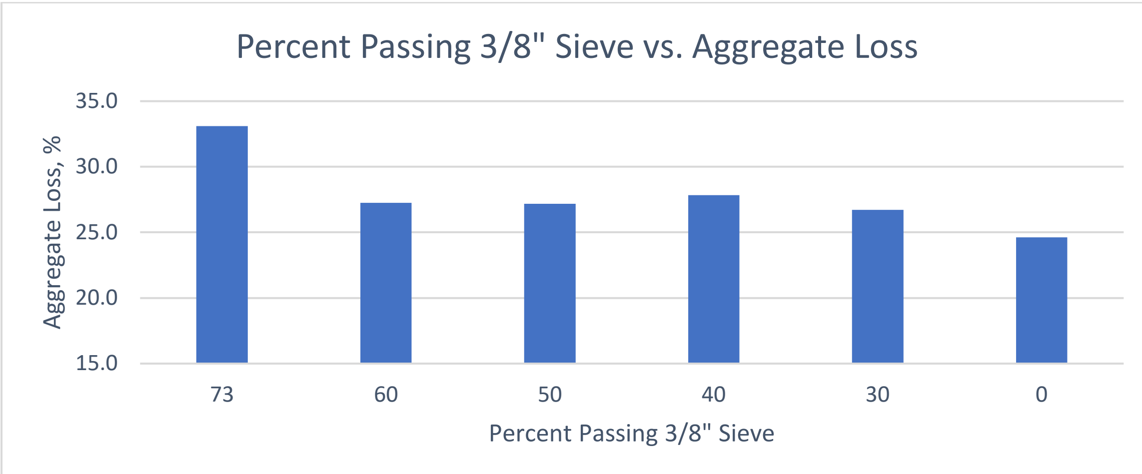


Figure 3-4. Chart. Aggregate Loss Based on Percentage Passing.

3.3 Chip Seal Construction and Experiments

This section provides a summary of chip seal construction practices and experimental approaches across different regions.

Before chip seal construction, existing cracks were sealed. Heavily distressed areas were repaired with HMA patches, and badly rutted areas were pre-leveled with HMA. Fog seal was applied to new HMA substrate, e.g., patches or pre-leveling, to seal voids that might lead to emulsion drainage. Typically, a diluted CSS-1 type emulsion, with an application rate of between 0.10 and 0.18 gal/yd^2 as per WSDOT standards, was applied. The WSDOT chip seal construction process typically involved emulsion spraying, chip application, and rolling with pneumatic rollers to achieve aggregate embedment. In addition, it encompassed spreading choke and executing a final rolling step, employing either pneumatic rollers or steel drums. The ER and NCR specified the use of double steel drum rollers for final rolling, while the NWR, SWR, SCR, and OR specified pneumatic rollers. After rolling and breaking/curing, the chip seal was broomed to remove excess chips and choke, typically after two hours for CVRS-2P and 12 hours for CRS-2P, depending on the weather. Fog seal was typically applied within three days after brooming. Figure 3-5 illustrates the conventional chip seal construction process, which may be adjusted to meet specific route needs and regional specifications, including changes in roller passes and type of rollers. The detailed construction and experiments for each section are discussed below.

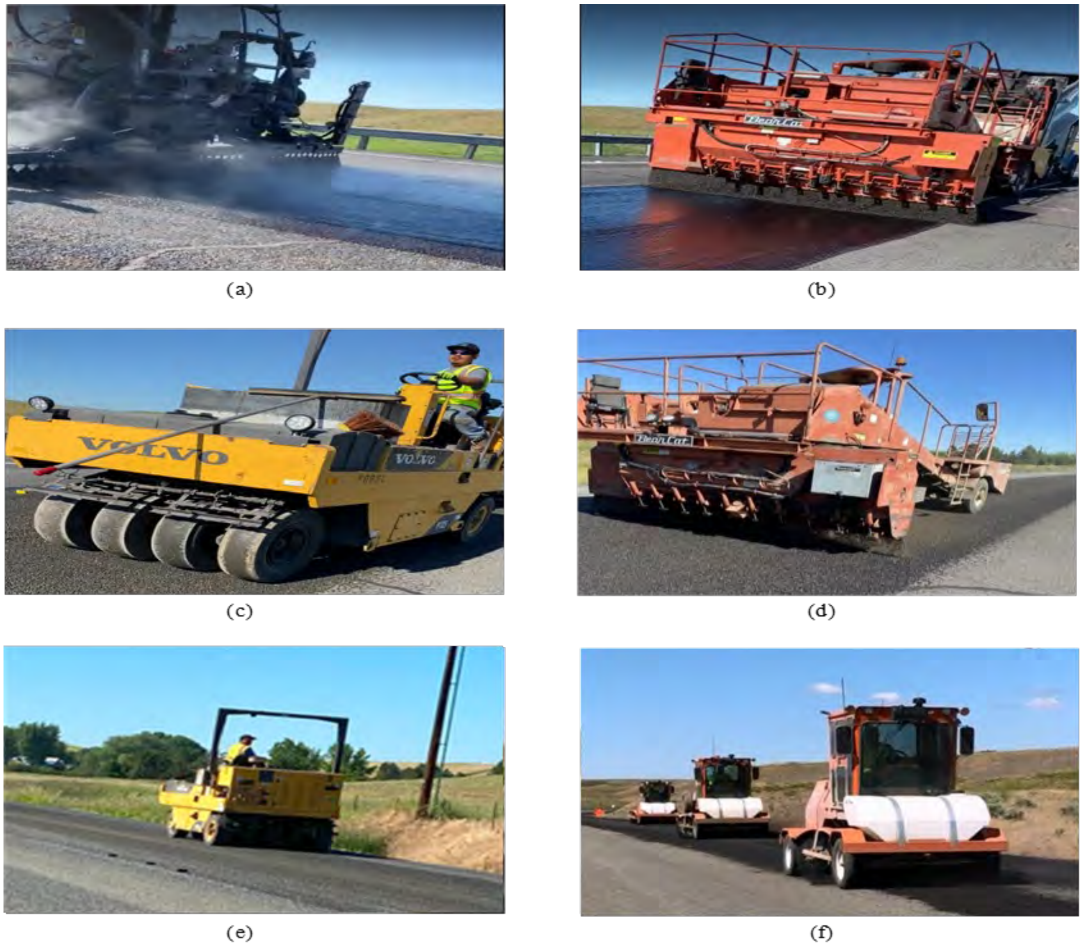


Figure 3-5. Photo. Conventional Chip Seal Construction Process on SR 26, a) Emulsion Spraying, b) Aggregate Spreading, c) Compaction, d) Choke Application, e) Final Compaction, and f) Brooming.

3.3.1 Eastern Region Projects

The Eastern Region chip seal sections included SR 26, SR 127, SR 27, SR 261, and US 195, and they were chipped in July and August of 2022. Experimental sections were designed on SR 26, SR 27, and SR 127 to evaluate rolling patterns and aggregate gradations.

3.3.1.1 SR 26, SR 27, and SR 127

SR 26, SR 27, and SR 127 included five one-mile experimental segments, while the remaining segments consisted of regular chip seal construction. The five experimental segments consisted of a combination of new chip gradations and/or rolling methods. The chip gradation was previously discussed. The specific mileposts for these test segments are provided in Table 3-4. In terms of rolling after choke application, the Eastern Region typically specified double steel drum compaction, but without vibration (in the vertical direction) to avoid chip breakdown. However, it was recognized that adequate rolling was significant for embedment and thus the retention of chips for a given application rate of emulsion. Therefore, to increase rolling efforts without crushing chips, the idea was to use an oscillatory steel roller that vibrated horizontally, instead of vertically (Figure 3-6).

Table 3-4. Test Section Mileposts by State Route

State Route (SR)	Section TS-1 Mileposts	Section TS-2 Mileposts	Section TS-3 Mileposts	Section TS-4 Mileposts	Section TS-5 Mileposts	Rest Section Mileposts
SR 26	102.76-103.76	103.76-104.76	104.76-105.76	105.76-106.76	106.76-107.76	107.76-116.74
SR 27	24.76-25.76	25.76-26.76	26.76-27.76	27.76-28.76	28.76-29.76	29.76- 32.26
SR 127	19.45- 20.45	20.45- 21.45	21.45-22.45	22.45-23.45	23.45-24.45	24.45- 27.05

Figure 3-6. Photo. Oscillatory Roller.

Another experiment involved increasing the number of roller passes on chips. Current WSDOT specifications require a minimum of two passes of pneumatic rollers after the application of chips and then a minimum of one pass of pneumatic or steel drum roller after the application of choke. The Eastern Region specified the use of a steel drum roller after the application of choke. During construction, it was found that the oscillatory roller crushed chips (Figure 3-7). In addition, because of the presence of ruts in the wheelpath, the steel drum bridged over the wheelpath and could not effectively compact chips in the wheelpath. Therefore, after the third test segment of SR 26, the oscillatory roller was switched to a combination roller (COMBO), which had one front steel drum and rear pneumatic wheels, as shown in Figure 3-8. The steel drum could effectively compact the chips outside the wheelpaths where snowplowing was a major concern for the loss of chips, while the pneumatic wheels compacted the wheelpath well. Table 3-5 details the chip gradations and final chip compaction efforts.

Figure 3-7. Photo. Close View of Crushed Chips.

Figure 3-8. Photo. Combination Roller (Combo): Steel Drum (front) and Pneumatic Wheels (back).

Table 3-5. Rolling Patterns on Chips on SR 26, SR 27, and SR 127.

Sections	Chip gradation	Number of pneumatic roller passes	Number of oscillatory roller passes (actual)	Number of combinational roller passes	Number of steel drum passes on choke
Test Section 1	3/8”-#4 Modified	2	2 (2)	0 at SR 26 and 2 for SR 27 and SR 127	1
Test Section 2	3/8”-#4 Modified	4	1 (1)	0 at SR 26 and 1 for SR 27 and SR 127	1
Test Section 3	3/8”-#4 Modified	6	0 (0)	0	1
Test Section 4	3/8”-#4 Regular	2	2 (0)	2	1
Test Section 5	3/8”-#4 Regular	4	1 (0)	1	1
Rest Section	3/8”-#4 Regular	2	0 (0)	0	1

Final compaction for all sections was achieved by using a COMBO roller after the application of choke, except for test sections 1 and 2 of SR 26.

3.3.1.2 SR 261 and US 195

The SR 261 and US 195 sections did not include experimental sections. However, given the lessons learned from SR 26, SR 27, and SR 127, the contractor continued to use a combination roller for the final compaction of choke. The new chip seals on US 195 and SR 261 were applied over existing chip seals.

Ambient temperatures during the construction of US 195 ranged from 78°F to 89°F (25.5°C to 31.7°C). Tracking and bleeding were observed at some locations during construction. Figure 3-9 visually represents observed bleeding on US 195 during monitoring.

(a)

(b)

Figure 3-9. Photo. US 195 (a) Bleeding in the Wheelpath, and (b) Close-up View with Chips.

3.3.2 Projects in Other Regions

3.3.2.1 North Central Region (SR 17)

The contractor reduced the application rate to 0.42 gal/yd^2 due to high-volume traffic. During construction, temperatures ranged from 85°F to 99°F (29.4°C to 37°C). CVRS-2P emulsion was used. The same contractor for the North Central and Southwest regions, as in the Eastern Region, sought approval and was allowed to follow the practices of using the combination roller for the final compaction of choke. The contractors sprayed water to cool the chip seal during sweeping, inadvertently causing premature raveling at some locations, according to the inspectors. Figure 3-10 shows an example of premature raveling at the SR 17 section.

Figure 3-10. Photo. SR 17, Water Effects on Bleeding.

3.3.2.2. SR 410 South Central Region

CRS-2P emulsion was utilized for this project, which required sweeping after an overnight curing. Construction took place from July 25 to July 26, 2022, with temperatures ranging from 82°F to 94°F (27.7°C to 34.4°C). However, most measured points were located within shaded areas. For the final rolling of chips, the contractor used a 4-ton pneumatic roller.

3.3.2.3. SR 20 Northwest Region

Construction occurred amid temperatures ranging from 90°F to 98.1°F (32°C to 37°C). CRS-2P emulsion was used, necessitating sweeping after overnight curing, similar to the SR 410 section. The contractor opted for a larger, approximately 9-ton pneumatic roller for final rolling. The section of SR 20 evaluated in the study was chipped during two days of construction (July 25th and July 26th) in the summer of 2022.

3.3.2.4 SR 142 Southwest Region

The SR 142 section used CRS-2P emulsion. Construction occurred over two days on August 18 and August 19, 2022. Standard rolling procedures were followed, with a pneumatic roller utilized after the choke. Ambient temperatures during construction ranged from 86°F to 83°F (30°C to 28.3°C). For the final compaction of choke, the contractor used a 4-ton pneumatic roller. A 0.5-mile segment of SR 142 within the City of Lyle was designated as an environmental area, where construction solely utilized chips without choke.

3.3.2.5. SR 106 Olympic Region

This chip seal construction also utilized CRS-2P emulsion with a standard gradation of 3/8 in. - #4. During construction, temperatures soared to 97°F (36°C). The contractor used a 4-ton pneumatic roller for the final compaction of choke. Sweeping was necessary after overnight curing because of the type of emulsion used.

3.4 Measurements with a Laser Texture Scanner

3.4.1 Portable Laser Texture Scanner

In this project, a laser texture scanner, as shown in Figure 3-11, was used to collect texture data about the chip seal during and after construction. The laser had a scanning area of up to 4.09 inches (104.0 mm) long and 2.835 inches (72.01 mm) wide. In addition to the measurement of MPD that was displayed on screen, the scanning data could also be used to restructure 3-D chip seal in a computer, as shown in Figure 3-12, although this 3-D image is for visual purposes and was not needed to assess chip seal quality.

(a) (b) (c)

Figure 3-11. Photo. Laser Texture Scanner Components (a) Laser Case, (b) Laser Scanner and Charger, (c) Shield and Calibration Plate.

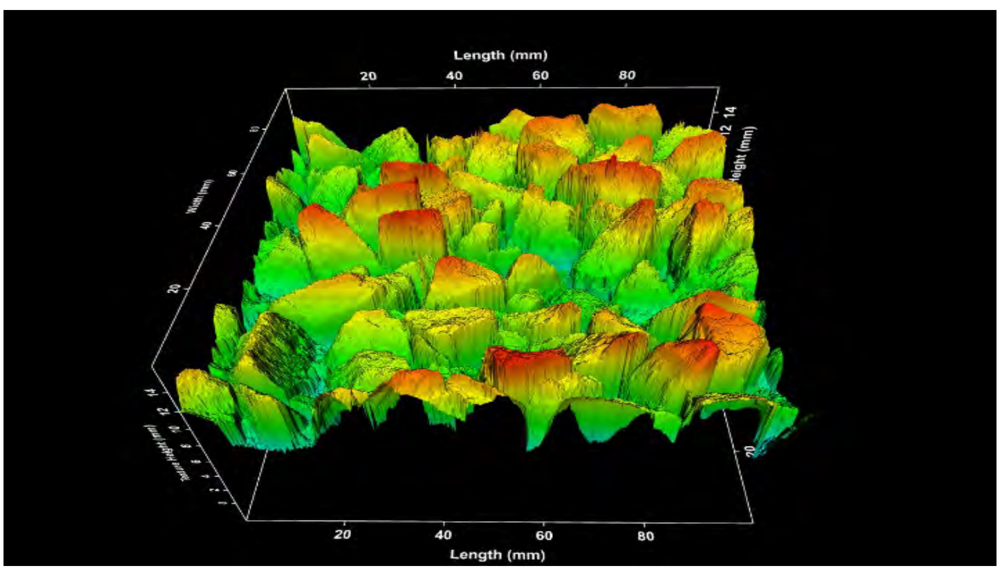


Figure 3-12. Photo. 3-D Graph of Scanned Surface.

The precision of the scanner depends on the number of scan lines within the scanning area. More scanning lines leads to higher precision but takes a longer time to scan. The number of scan lines directly influences measurement time, ranging from 5 to 50 scan lines with measurement times of from 45 seconds to 4 minutes. After trials of different numbers of lines, five lines of scan were found to provide expedited readings without compromising accuracy and therefore were used throughout this study.

For a given station, the MPDs were measured at three locations in each direction: inner wheelpath (IW), outer wheelpath (OW), and between the wheelpaths (or center of the lane). Because of the continued rolling/embedment of chips by construction vehicles during construction and controlled traffic, the MPD in the wheelpaths continued to decrease. The measurement between the wheelpaths or at the shoulder, instead, was relatively stable and was considered a reference that reflected whether the proper application rate of emulsion was applied and/or compaction efforts were adequate to embed the chips. MPD measurements were taken every 0.2 miles (1,056 ft) on the experimental segments on SR 26, SR 27, SR 127 and every 1 mile for the remaining portion of each project and other projects. Because of time limitations, the study's MPD measurements did not cover the whole project length except on SR 26, SR 127, US 195, and SR 261. For all the chip seal projects, in addition to measurements in summer 2022 during construction, the team revisited and took measurements on SR 26, SR 27, SR 127, and US 195 in fall 2022, summer 2023, and fall 2023. Other routes (SR 20, SR 410, SR 142, SR 106, and SR 17) were revisited in the summer of 2023 only. Measurements during revisiting were taken in the outer wheelpaths only because of live traffic and safety concerns.

3.4.2 MPD Measurements with the Inertial Profiler (PIP)

A portable laser texture scanner is easy to use during construction around construction vehicles. However, chip seal projects are often tens of miles long, and collecting data can be time-consuming. In addition, chip seal construction progresses quickly, as does traffic control. After construction has been completed and traffic control has been removed, it can be difficult to collect data with live traffic, especially when traffic volumes are high.

The Inertial Profiler is another texture scanner that can be mounted on a vehicle, allows for rapid assessment at highway speeds (0 to 100 mph), and enables measurements at intervals as short as 1 inch. It eliminates the need for traffic control, enhancing safety and expediting data collection. Figure 3-13 shows the SSI profiler equipment mounted on the rear of a pickup truck. This device can also measure rut depth and pavement roughness. The Inertial Profiler was used for measuring the MPD of chip seal projects in the Eastern Region for experimental purposes.

Figure 3-13. Photo. SSI Profiler Mounted on a Pickup Truck.

Chapter 4 FIELD RESULTS AND ANALYSIS

The results from the data collected in the field were analyzed to study chip seal performance and also to develop a draft specification for chip seal construction.

4.1 Relationship between MPD and Percent Embedment of Chips

A previous study by Umutoniwase (2022) established a relationship between MPD and percent embedment of chips. However, that relationship was based on laboratory-prepared chip seal samples, and laboratory and field conditions, such as compaction methods, may be different. Therefore, to develop such a relationship based on realistic field conditions, cores of chip seal on substrate pavement on SR 127 and SR 27 were extracted, as shown in Figure 4-1. The MPD values of the cores were measured by using a laser texture scanner. On SR 127, chips on top of cores were removed (Figure 4-2) and the height of chips and embedment were measured by using a digital caliper to determine the percent embedment. The same procedures were conducted on the SR 27 chip seal directly but without extracting cores. The MPD values of the chip seals were measured at given spots, and chips were removed from these spots in the field to measure the heights and embedment in the laboratory (Figure 4-3). These measurements included those immediately after sweeping as well as chips that had been subject to traffic.

(a) (b)

Figure 4-1. Photo. SR 127 Core: (a) Surface of Core before Chip Pull-Out, (b) after Chip Pull-Out on a Half Core.

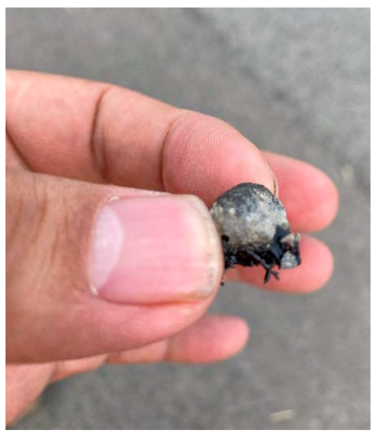


Figure 4-2. Photo. Chip Pulled Out from the Core Surface.

Figure 4-3. Photo. Extracted Chips from SR 127 in the Field.

Figure 4-4 illustrates the relationship between MPD measurements obtained from both field measurements and cores extracted during construction, and the embedment percentage measured for the extracted chips. This graph demonstrates a high correlation between the embedment percentage and MPD. As MPD increases, the embedment percentage decreases.

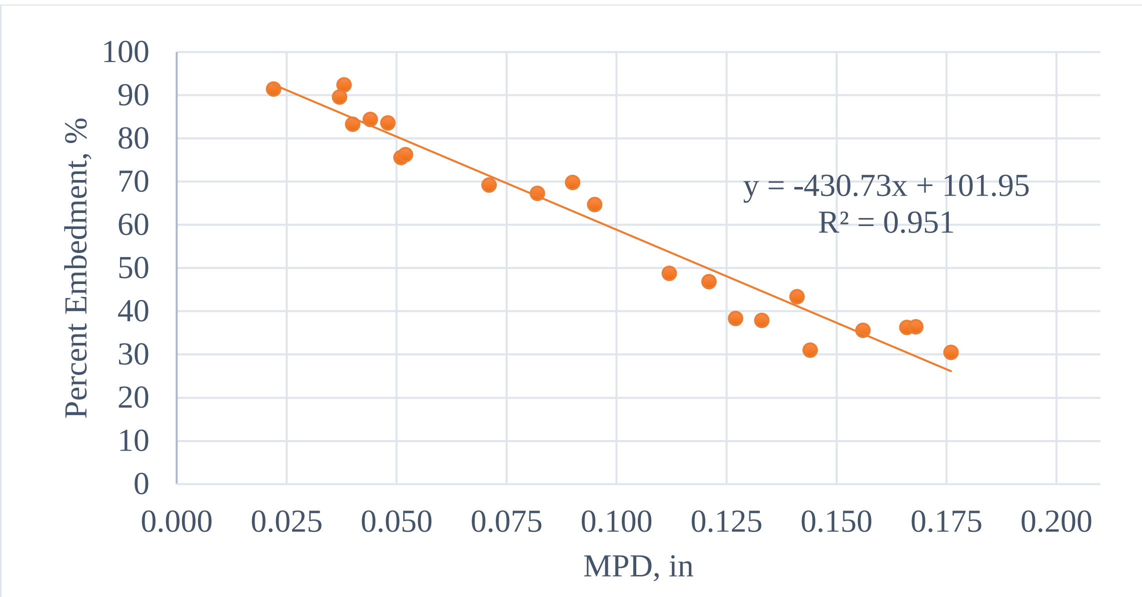


Figure 4-4. Graph. Relationship between MPD Measurements and Embedment Percentage.

4.2 Chip Seal Field Performance Analysis

4.2.1 Eastern Region Chip Seal Projects

Traditionally, contractors have subjectively determined emulsion application rates. Before ER chip seal project construction in this study, laboratory tests were conducted on the chip seal installed on cores extracted from existing SR 26 pavement. The chip seal samples were subjected to laboratory raveling and bleeding tests to determine emulsion application rates, following the test procedures by Umutoniwase (2022). A recommendation of 0.45 gal/SY (at ambient temperature) was made for Eastern Region projects. Even though 0.45 gal/SY was the target of the emulsion shot rate by the contractor, the actual shot rates during construction, as measured by WSDOT after temperature correction, exhibited high variability, ranging from 0.36 to 0.54 gal/SY, as illustrated in Figure 4-5. This indicated a need for better control of construction.

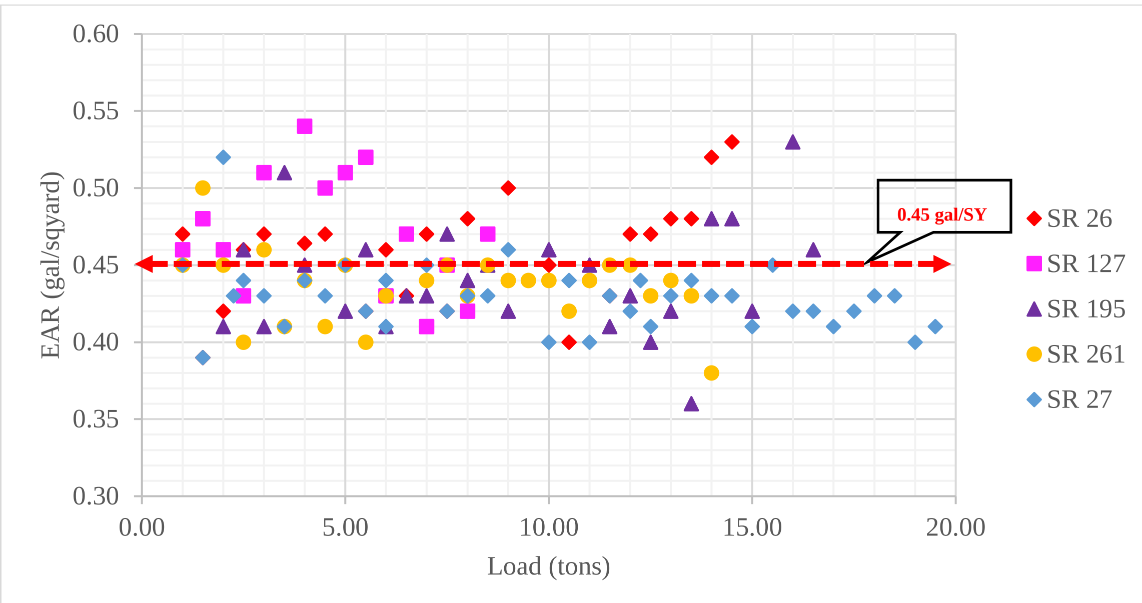


Figure 4-5. Graph. Shot Rates for Eastern Region Projects.

4.2.1.1. SR 26: Lacrosse Airport Rd to Dusty

As of summer 2023, SR 26 was performing well, showing moderate bleeding, as illustrated in Figure 4-6. The project covered a total of 13.98 miles and experienced an average daily traffic (ADT) of 1,882 vehicles, with 19.4 percent being trucks. The area along SR 26 has a semi-arid climate characterized by hot, dry summers, cold winters, and low annual precipitation. As stated previously, this section was constructed using both a modified and a standard chip gradation of 3/8 in. - #4, with a CVRS-2P emulsion.

Figure 4-6. Photo. Bleeding in the SR 26 Wheelpath.

MPDs were measured at the inner wheelpaths, outer wheelpaths, and between the wheelpaths (center of lane) during construction in summer 2022. During subsequent monitoring stages, measurements were taken at the outer wheelpath and center in fall 2022 and summer 2022, and only at the outer wheelpath in Fall 2023 because of live traffic and safety concerns. However, the measurements obtained at the outer wheelpath during all monitoring stages were used for the performance analysis of the project, while the measurements at the center were used as a benchmark.

Figure 4-7 shows the MPD values for the center of lane (C) and outer wheelpath (OW) across the SR 26 sections over time. The figure shows that the MPD in the OW decreased quickly from summer 2022 to fall 2022 as a result of embedment caused by in-service traffic and relatively fresh emulsion residue. However, the decrease rate of the MPD from the fall of 2022 to the summer of 2023 and then in fall of 2023 slowed down because chip seals had been consolidated, and asphalt residue became harder because of aging.

A previous study by Umutoniwase (2022) found that an MPD above 0.15 in. was desirable for chip seal performance, as insufficient embedment can lead to raveling while excessive embedment may cause bleeding. In the summer of 2022 immediately after construction, the modified chips had higher MPD values in the outer wheelpath than the regular chips, as shown in Figure 4-7, suggesting that the modified chips may have performed better. However, as of fall 2023, there was no noticeable difference between modified chips and regular chips in the MPD of the OW. In addition, there was no clear benefit from different rolling patterns in the experimental sections. The average MPD in the outer wheelpath of SR 26 was about 0.060 in. in the fall of 2023.

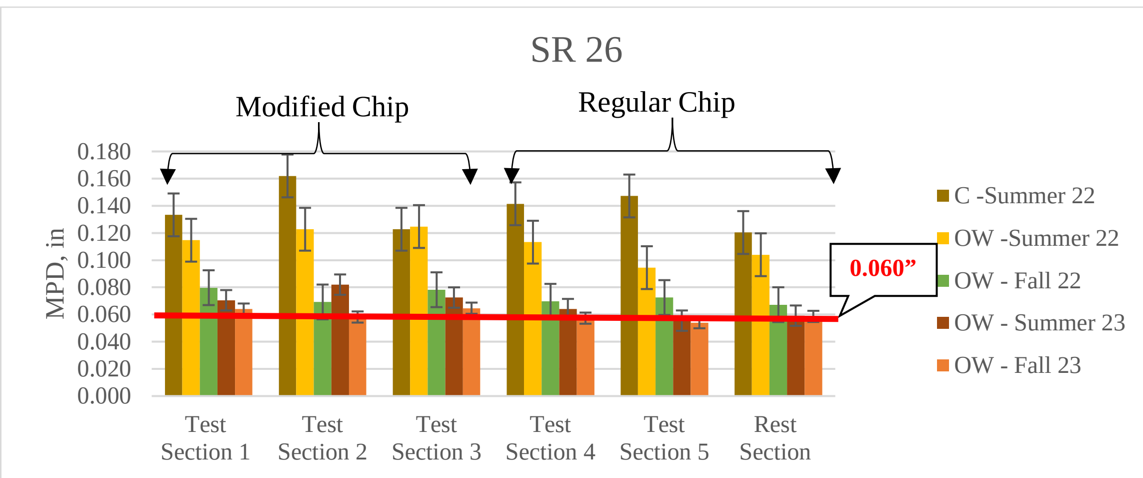


Figure 4-7. Chart. MPD at SR 26 Over Time.

4.2.1.2. SR 127: Big Alkali Rd to Dusty

The SR 127 section had an ADT of 783 and a truck percentage of 26.9 percent. The area along SR 127 experiences a semi-arid climate characterized by hot, dry summers, cold winters, and low annual precipitation.

Figure 4-8 illustrates the MPDs at the center of the lane and outer wheelpath over time. Again, the MPD in the outer wheelpath dropped quickly from the summer of 2022 to the fall of 2023 and then decreased slowly. Note that 7.6 miles of chip seal on SR 127 were over the existing chip seal surface and the rest 4.1 miles were over the new HMA inlay (MP 23 to MP 27). As of fall 2023, the average MPD in the outer wheelpath of the new chip seal over the existing chip seal surface was about 0.060 in. while the MPD of the new chip seal over the new HMA was about 0.084 in.

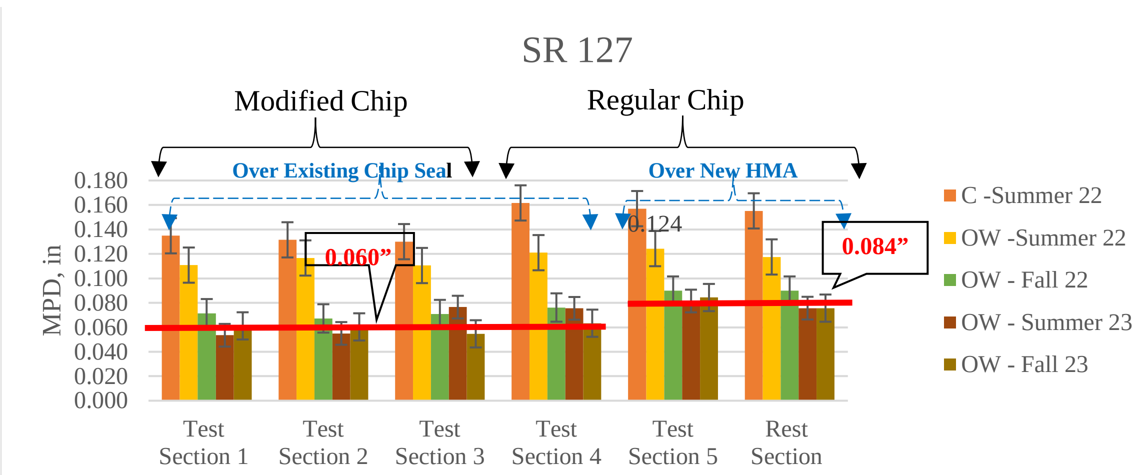


Figure 4-8. Chart. MPD Wheelpaths on SR 127 Over Time.

The chip seal over the new HMA exhibited good performance, but the chip seal over the existing pavement showed medium bleeding, as shown in Figure 4-9. Therefore, an outer wheelpath MPD of between 0.060 in. and 0.080 in. may indicate good performance after one year in service. Later in this report, based on SR 20 data, it found that 0.065 in. may be a proper threshold.

(a) (b)

Figure 4-9. Photo. Condition on SR 127: (a) Chip Seal Over New HMA; and (b) Chip Seal Over Existing Chip Seal.

Slight raveling problems were found, particularly noticeable in the chip seal over the fresh HMA in the centerline and between the wheelpaths, which was potentially exacerbated by snowplow operations. Concerns also arose regarding emulsion infiltration into the new HMA, which had an open texture, possibly due to inadequate fog seal application before the chip seal. This resulted in lower effective emulsion and a high MPD.

Figure 4-10 (a) visually depicts bubbling observed during the construction of SR 127, showing likely emulsion infiltration into the leveled HMA. Figure 4-10 (b) shows the resulting raveling problems. The MPD between the wheelpaths in the stations of raveling was 0.178 in. Therefore, to prevent raveling from snowplowing, an upper limit of MPD between wheelpaths immediately after brooming, e.g., 0.170 in., can be used.

(a)

(b)

Figure 4-10. Photo. SR 127: (a) Emulsion Infiltration Due to Inadequate Fog Seal; (b) Raveling at the Centerline.

The SSI Profiler was also used to collect the MPD in both wheelpaths (OW and IW) along the entire SR 127 section at 1-foot intervals in fall 2022. Figure 4-11 illustrates the difference between the MPD of new chip seal surfaces over existing chip seal and the MPD of new chip seal over new HMA. The MPD of the new chip seal over new HMA surface was higher (0.082 in.), likely because of emulsion drainage into the HMA pores, while an MPD of 0.072 in. was found for the chip seal existing surface into which the emulsion typically does not easily penetrate. The difference between the MPDs of the chip seals corroborated the theory of "leakage" of an emulsion into new HMA. Therefore, more fog seal needs to be applied to new HMA before the chip seal, or a higher application rate of emulsion is needed to compensate for the "lost" emulsion.

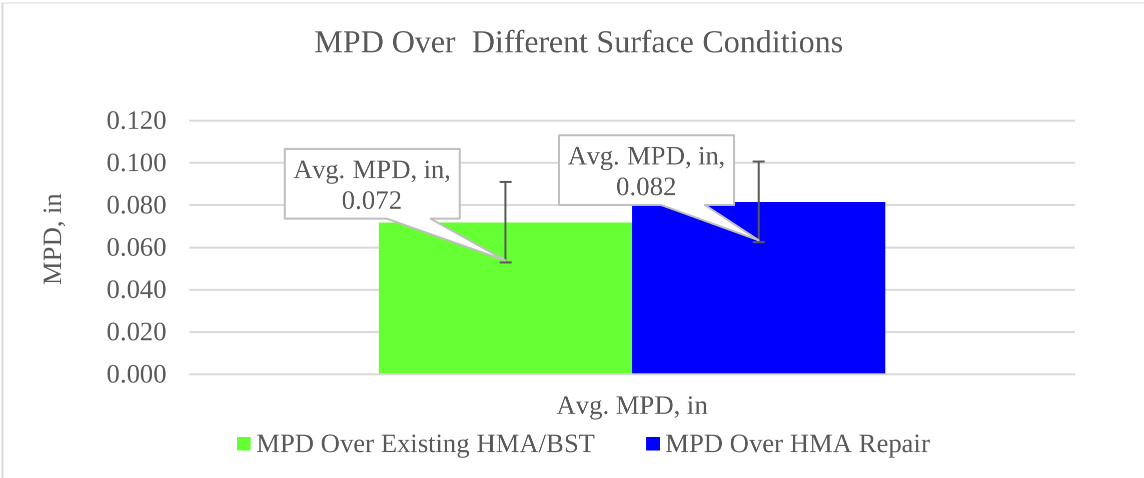


Figure 4-11. Chart. The MPD of SR 127

4.2.1.3. SR 27: Garfield to Rockford

The SR 27 section was characterized by an ADT of 945 vehicles, of which 7.8 percent were trucks. This state highway passes through a farm area, with most of the trucks being agricultural vehicles. The ambient temperature in this section ranges from 90°F to 98°F (32°C to 37°C) in summer. This section experiences a temperate climate with warm summers, cold winters, and moderate precipitation throughout the year.

During monitoring in the summer of 2023 and fall of 2023, measurements were obtained from MP 24.76 to MP 35. Figure 4-12 illustrates differences in MPD between test segments in terms of chip gradations and compaction efforts, as well as MPD evolvement over time. As of fall 2023, the average outer wheelpath MPD was about 0.055 in. after one year in service. As shown in Figure 4-13, medium-level bleeding was found in the wheelpath on SR 27 in the summer of 2023 which corroborated the finding that a wheelpath MPD value of 0.065 in. or lower may indicate the poor flushing performance after one year.

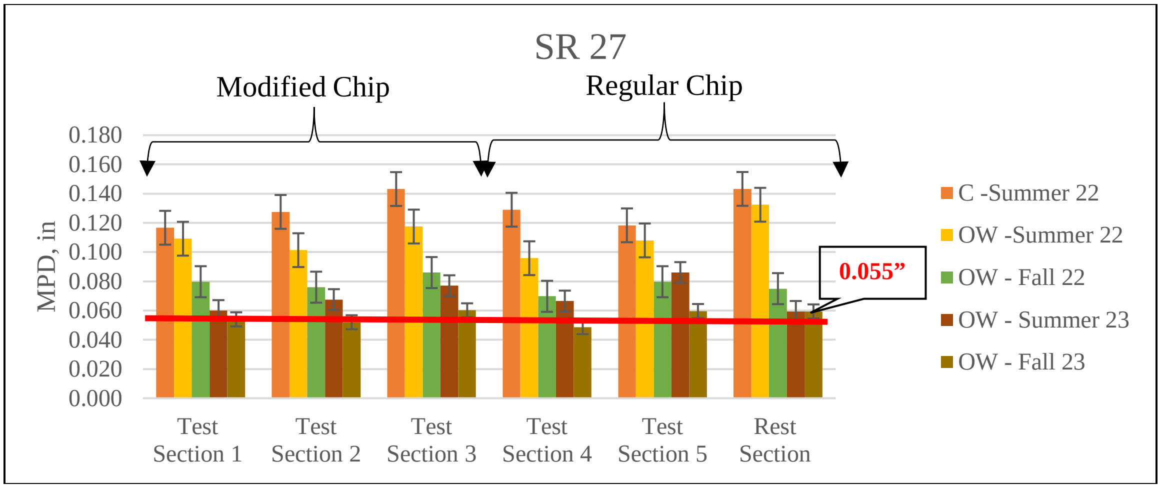


Figure 4-12. Chart. MPD of the Wheelpath on SR 27 Over Time.

Figure 4-13. Photo. Condition of SR 27 in Summer 2023.

Similar to the SR 26 and SR 127 test segments, no significant differences were observed among the various rolling patterns, as well as modified gradation. Further studies focusing on alternative chip sizes (e.g., single size) and compaction methods may be warranted.

4.2.1.4. US 195: Colton to Jct SR 27

US 195 spans 11.35 miles and experienced an ADT of 5,228 vehicles, with trucks accounting for 13.7 percent of the traffic. This section has a temperate climate with hot summers, cold winters, and moderate precipitation throughout the year. Like the other section in the Eastern Region, this section was constructed with graded chips of 3/8 in. - #4 and CVRS-2P emulsion.

Figure 4-14 shows a decrease in MPD values on US 195 over time, particularly in the outer wheelpath, dropping from 0.108 in. in summer 2022 to 0.046 in. in winter (November) 2022, further declining to 0.040 in. in summer 2023. Accordingly, the chip seal on US 195 experienced severe bleeding, as shown in Figure 4-15. As a result, the WSDOT maintenance crew re-paved a stretch of chip seal with HMA in the fall of 2022, a few months after chip seal construction.

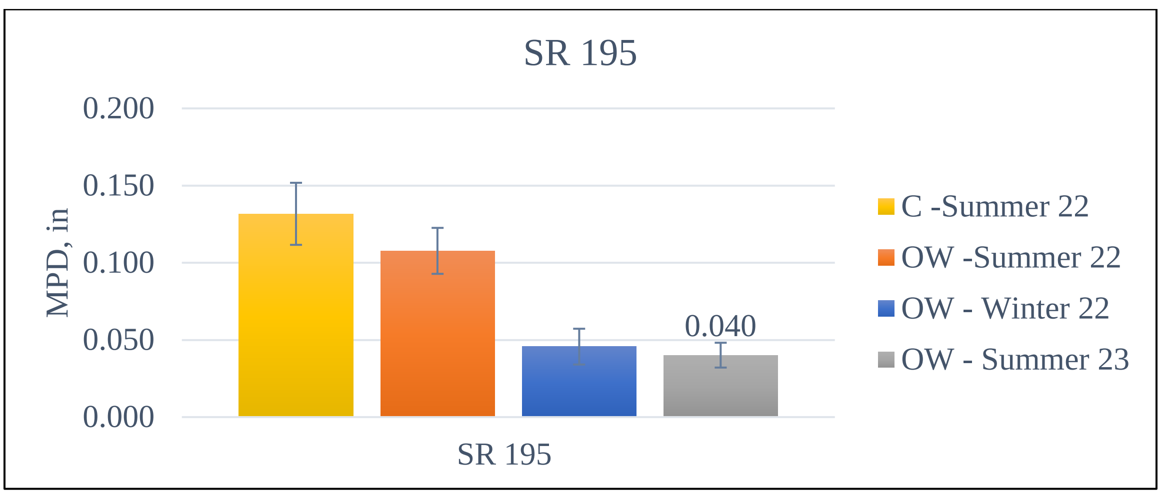


Figure 4-14. Chart. MPD of US 195 Over Time.

Figure 4-15. Photo. Bleeding Issues on US 195.

During the summer 2023 visit, both the MPD and rut depths (via dipstick) in the wheelpath were measured in a number of spots. A strong correlation between rut depth and MPD was found, as shown in Figure 4-16. Deeper ruts tended to yield lower MPD values or bleeding, as shown in Figure 4-17. Previous research has indicated that chip sealing does not improve rutting in existing pavement (Umutoniwase 2022). Therefore, the rutting in the chip seal would result from the rutting of pavement before the chip seal. It was suspected that emulsion and/or asphalt residue may have flowed toward the rutted area during and after construction and caused high levels of embedment and bleeding, as illustrated by Figure 4-18.

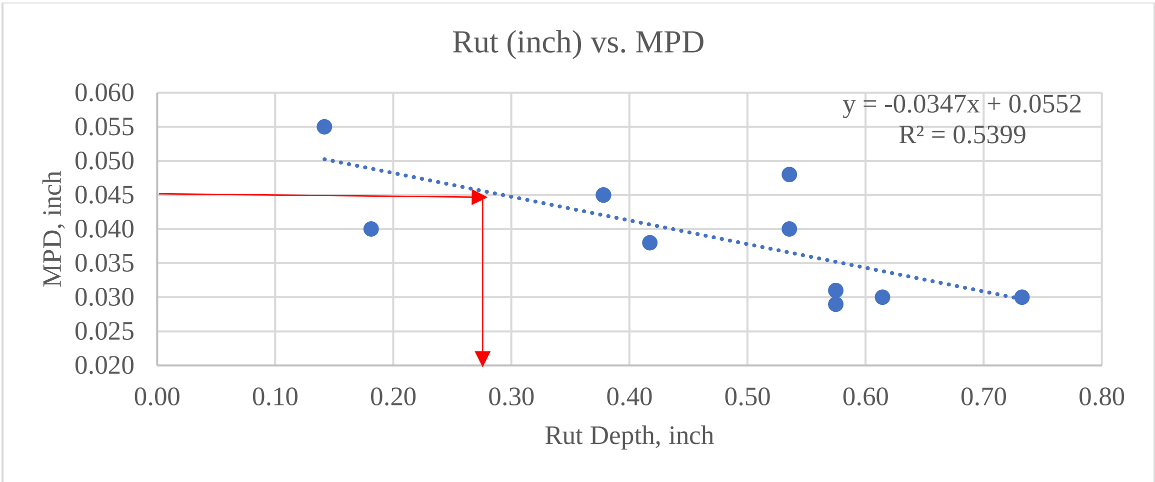


Figure 4-16. Graph. Correlation between Rut Depth and MPD.

(a) (b)

Figure 4-17. Photo. US 195 (a) Severe Bleeding in the Wheelpath; and (b) Chip Embedded 100 Percent.

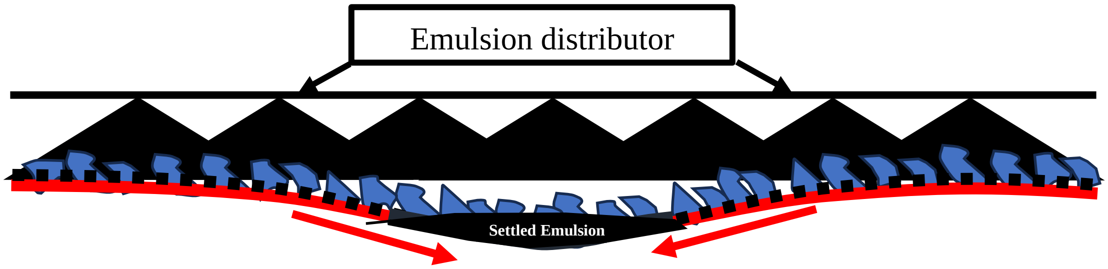


Figure 4-18. Photo. Schematic Illustration of Emulsion Migration.

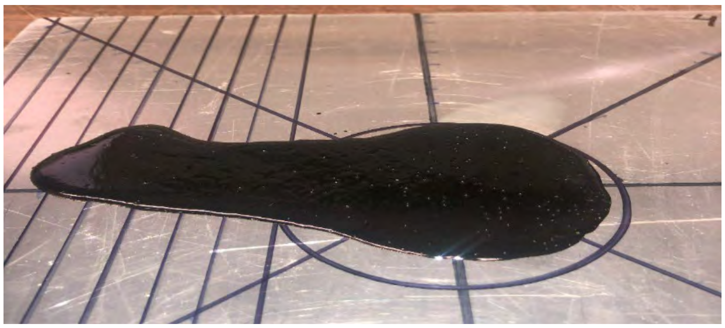
To investigate the mechanism, an experiment was designed in the laboratory to mimic this phenomenon. A chip seal sample was prepared by installing emulsion and chips on an HMA sample. After the compaction of chips by the gyratory compactor, choke was placed on the chips and subjected to compaction again. After overnight curing, the chips and choke were broomed. The prepared sample was placed in a chamber at a constant temperature of 140°F (60°C), which is close to the pavement temperature in summer in the Eastern Region. The sample was tilted to 3.6 degrees, which represented a cross-slope of pavement with a rut depth of ½ in. Figure 4-19 shows that after overnight in the oven, asphalt residue dripped to the lower side of the sample. This showed that asphalt residue migrated between chips even after compaction and brooming of chips. This can be explained by the fact that asphalt emulsion and its asphalt residue exhibit viscoelastic behavior and, under gravitational force, they continue to flow between chips, especially at high service temperatures.

Figure 4-19. Photo. Asphalt Dripping after Tilting of a Sample in the Oven Overnight.

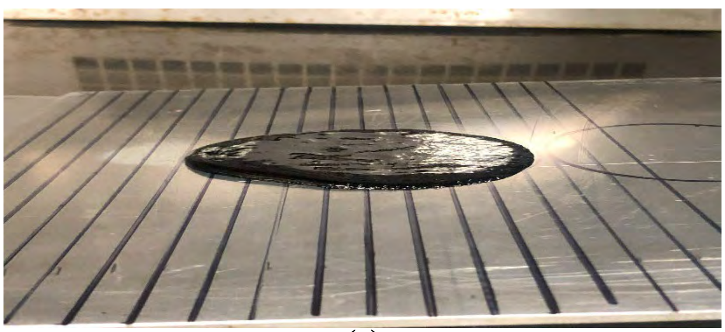
The above findings indicate the necessity for comprehensive rut management to ensure optimal pavement performance. In Figure 4-16, taking 0.045 in. MPD as a severe bleeding threshold corresponds to a rut depth of 0.27 in.. It is recommended to address a rut depth deeper than ¼ in. before a chip seal. Approaches for mitigating rutting before the chip seal can include strategic placement of the chip seal in wheelpaths, preferably one summer before the regular chip seal to allow the strategic chip seal to cure and age in summer. A second option is pre-leveling the existing pavement. However, this may be limited by the budget available.

Other approaches include micro-milling to remove the rut or the use of high float emulsion, which is designed for chip seal construction on steep grades. To demonstrate the effectiveness of high float emulsion on pavement with a deep rut, simple flow tests, instead of the ASTM float test, were conducted to visualize the effects of different emulsion types. Plates were tilted to achieve an inclination of 3.6°, and emulsions were placed at the center of the plates. Four tests were conducted, with two samples of CRS-2P emulsion and two samples of HFRS-2P emulsion. In both samples, conditioning of the emulsion at 80°C was applied to heat and mix the emulsions, and the test was performed within a controlled chamber at 176°F (80°C). Figure 4-20 illustrates the set-up of the emulsion flow test. The CRS-2P emulsion was more flowable than the high-float HFRS-2P. This may have been related to the “gel” structure of high-float emulsion (Sarkar et al., 2022).

(a)



(b)



(c)

Figure 4-20. Photo. Emulsion Fluidity Test: (a) Test Set-Up; (b) CRS-2P Emulsion Fluidity; and (c) HFRS-2P Fluidity.

In addition, the US 195 chip seal exhibited extensive “blowup” of the chip seal and underlying pavement in the wheelpath as of summer 2024, as shown in Figure 4-21. Figure 4-21 (b) shows the “blowup” ends at the interface of the surface HMA and underlying HMA. These “blowups” typically started at the edge of the wheelpaths and then encroached on the center of the wheelpath. It is believed this is associated with moisture damage and/or inadequate compaction of existing HMA patch or wheelpath grind and inlay. No density has been specified for HMA patching or pre-leveling. This phenomenon needs further investigation. Before the chip seal, the SR 195 section was in poor condition, which may have led to accelerated "blowup." This highlights the importance of selecting appropriate candidate projects for chip seal.

Figure 4-21. Photo. US 195 Extensive Blowup Under the Wheelpath.

4.2.1.5. SR 261: Snake River to SR 260

The SR 261 section had a truck traffic percentage of 13 percent and an ADT of 436 vehicles. The area along SR 261 experiences a semi-arid climate characterized by hot, dry summers, cold winters, and relatively low annual precipitation. This section was constructed with a graded chip of 3/8 in. - #4 and CVRS-2P emulsion.

Figure 4-22 shows a decrease in the MPD of SR 261 over time in the outer wheelpath, decreasing from 0.125 in. in the summer of 2022 to 0.083 in. in the summer of

2023. As seen in Figure 4-23, this section demonstrated good performance. However, this can be attributed to the low level of traffic.

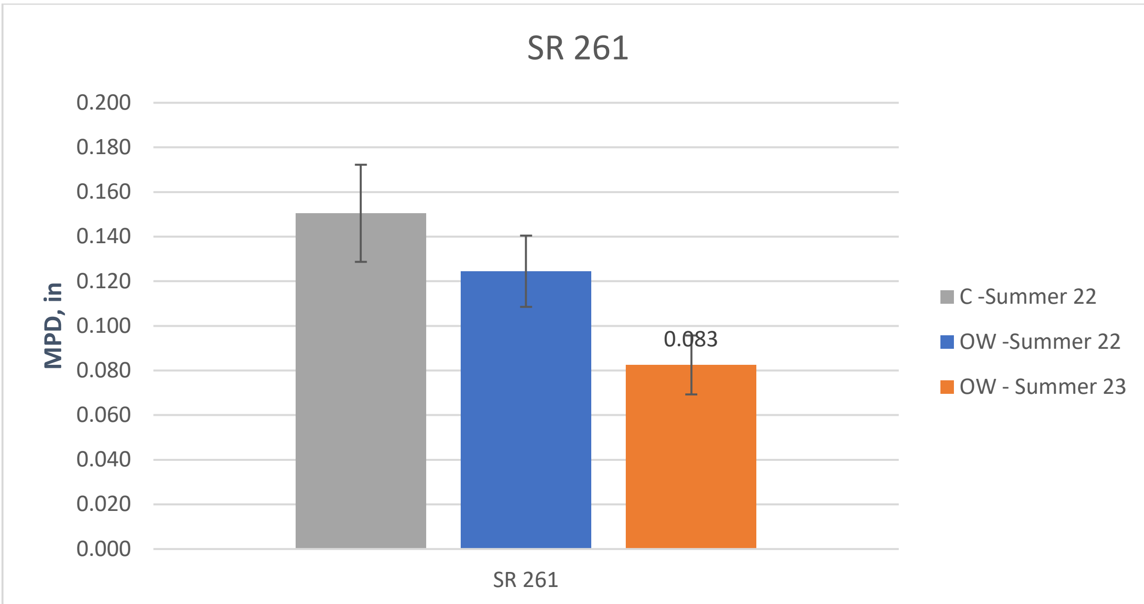


Figure 4-22. Chart. MPD of SR 261 Over Time.

Figure 4-23. Photo. Condition of SR 261 in Summer 2023.

4.2.2 North Central Region: SR 17 (Lind Coulee Bridge to I-90)

SR 17 had an ADT of 9,983 vehicles, with 14.9 percent being trucks, making it an ideal candidate for studying chip seal construction under high traffic conditions. SR 17 experiences a semi-arid climate with hot, dry summers, cold winters, and lower precipitation levels than other areas in the state.

During construction in the summer of 2022, the MPD measurements were collected from MP 43 to MP 48. This section was constructed with a chip gradation of 3/8 in. - #4 and CVRS-2P emulsion. The average MPD at the outer wheelpath decreased from 0.121 in. in the summer of 2022 to 0.055 in. in the summer of 2023, as shown in Figure 4-24. This was in line with the severe bleeding in the wheelpath in the summer of 2023 (Figure 4-25), especially at the north end of the project. In fact, one stretch of chip seal had been repaved with HMA by the WSDOT maintenance crew as of summer 2023.

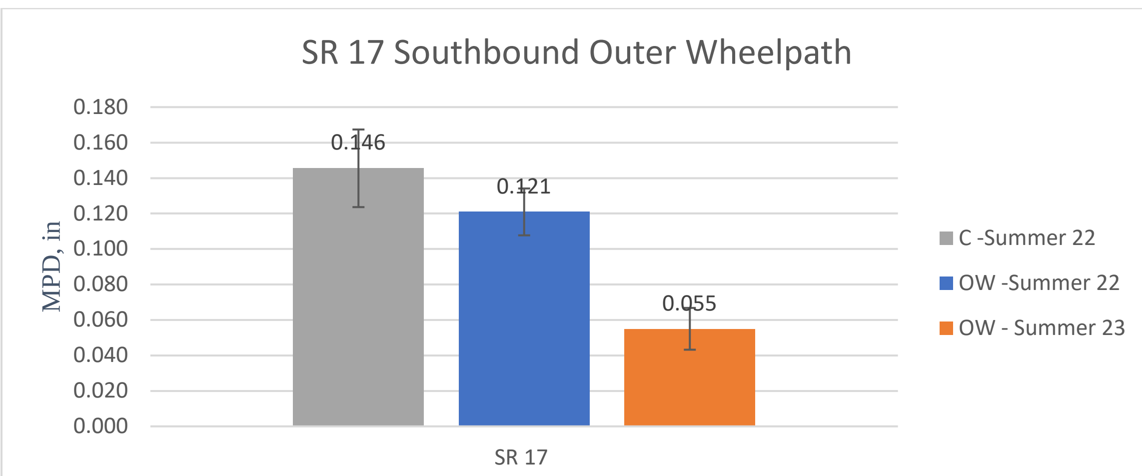


Figure 4-24. Chart. MPD of SR 17 Over Time.

(a) (b)

Figure 4-25. Photo. SR 17: (a) Bleeding in the Wheelpath and (b) Close-up View.

Within the SR 17 chip seal, the severity of bleeding one year after construction varied. The north end (MP 48 area) had the most severe bleeding, followed by the south end (MP 43 area) and then MP 44 to MP 47 (Figure 4-26). The north end also had the lowest MPD between wheelpaths, 0.120 in., during construction in the summer of 2022, followed by the south end (MPD of 0.129 in.). The average MPD from MP 44 to 47, which had only light bleeding, was 0.155 in. immediately after chip seal installation in the summer of 2022. This suggests that MPD between the wheelpaths could be a good indicator of the performance of the chip seal.

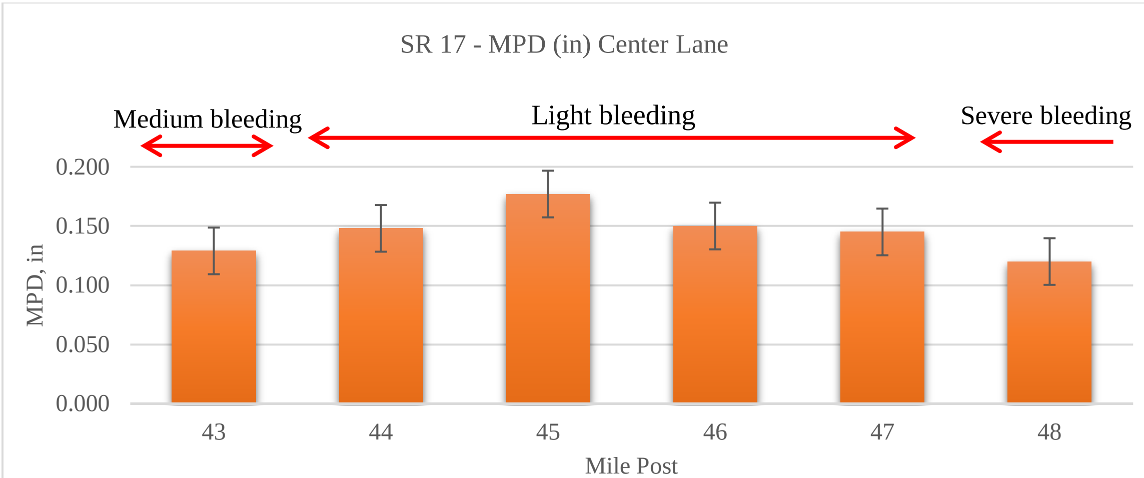


Figure 4-26. Chart. MPD between the Wheelpaths at SR 17 during Construction.

4.2.3 South Central Region: SR 410 (288th Ave to Crystal Mountain Blvd)

The SR 410 section, located near Mount Rainier National Park, had an ADT of 2,021 vehicles, with 8 percent trucks. For this section, a chip gradation of ½ in. - #4 was used, and CRS-2P emulsion was applied. This section experiences a mountainous climate, with cold, snowy winters, cool to moderately warm summers, and high precipitation throughout the year.

During construction, the SR 410 section was evaluated from MP 36 to MP 50. Figure 4-27 shows that the MPD at the outer wheelpath in the summer of 2022 dropped from 0.103 in. to 0.078 in. in the summer of 2023. As of summer 2023, the SR 410 section did show very good performance, as shown in Figure 4-28. Note that SR 410 is heavily canopied by trees with only part-time exposure to sunshine during the day.

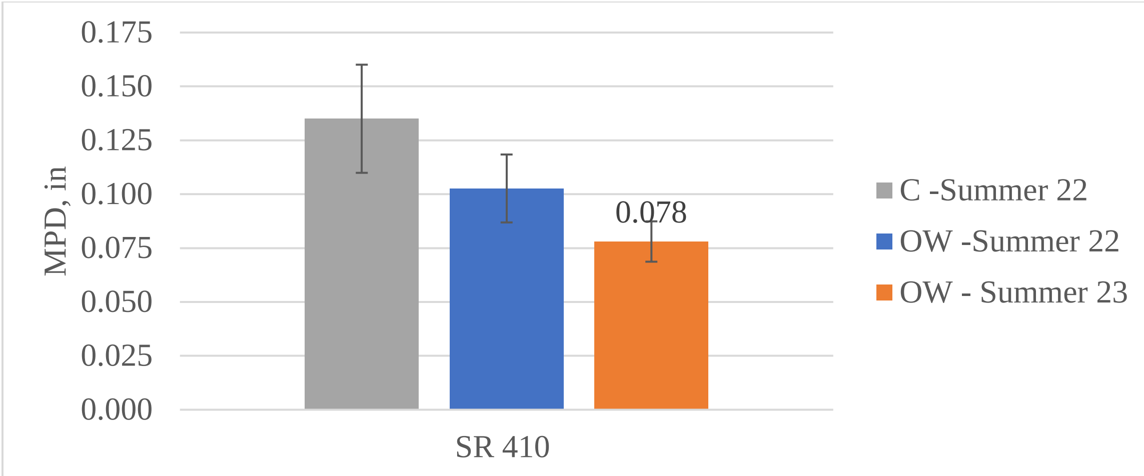


Figure 4-27. Chart. MPD at SR 410 over Time.

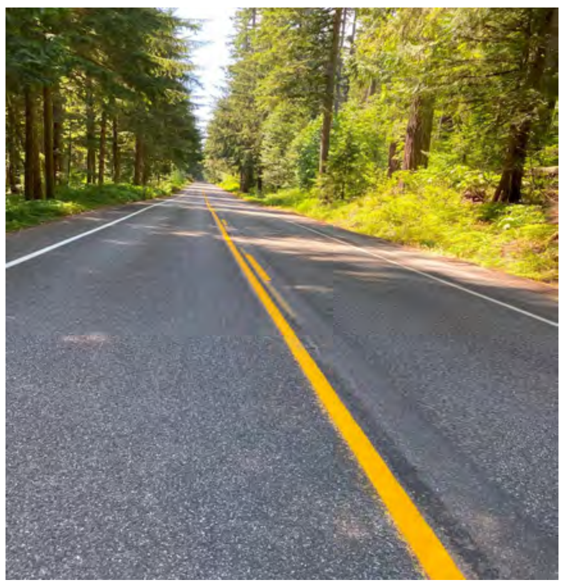


Figure 4-28. Photo, Condition of SR 410 in Summer 2023.

4.2.4 Olympic Region: SR 106

SR 106 had an ADT of 1,244 and a truck percentage of 5.3 percent. The area along SR 106 in the Olympic Region experiences a temperate maritime climate, with mild, wet winters, cool summers, and high annual precipitation. During construction in the summer of 2022, a graded chip of 3/8 in. - #4 and a CRS-2P emulsion were used for this section.

Because of a schedule conflict, data were not collected after brooming. Instead, the team used hand sweeping after the final rolling of choke.

Figure 4-29 illustrates the MPD over time. After 11 months of traffic, the texture depth decreased to 0.078 in. in the summer of 2023. SR 106 demonstrated good performance after one year in service, as indicated by Figure 4-30.

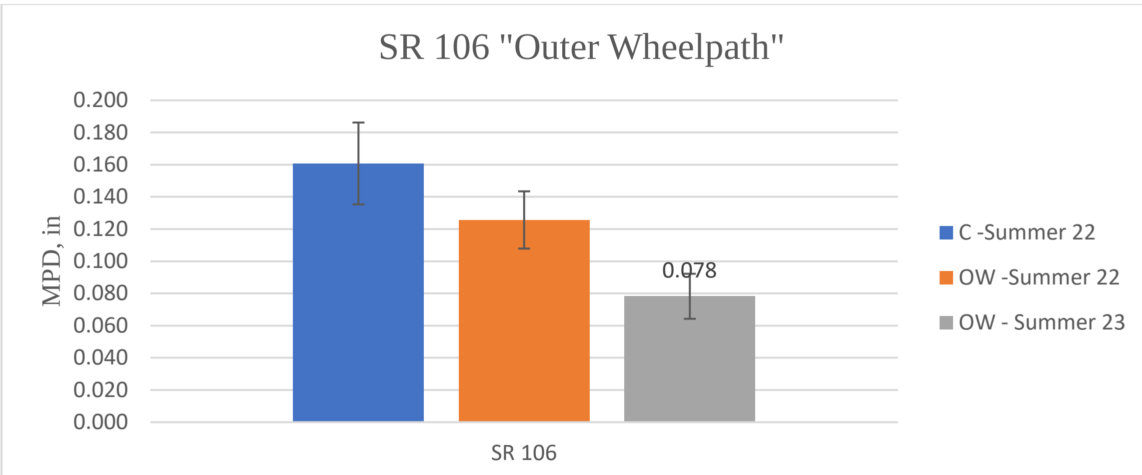


Figure 4-29. Chart. SR 106 MPD in the Outer Wheelpath.

Figure 4-30. Photo. SR 106 Chip Seal in the Summer of 2023.

4.2.5 Northwest Region: SR 20 (Rocky Creek to Granite Creek)

SR 20 had an ADT of 1,606, including 7 percent trucks. The chip gradation was ½-in. No.4 and CRS-2P was used in this project.

Figure 4-31 shows the MPD in the outer wheelpath decreased from 0.110 in. in the summer of 2022 to 0.067 in. in the summer of 2023. As of summer 2023, SR 20 had good performance, as shown in Figure 4-32. On the basis of this SR 20 section and other sections, a threshold of 0.065 in. or higher in the outer wheelpath after one year in service may indicate good performance, as previously stated.

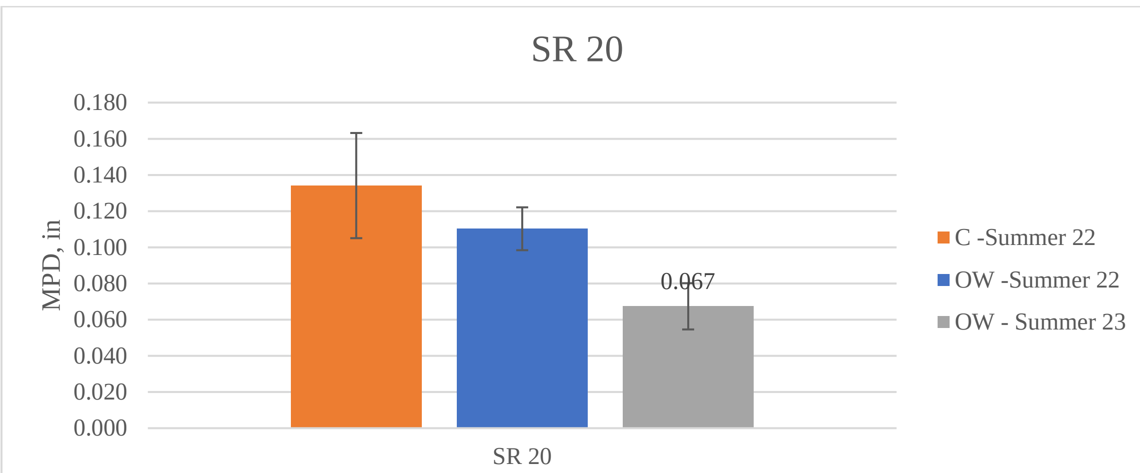


Figure 4-31. Chart. Summary of MPD of SR 20 Over Time.

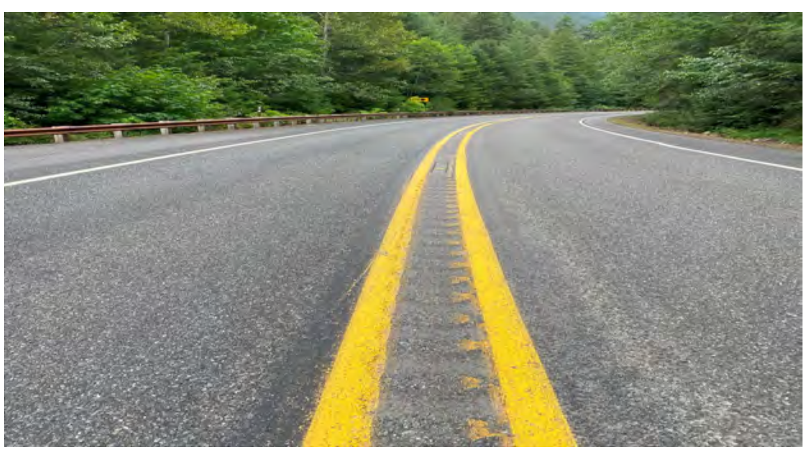
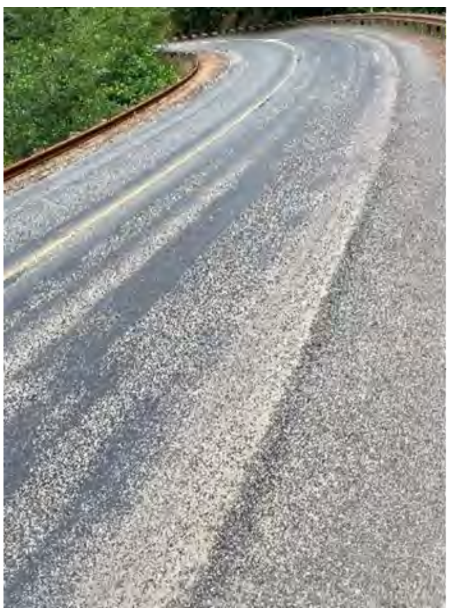


Figure 4-32. Photo. Condition of SR 20 in Summer 2023.

However, in the summer of 2023, raveling was observed in sections with sharp curves (MP 127.2 to MP 127.3), as shown in Figure 4-33. They were out of the milepost range that the team monitored during construction. In this study, the superelevation was used as an indicator of the radius of curves because the superelevation slope is part of the geometric design to offset the centrifugal forces of vehicles on sharp curves. The combined lateral and longitudinal forces may exert a larger force on chips than the longitudinal forces on straight sections.

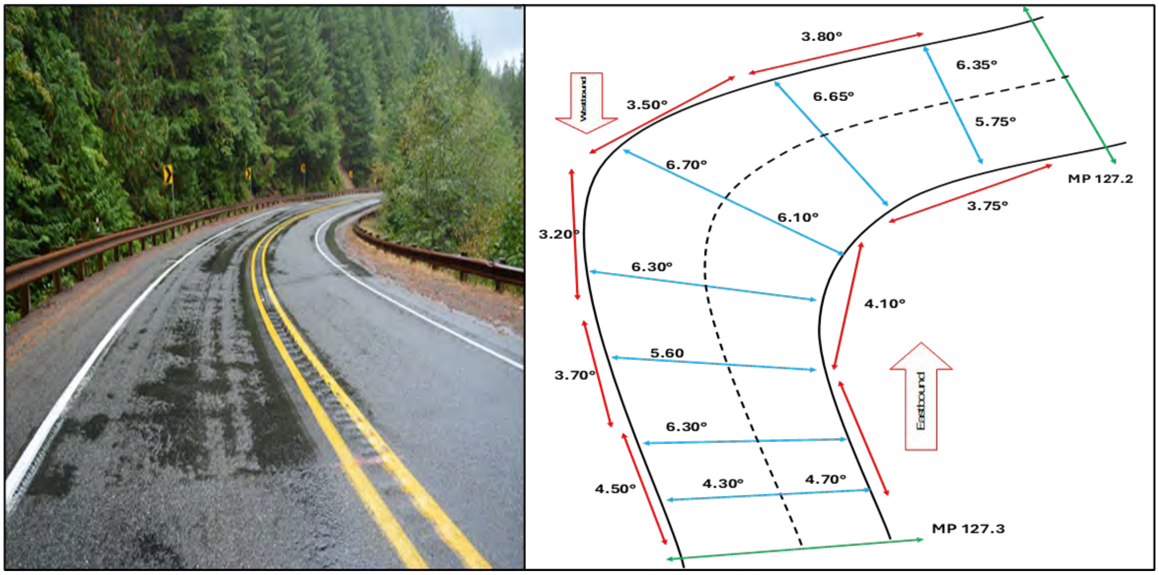


(a)

(b)

Figure 4-33. Photo. SR 20: (a) Curve with Loss of Chips; and (b) Close View of Raveling.

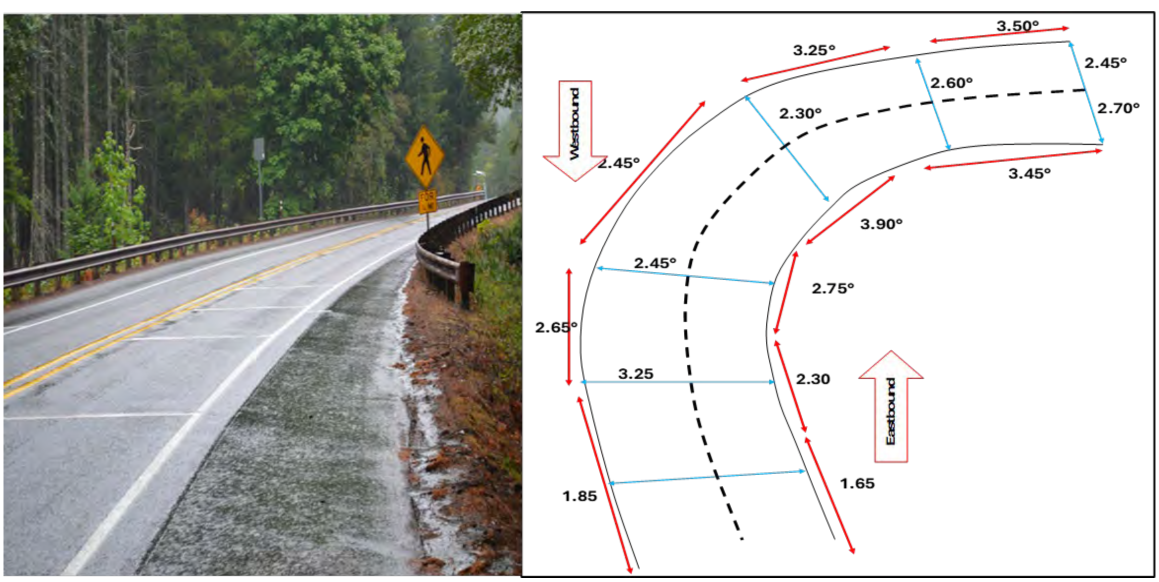
Figure 4-34 shows a sharp curve with raveling and measured cross-slopes (Figure 4-34(b)). The areas with raveling had cross-slopes of 5 percent or higher.



(a) (b)

Figure 4-34. Photo. Effects of Superelevation on Curve Slope, a) Field View; b) Superelevation Sketch of Sharp Curve with Raveling.

In another curve (Figure 4-35) on SR 20, the cross slope was up to 3.25 percent, and no raveling was noticed. Therefore, there may exist a cross-slope (e.g., 4 percent) beyond which raveling is pronounced.



(a) (b)

Figure 4-35. Photo. Performance of Low Superelevation on Curve Slope: (a) Field View; (b) Superelevation Sketch of Curve.

4.2.6 Southwest Region: SR 142 (Lyle to Goldendale)

SR 142 had an ADT of 723 with a truck percentage of 14.2 percent. The average MPD between the wheelpaths was recorded at 0.146 inches immediately after construction in the summer of 2022. Initially, the average MPD in the OW in summer 2022 was 0.111 in., while during the summer of 2023, the MPD decreased to 0.055 in., as shown in Figure 4-36. As of summer 2023, SR 142 had shown slight bleeding, as shown in Figure 4-37.

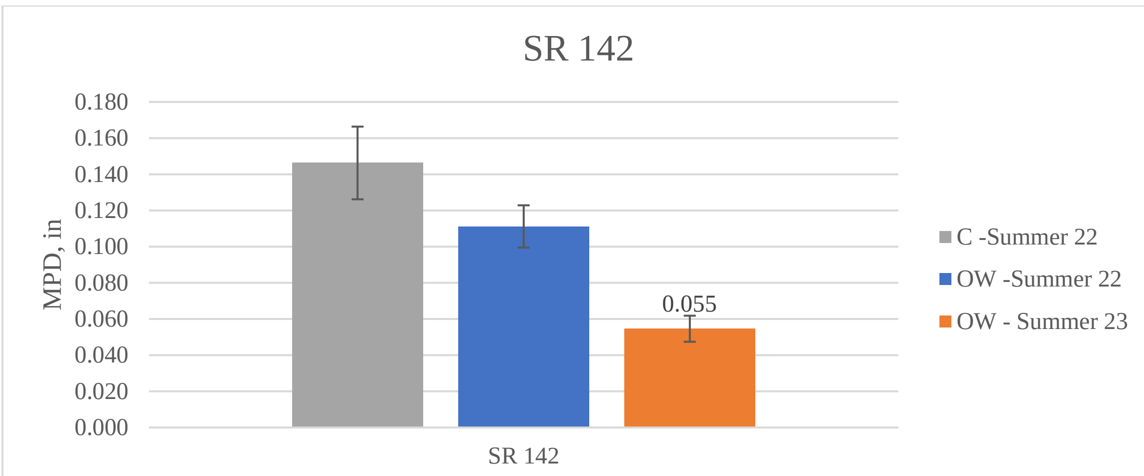
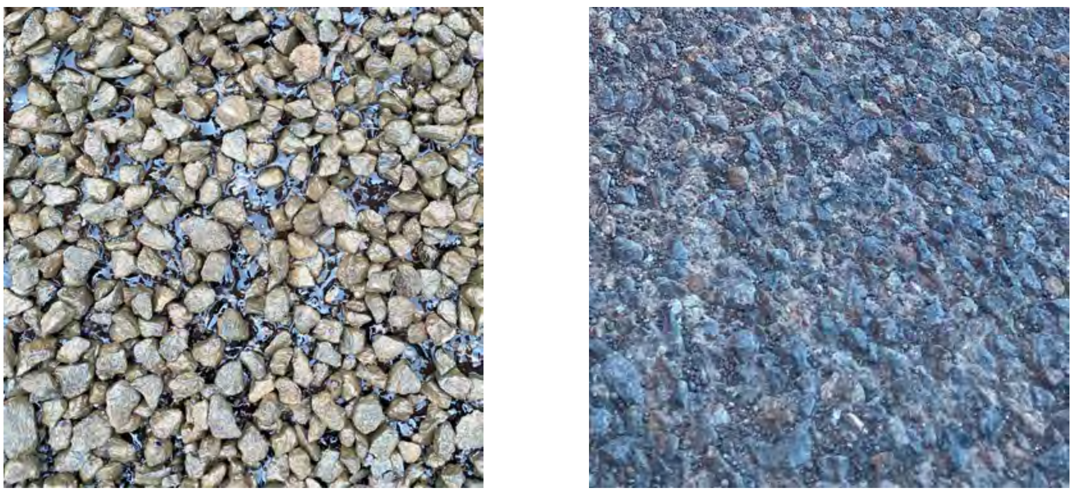


Figure 4-36. Chart. MPD of SR 142 Over Time.

Figure 4-37. Photo. Slight Bleeding of SR 142.

During the construction of SR 142, a one-mile section located in the City of Lyle was designated as an environmental area. This area was built exclusively using chips (3/8 in. - #4) without applying choke because of residents' concerns about dust. Figure 4-38 (a) depicts the surface obtained from the use of only chips, initially displaying a porous and open surface. However, after one year of service, no significant difference in texture was observed between sections with or without choke on SR 142 (Figure 4-38 (b)). The effectiveness or amount of choke may warrant further studies.



(a) (b)

Figure 4-38. Photo. Surface Texture of SR 142 without Choke: (a) During Construction; and (b) After One Year.

4.2 Developed MPD Threshold for Construction Quality Verification

A previous study used MPD from a portable laser texture scanner as a quality verification measure of chip seal construction and established that a minimum mean MPD value of 0.150 in. (3.81 mm) outside the wheelpath immediately after brooming is needed for good performance of the chip seal to avoid loss of chips or bleeding (Umutoniwase et al. 2024). However, this MPD measurement of 0.150 in. was developed on the basis of only one project and therefore needed to be verified for other project conditions, such as traffic levels, materials, and existing pavement conditions.

A high application rate of emulsion often leads to high embedment of chips and thus low MPD, or vice versa. For a given emulsion application rate, inadequate rolling of chips results in low embedment, and brooming removes the large chips (e.g., 3/8 in.) with low embedment and leaves only small chips (e.g., #4) with deep embedment in asphalt residue, which also leads to low MPD. However, the MPD in the wheelpath constantly changes because of construction vehicles and controlled traffic before brooming and after the section has been open to public traffic. Therefore, the MPD between wheelpaths may be a good measurement because it stays relatively stable after construction. The MPD on the shoulder is also a preferred location, but not every chip seal project covers the shoulder. Therefore, the MPD between wheelpaths immediately after brooming can be used as a performance indicator.

Analysis of projects in this study indicated that other factors also affect chip seal performance, such as traffic and truck levels, rut depth in the existing pavement, type of existing pavement (e.g., new HMA, existing HMA, or existing chip seal), and shaded area. A model was built to relate these factors to chip seal performance, as shown in Equation (7). Table 4-1 shows the data used for building the model.

$$MPD_{1\text{-}yr/wp} = 0.55 \times MPD_0 - 39.44 \times RD - 0.01 \times ADTT + 4.57 \times SHD - 5.77 UNDER \quad \text{(Equation 7)}$$

where:

$MPD_{1\text{-}yr/wp}$=Mean wheelpath MPD after one year in service, mil (=0.001 inch)

$MPD_{0/c}$=Mean MPD at the center of the lane immediately after brooming but before opening to traffic, mil

RD=Average rut depth of existing pavement prior to chipping, inch

ADTT=Average daily truck traffic (or ADT multiplied by truck percentage)

SHD=Shaded area: 0 for No and 1 for Yes

UNDER=Underlying pavement: 0-Existing HMA or chip seal; and 1- New HMA or new chip seal.

Table 4-1. Data Used for Building the Model.

Sections	SHD	New HMA	Rut, in	ADTT	Mean $MPD_{0/c}$, mil	Mean $MPD_{1-yr/wp}$, mil
SR 26	No	No	0.35	365.3	137.8	67.2
SR 27	No	No	0.24	74.1	126.9	69.4
SR 127 Over existing chip seal	No	No	0.26	210.6	139.5	65.1
SR 127 Over new HMA	No	Yes	0.0	210.6	155.1	78.6
SR 195	No	No	0.49	715.7	131.7	40.1
SR 261	No	No	0.18	56.8	150.5	78.8
SR 20	Yes	No	0.17	115.6	134.1	65.5
SR 410	Yes	No	0.15	161.9	135.0	77.2
SR 17	No	No	0.27	1353.4	145.5	57.8
SR 142	No	No	0.19	102.7	146.3	58.4

Figure 4-39 shows the measured and calculated MPD_{1-yr} based on Equation (7). A good agreement was found, indicating the effectiveness of the model.

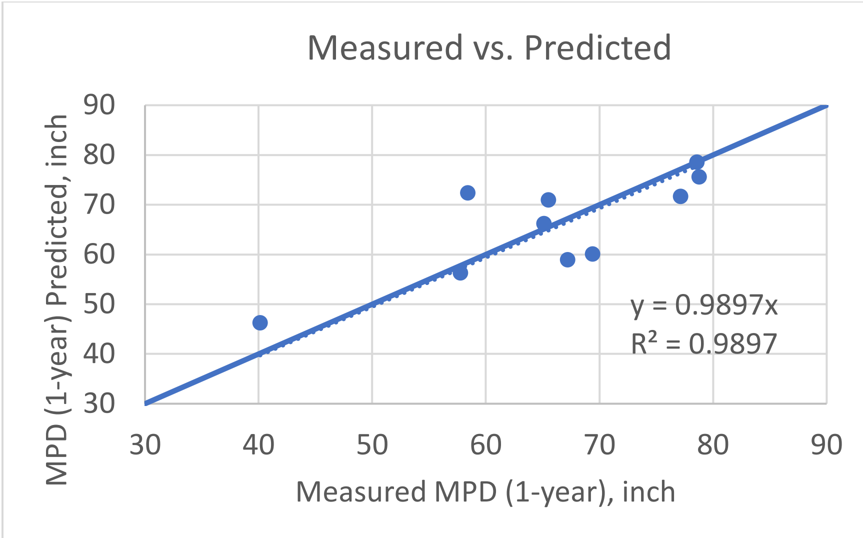


Figure 4-39. Graph. Mean Wheelpath MPD Measured vs Predicted.

According to Equation (7), a higher initial MPD immediately after brooming between wheelpaths often indicates higher MPD in wheelpaths after in-service and less bleeding potential. Most of the mean MPDs at the center of the lane immediately after brooming are between 0.130 in. and 0.155in., which corresponds to a percent embedment of 30 to 50 percent based on Figure 4-4. In the wheelpaths, most MPDs immediately after construction range between 0.100 in. and 0.120 in. or 50 to 60 percent embedment as a result of construction vehicles and controlled traffic before brooming.

Given the relationship in Equation (7), higher rut depths in existing pavement lead to the migration of emulsion asphalt to the rutted wheelpath, as previously discussed in this report. This migration results in lower MPD in the wheelpath and increases the potential for bleeding. High-volume trucks embed and flatten chips to their least dimension side quickly, which increases embedment, resulting in lower MPD and a higher bleeding potential. In comparison to shaded areas, asphalt residue in chip seals in unshaded areas are often softer in summer because of exposure to sunshine. This softness makes it easier for chips to settle into their lowest dimensions under traffic, which may increase the potential for bleeding. For underlying pavement, a new HMA allows chips to penetrate deeper, which increases embedment and leads to a lower MPD. In addition, emulsion can leak into underlying new HMA, thus increasing the initial MPD immediately after construction.

As stated previously, an MPD of 65 mils (or 0.065 in.) or higher in the outer wheelpath after one year in service indicates good chip seal performance. To establish the initial MPD for construction quality control and assurance, Equation (8) is rearranged, replacing $MPD_{1\text{-}yr}$ with 65 mils, as shown below:

$$MPD_{0/c}=(65+39.44\times RD+0.01\times ADTT-4.57\times SHD+5.77UNDER)/0.55 \qquad \text{(Equation 8)}$$

For a given project, a specification of $MPD_{0/c}$ can be determined for quality assurance and/or incentives/disincentives, based on project site conditions such as rut depth, traffic, etc. However, the raveling issue of a sharp-turn curve on SR 20 fell outside the scheduled monitoring zone, and thus no initial MPD at the center of the lane was available during construction. Pending further verification, it is recommended that for projects with 20 percent or more length and a superelevation of 4 percent or higher, 10 mils should be deducted from the requirement for the initial MPD at the center of the lane to increase embedment and mitigate raveling potential.

Note that this relationship is based on a limited number of chip seal projects, and further study based on more data may be warranted to verify the relationship. Nonetheless, the above relationship serves as a data-driven starting point for developing chip seal construction quality specifications.

To establish the lower limit for the MPD threshold, the coefficients of variation (COV) of mean MPD at the center of the lane immediately after brooming (or mean $MPD_{0/c}$ in Equation (8)) were determined, as shown in Figure 4-40. The average COV was found to be 15 percent. Note that COV is equal to standard deviation (σ) divided by mean value (μ). As a starting point, the lower specification limit (LSL) is proposed as the mean value minus one standard deviation, which is based on a 68.27 percent confidence level, as shown in Equation (9). A more vigorous, statistics-based specification is recommended for future development.

$$LSL = \mu - 1\times \sigma = \mu - 1\times COV \times \mu = \mu - 1\times 0.15 \times \mu = 0.85\ \mu \qquad \text{(Equation 9)}$$

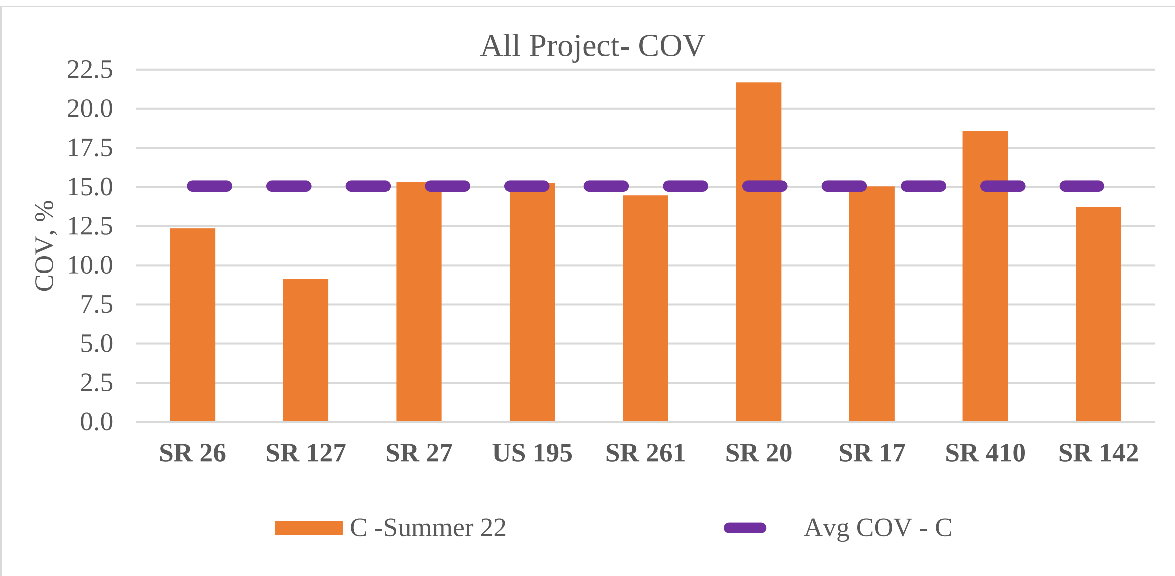


Figure 4-40. Graph. COV of MPD Across Different Wheelpaths.

Based on SR 127, which exhibited raveling outside the wheelpaths, an upper specification limit (USL) of 170 mil is recommended. In addition, Equation (8) may produce very low mean $MPD_{0/c}$ for some very low-volume roads, e.g., below 130 mils. To safeguard against unexpected traffic, such as detoured traffic, a minimum mean $MPD_{0/c}$ of 130 mils (or LSL of 110 mils) is recommended for any chip seal project.

Chapter 5 Conclusion and Recommendations

Chip seal, a cost-effective pavement surfacing method, is widely used by state and local governments in Washington state. However, chip seal construction acceptance relies on the experience and visual observations of field engineers/inspectors, which has led to significant variations in chip seal performance, with some projects experiencing premature failure. This study was conducted to develop a quality specification for chip seal construction. A number of chip seal construction projects were monitored, and MPD measurements were collected using laser texture scanners during and after construction. Based on this study, the following conclusions and recommendations can be made:

5.1 Summary of Findings

Based on this study, the following conclusions can be made:

1. Oscillatory rollers crush chips and are not recommended for use in rolling chips.
2. A combination of pneumatic tire and steel drum roller, as specified in WSDOT 5-02.3(1), seems to be effective at compacting both the wheelpaths and center of the lane, while steel drums alone may not compact the wheelpath well because of bridging as a result of rutting.
3. A relationship between MPD and the percent embedment of chips was developed on the basis of field-compacted samples.
4. The emulsion application rate exhibits high variability during construction, manifesting the need for quality control and assurance.
5. Based on one year of performance monitoring, no pronounced difference was noticed between conventional chip gradations and modified gradation of chips. The same applies to the different compaction patterns experimented with.

6. When the chip seal is placed on the new HMA inlay, the emulsion may leak into the underlying new HMA inlay. A higher fog seal on the HMA inlay or a higher chip seal emulsion rate may be warranted. When the MPD is above 0.170 in. (or 170 mil), raveling may occur outside the wheelpaths, likely due to snowplow operation.
7. There is a strongly converse relationship between rut depth and MPD value. Laboratory tests verified that asphalt emulsion and/or residue can migrate between chips even after compaction to a rutted area, which can lead to bleeding.
8. It is recommended that if the existing rut depth is 0.25 in. or higher, the rut should be milled, filled with pre-leveling or a wheelpath chip seal.
9. A sharp-turn curve may be susceptible to a loss of chips, and it is recommended to increase percent embedment (or lowering MPD) or apply HMA, instead.
10. After one year in service, good chip seal performance has been reported when the MPD was 0.065 in. or higher.
11. Because of continuous passes of construction vehicles and controlled traffic, it is recommended to use MPD at the center of the lane as a reference.
12. A model was developed to relate MPD at the center of the lane after one year of service to other site conditions and initial MPD.
13. The optimal percent embedment was found to be between 30 and 50 percent at the center of the lane, and between 50 and 60 percent in the wheelpath (because of construction vehicles and controlled traffic).

5.2 Recommendations for Implementation

5.2.1 Recommended Changes for Chip Seal Construction

On the basis of the findings, the following recommendations are proposed:

1. Rut that is 0.25 in. or deeper should be milled or filled with pre-leveling or wheelpath chip seal. If a wheelpath chip seal is used, it is recommended to install it at least a year before to allow sufficient aging of the chip seal asphalt residue, or that a lower emulsion rate be used if applied the same year as regular chip seal.
2. It is recommended that the final rolling of the chip seal use a combinational roller, as specified in WSDOT Standard Specification 5-02.3(1), as follows:

"Rollers for final finishing shall be a combination of self-propelled pneumatic tired rollers and smooth-wheeled rollers. Each roller shall not weigh less than 12 tons and shall be capable of providing constant contact pressure. Operation of the roller shall be in accordance with the manufacturer's recommendations."

5.2.2 Draft Specification for Chip Seal Construction Assurance

As part of this report, a draft specification was developed for which the lower specification limit of mean $MPD_{0/c}$ between wheelpaths can be determined, based on Equation (9). The upper limit MPD was set to be 170 mils, based on the raveling issue of SR 127 over the new HMA. A spreadsheet program was developed to facilitate calculation.

In addition, a test protocol was developed to establish best practices and requirements for the use of the laser texture scanner (see Appendix B). Because this is a new technology for chip seal construction quality assurance, only incentives are proposed to encourage contractors to adapt this specification to improve construction quality. In addition, as a quick assessment for easy implementation, a simple percentage within limits (SPWL) is used that is based on a simple count of data within the upper and lower limits in terms of percentage. Later, this SPWL can be easily transitioned into the statistical percentage within limits, such as 106.2.(2) in WSDOT's Standard Specifications.

To facilitate implementation, one blanket lower limit of MPD is recommended for regular chip seal projects. However, for high-risk projects that have high ADT or a high rut depth, or that are in mountain passes, the design spreadsheet that was developed based on the model and accounts for various site conditions is recommended for use.

The proposed specification is as follows:

5-02.3(5) Application of Aggregates Is Supplemented with the Following:

Immediately after the brooming, but before opening to public traffic, the Engineer will measure the mean profile depth (MPD) in accordance with the test protocol. The number of test locations will be based on the table below, rounding up to the whole number. Test locations will be at the center of the travel lane, and the stationing will be determined by the Engineer in accordance with WSDOT Test Method T 716.

Total length of Treatment (lane mile)	Number of test locations per lane mile	Number of test locations per project
0 – 1	-	5
>1	3	5

All of the test results will be obtained and evaluated for each separate section of the Contract. The section limits are specified in the plan sheet. The simple percentage within limit (SPWL) will be determined based on the following:

Upper Specification Limit: 170 mils (0.170 in.)

Lower Specification Limit:

- Use design spreadsheet if ADT ≥ 5,000, or average rut depth in existing pavement ≥ ½”, or located in the mountains,
- Otherwise: 110 mils

5-02.5 Payment Is Supplemented with the Following:

“MPD price adjustment” will be a $500 incentive per lane mile when the simple percentage within limit (SPWL) of MPD for an individual section of the Contract is 70 percent or higher. If the percentage within limits (PWL) for an individual section of the contract is less than 70 percent, then no disincentive is applied.

5.3 Recommendations for Further Studies

While this study made some good findings, as one of few studies that have collected data in the field to assist decision-making, it was not meant to be exhaustive. Based on this study, further studies are recommended, as follows:

1. The draft specification and model were developed on the basis of only one year of performance of chip seal. It is recommended to continue monitoring these chip seal projects through at least three to four years of performance (i.e., 2025 and 2026) or longer to verify the findings and specifications.
2. It is recommended that further study of chip gradation, toward single-size chips, is conducted.
3. A guideline for the selection of proper emulsion that suits different climatic conditions should be studied and developed. Currently, the selection of emulsion type is based on experience only and may not apply to different site conditions.

4. Chip seal "blowups," such as those on US 195, which are suspected to be related to moisture damage, warrant further study.
5. The effects of sharp-turn curves, as well as uphill and downhill slopes, on chip seal performance need to be quantified and possibly included in the model for determination of the lower limit of chip seal specifications.
6. Pavement Profiler, which can measure macrotexture at highway speed, is worth exploring to expedite measurements for quality acceptance.
7. Analogous to HMA mix design, the chip seal mix design procedure should be developed before chip seal construction to ensure good performance, instead of relying on the contractor/supplier's experience.
8. The effectiveness of choke is worthy of further investigation.

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APPENDIX A

Survey on Chip Seal Construction Quality Acceptance

Name:
Agency:
Title:
Email:
Phone:

1. What does your agency use chip seal for?
    a. Preservation (proactive)
    b. Maintenance (reactive and temporary, e.g., wheelpath rut repair)
    c. Rehabilitation (reactive and long-term, e.g., 6 years)
    d. Low-volume road surfacing
    e. Others ___________________
2. How soon is chip seal placed after HMA overlay or reconstruction?
    a. 0-1 year
    b. 1-3 years
    c. 3-5 years
    d. Whenever needed
3. Others __________________Does your agency place chip seal over:
    a. HMA pavement-good condition
    b. HMA pavement-poor condition
    c. Existing chip seal
    d. Others __________________
4. What type of chip seal is mostly used?
    a. Single-chip
    b. Double chips
    c. Chips with choke
    d. Others ___________________
5. What is the Average Daily Traffic (ADT) for chip seal project?
    a. <1,000
    b. <3,000

c. <5,000

d. <10,000

e. Others ___________________

6. What is the minimum air temperature for chip seal construction?

a. 50°F

b. 60°F

c. 70°F

d. By Season?

e. Others ___________________

6.1 What Season?

i. Spring

ii. Summer

iii. Fall

7. Is there a maximum air temperature for chip seal construction?

a. Yes (please provide maximum air temperature below)

____

b. No

8. Is there an elevation limitation for chip seal construction?

a. Yes (please provide maximum elevation below)

____

b. No

9. Is the rut filled before chip seal and how early?

a. Yes (please provide the rut depth that needs to be filled below)

____

b. No

9.1 If your answer was "Yes," when it carried out?

i. Same year as the chip seal construction

ii. One year before the chip seal construction

iii. Two years before the chip seal construction

iv. Others ___________________

10. Are the cracks sealed before chip seal and how early?

a. Yes (please provide the crack width that needs to be sealed below)_________________

b. No

10.1 If your answer was "Yes" when are the cracks sealed?

i. Same year as the chip seal construction

ii. One year before the chip seal construction

iii. Two years before the chip seal construction

iv. Others __________________

11. Is the existing pavement repaired with patches before chip seal?

a. Yes

b. No

11.1 If your answer was "Yes", when is it repaired?

i. Same year as the chip seal construction

ii. One year before the chip seal construction

iii. Two years before the chip seal construction

iv. Others __________________

12. Does your agency have a design method for emulsion and chip application rates?

a. McLeod

b. Modified McLeod

c. Kearby

d. Modified Kearby

e. AASHTO PP82

f. Others __________________

13. Is there a calibration or verification of the emulsion and chip application rates during construction?

a. Yes

b. No

13.1.1 How is the calibration or verification of the emulsion and chip application rates?

____

14. What is the top size of the chips mostly used and conditions (e.g., pavement condition, traffic, etc.) to use this size?

  a. ¾" (please provide the conditions to use below)

  ____

  b. ½"(please provide the conditions to use below)

  ____

  c. 3/8" (please provide the conditions to use below)

  ____

  d. Others ___________________

15. What is the gradation of the chips mostly used?

  a. Single (please provide the gradation below)

  ____

  b. Graded (please provide the gradation below)

  ____

  c. Others ___________________

16. Are choke stones (or sand) used on top of chips?

  a. Yes

  b. No

16.1 If your answer was "Yes", please provide:

  i. Top Size ___________________

  ii. Gradation ___________________

17. Please list one or two most used emulsions and conditions (e.g., pavement, traffic, etc.) they are used:

  a. Emulsion type 1 (please provide the condition to use below)

  ____

  b. Emulsion type 2 (please provide the condition to use below)

  ____

  c. Hot applied asphalt binder (please provide the condition to use below)

  ____

18. What are the rolling requirements of chip seal?

  a. Steel roller (please provide the number of passes below)

  ____

  b. Pneumatic roller (please provide the number of passes below)

____

c. Oscillatory roller (please provide the number of passes below)

____

d. Others ___________________

19. Is fog seal used after chip seal placement?

a. Yes

b. No

19.1 If your answer was "Yes", How soon is the fog seal applied?

a. Immediately after brooming

b. 1 day after

c. 2 days after

d. More than 2 days

19.2 If your answer is "Yes", please provide,

- What type fog seal?_______________________
- What dilution do you use?_______________________
- What is the application rate used?_______________________

19.3 Is fog seal applied to chip seal with choke?

a. Yes

b. No

20. Is the chip embedment inspected during or after construction?

a. Yes

b. No

20.1 If your answer is "Yes", please provide,

- How it is measured? _______________________
- What is the threshold? _______________________

21. Is there a quality acceptance specification of chip seal construction?

a. Yes (please provide the quality acceptance specification below)

____

b. No

22. What is the major distress in chip seal during construction?

a. Loss of chips

b. Bleeding

c. Others ___________________

23. What are the most common issues that happen during construction of a chip seal??

a. Loss of chips

b. Bleeding

c. Cracking

d. Rutting

e. Blow-up

f. Others ___________________

24. Please list any other comments you may have:

____

APPENDIX B

Test Protocol to Measure Mean Profile Depth for Chip Seal Embedment Using a Portable Laser Scanner

1. Scope

1.1. This practice covers the measurement of the mean profile depth (MPD) of the chip seal during its construction.

1.2. The mean profile depth can provide an estimate of the mean texture depth measured according to Test Method E965.

1.3. The mean profile depth can be used to estimate the percent of embedment of chip seal in the field as well as in the laboratory.

1.4. Units: English or metric

2. Referenced Documents

2.1. ASTM Standards:

- *E1845* Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth
- *E965* Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique

3. Terminology

3.1. Definitions:

3.1.1. *Length of Scan:* The length of an individual line scan that will be performed. ASTM test methods for the MPD calculation require a line scan length of 100 mm.

3.1.2. *Mean Profile Depth (MPD):* The average of all the mean segment depths of all of the segments of the profile in a specific area.

3.1.3. *Embedment Depth (ED):* Depth of aggregate that is embedded in the emulsion.

4. Summary of Practice

4.1. This practice uses a portable laser scanner to measure the surface profile of the chip seal macrotexture.

4.2. The laser scanner provides the measured profile with an established base length based on the set scan area.

4.3. The profile measured by the device performs an established analysis to obtain the MPD and applies a filter from 2.5 mm to 3.0 mm depending on the configuration that is required.

4.4. The laser device provides the analysis and measurements based on the segmentation of the measured profile and the determination of the highest peak in each half-segment.

4.5. The laser device calculates the difference between that height and the average level of the segment. The average value of these differences for all the segments that make up the measured profile is reported as the MPD.

4.6. The value obtained with the device serves as a reference for estimating the percentage of embedment of the chip seal.

4.7. The MPD measured helps predict the performance of chip seal constructions.

4.8. The measured MPD helps control the occurrence of premature distresses during and after construction (e.g., bleeding, flushing)

5. Significance and Use

5.1. The results of the measurement of the MPD have the potential to be useful in the estimation of chip seal embedment and also as a possible performance indicator.

5.2. The MPD can be obtained with the help of the laser scanner and in the same way, using the technique Test Method E965 as a reference Method of validation.

5.3. This practice uses the measured MPD from a laser scanner during the construction to control the expected initial embedment percent.

5.4. Recommendations related to the test protocol and collection of data are based on a previous research procedure in the field.

5.5. This protocol provides the information related to the process developed to provide enough data points as well as to keep the operator safe.

6. Laser Scanner Setup

6.1. Laser Setup

The laser device can perform measurements based on the standard configuration or established by the user. The configuration will depend on factors such as:

- Chip seal construction process.
- Level of traffic control during construction (i.e., operator safety)
- Use of data (quality control or Research)
- Weather

The types of configurations can be established with units in the English System or the International System (SI).

6.2. Scan area setup:

6.2.1. Scanning Area

The scanning area of the laser scanner will depend on the configuration established by the user and the level of detail required. The total area that the device can cover is 2.835 in width (72.01 mm) and 4.095 in length (104.01 mm).

This area can be adjusted depending on the configuration and requirements in the field measurements.

If the scan area and the number of scan lines are set, the spacing between each scanning line will be set automatically. However, the laser device also has the settings to edit the scan area, the number of scan lines, and the spacing.

6.2.2. Dry and Wet Surface

The laser scanner device can perform measurements on wet and dry surfaces. A light sweep is recommended to remove dust and small particles that may cause variations in measurements. This test protocol has shown that a slightly wet surface does not affect measurements.

6.2.3. Number of Scan Lines

The number of scan lines that the device can perform can be set directly in the software of the laser device.

The number of scan lines is set by the width of the area and the minimum spacing required by the laser device basin with the capacity to perform from 1 to 2917 scan lines if the standard width of 2.835 in width (72.01 mm) is used.

The number of scan lines can cause a variation of 0.01 in the MPD depending on the increment of scan lines. The greater the number of scan lines, the greater the resolution of the measurements.

6.2.4. Recommendations:

The number of scanned lines should be 5 to provide measurements of MPD repeatable over the same spot.

The measurement time does not include the handling and transfer of the laser to the measurement point. It is recommended to take measurements within traffic control, to avoid accidents and keep the operator safe from the traffic.

7. Materials and Apparatus

The principal instruments used to perform the scans and preparation of the surface consist of the following pieces of equipment:

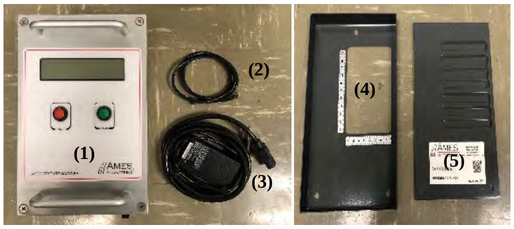
7.1.*Laser Scanner:*

Figure 1 shows (a) the kit where the device is transported, and (b) the interior where the laser scanner and its instruments are stored.

Figure 1. Laser Texture Scanner; (a) AMES Case; (b) AMES Case Interior View

7.2.Interior instruments

The AMES case carries five (5) components. Figure 2(a) shows the main components as (1) laser scanner; (2) ethernet interface cable; and (3) ethernet changer supply unit. Figure 2 (b) shows the necessary instruments for taking measurements and calibrating the device: (4) sampling plate; and (5) reference plate (104 × 70 mm)



(a) (b)

Figure 2. Interior components of laser scanner device

7.3.Surface preparation instruments:

For the preparation of the test surface, it is necessary to (1) gently clean or sweep the test spots; and (2) delimit the sample area with a painting. Figure 3 shows the necessary instruments for these two actions; (a) spray paint to mark the surface where the scanning will be performed; (b) a small straw broom, (12 × 6 × 1 inch (L×W×H)), or (c) a hand nylon brush (6 × 4.5 × 1 inch (L×W×H)). These dimensions are recommended to provide a gentle sweeping of the spot.

Figure 3. Surface Preparation Materials; (a) Paint Spray; (b) Small Brush; and (c) Hand Nylon brush

The spray paint is recommended to be oil-based, to maintain a longer adherence to the surface of the chip seal.

8. Procedure and recommendations

The following procedure is based on considerations related to traffic control, the time needed to take measurements, the safety of the operator, the weather, and the battery life of the device.

8.1.Record the project condition.

8.1.1. Record the project ID, road number, direction, milepost or station and offset, weather, and other relevant information.

8.1.2. Record the type of existing pavement (e.g., existing HMA, new HMA, existing chip seal, HMA patch, etc.). Also record the condition of existing pavement, e.g., existing chip seal with bleeding, etc.

8.2.Test Area and Previous Preparation:

8.2.1. Locate the spots for measurements.

8.2.2. Depending on the geometry of the road, the number of lanes, and the level of traffic, the preparation of the surface will vary.

8.2.3. It is advisable to consider the shoulder (if chipped) or center of the lane as a point of reference.

8.2.4. It is necessary to place a mark (e.g., number or letter) right on the shoulder to recognize the location and measured point.

8.2.5. As part of the preparation of the scanning area, it is necessary to take photos in advance of the locations and reference of the points to be taken as shown in the previous figures.

8.2.6. Once the test area is ready and the initial control photos are collected, the scanning can be performed.

8.3.Scanning procedure:

To perform the scanning of the spots marked, it is necessary to follow the safety recommendations.

8.3.1. Safety Recommendations:

8.3.2. While the scan is running it is recommended for the operator to stay out of the road at the shoulder. This will minimize operator exposure to the traffic during the scanning.

8.3.3. Always be cautious of the direction of the traffic on the lane section as well as on the laser.

8.3.4. Avoid logging the data while the laser scanner is on the road.

8.3.5. Bring the laser scanner to the shoulder and record the data after the scanning is done.

8.3.6. Repeat the same procedure for all the spots.

8.3.7. The measurements during and within the traffic control zone, it is recommended to be alert on the heavy machinery.

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