DEPARTMENT OF TRANSPORTATION

Effectiveness of Fog Seal on Chip Sealed Low Volume Roads

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WSB & Associates, Inc.

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16. Abstract (Limit: 250 words) This report was commissioned to gather information on the current practices of fog seal over chip seal that are being used by Cities and Counties within Minnesota. The report discusses current best practices and value added when compared to a stand-alone chip seal project. The information provided in this report was based off survey results from municipalities with fog seal over chip seal experience and review of technical literature withing the industry. Chapter 3 is a best practice guide for roadway owners and inspectors to assist in following practices that will lead to higher product quality. This guidance can be used to supplement a chip seal best practices manual.			
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FINAL REPORT

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- Steve Bot – City of St. Michael – Technical Liaison
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LIST OF ABBREVIATIONS

gal/sy	gallons per square yard
lbs/sy	pounds per square yard
mph	miles per hour
FA	Fine Aggregate
CSS	Cationic Slow Setting
CRS	Cationic Rapid Setting
AADT	Annual Average Daily Traffic
ESALs	Equivalent Single Axle Loads

EXECUTIVE SUMMARY

Chip seals have been widely used by agencies as a method of preventive maintenance to help extend the life of suitable roadways. However, there are concerns surrounding the use of chip seals such as chip retention issues causing vehicle damage and stripping. This report reviews fog seals applied to chip seal to improve chip seals as a preventative maintenance practice, determine cost effectiveness, and suggested application rates.

The scope of this project included preliminary data collection from agencies to determine experience with performing fog seals over chip seals. In this step, 450 agencies within the state of Minnesota were asked to respond to a survey. The 52 respondents were then narrowed down to 13 agencies that had suitable experience with fog seal on chip seals to ask more in-depth questions. The responses from these interviews and literature reviews were used to compile the following report.

Through the investigation done to develop this report it was discovered that, in most cases, adding a fog seal application to a chip seal will provide a better-quality product and added value to the roadway, thus extending pavement life. This was determined by correlating the additional cost of fog seal application to the increased surface durability and life of service. Additional benefits that have been listed also further increased the value of this preventative maintenance practice beyond durability with very few cons. There was no definitive evidence that the fog seal application will completely prevent the stripping of chip seals, but results did indicate there was a reduction in this issue.

The research that was put into this report has been developed into a best practices guide (Chapter 3) that can be used to supplement a chip seal best practices manual. The guide provides advice to roadway owners and inspectors to assist in following practices that will lead to higher product quality.

CHAPTER 1: SUMMARY OF FINDINGS

1.1 INTRODUCTION

An online survey was distributed to 450 agencies within the state of Minnesota; 52 agencies responded to the survey. A follow-up interview was conducted with 13 agencies that had extensive experience with the applications of fog seal on chip sealed low volume roads. The main topics discussed during the interviews can be categorized into following aspects:

- Background information such as traffic volume, speed limit, and condition of the roadways at the time of application
- Time interval between the applications of fog seals and chip seals
- Application rates
- Project costs
- Life expectancy and performance
- Pros and cons and/or lessons learned
- Feedback from the constituents and/or the maintenance crews

Fog-sealed Chip Seal in Residential Neighborhood

1.2 BACKGROUND INFORMATION

Based on the interviews conducted, the projects ranged from 180 to 9,500 Annual Average Daily Traffic (AADT). For this report, roadways with less than 1,000 AADT were analyzed. The application of fog seals over chip sealed roads have been placed on both rural and urban settings, with speed limit ranging from 30 miles per hour to 60 miles per hour.

Most of the agencies have placed fog seal over chip seal applications on newer pavements, within a year or up to six years after paving. Four of the agencies have placed fog seal over chip seal applications on older pavements, where more extensive cracking and distresses are present. The intent on placing these applications on older pavements is to hold the pavement together until a more significant repair can be programmed. Some agencies performed crack sealing and patching prior to applying a chip seal followed by a fog seal.

Since there was such a wide range of traffic volumes and speed limits for the data that was returned through the surveys and interviews, it was determined to be extraneous factors. A fog seal could be effectively applied to any road that has been chip sealed.

1.3 TIME INTERVAL BETWEEN THE APPLICATIONS OF FOG SEAL AND CHIP SEAL

Ten of the thirteen agencies interviewed stated that a fog seal is scheduled within a few days or up to one week after the chip seal has been placed. The time interval is dependent on the Contractor and the weather. A few agencies have a longer timeframe between the applications of a fog seal and a chip seal, which is up to four weeks depending on the schedule of the chip seal operations.

1.4 FOG SEAL APPLICATION RATES

The fog seal emulsion used by all agencies was CSS-1h. According to the 2020 MnDOT Standard Specifications for Construction, the application rate of CSS-1h is between 0.05 to 0.20 gallon per square yard depending on the level of raveling and porosity of the existing pavement.

Six agencies employ an application rate of 0.10 gallon per square yard. The other agencies have application rates ranging from 0.08 gallon per square yard to 0.15 gal/sy. The average starting rate for fog emulsion application was determined to be 0.10 gal/sy. One agency specified the application rate varies depending on the pavement condition but is in accordance with the MnDOT Standard Specifications for Construction. One agency stated that they bid and pay by the square yard with the contractor submitting the application rates for approval.

1.5 CHIP SEAL EMULSION APPLICATION RATES

The chip seal emulsions used by all agencies are either CRS-2 or CRS-2P, with the CRS-2P being the preferred choice. For fog seal over chip seal projects, many of the agencies employ an application rate of 0.20 to 0.34 gallon per square yard of emulsion on new pavements. One agency specified a higher rate of application on older pavements, which is 0.33 to 0.43 gallon per square yard of emulsion. Another agency specified the application rate varies depending on the pavement condition.

As compared to standalone chip seal projects, one agency employs a similar application rate (0.25 gallon per square yard) of CRS-2P with or without a fog seal. Two agencies have specified a higher application rate of CRS-2P (**Table 1**) for standalone chip seal projects as compared to fog seal over chip seal projects.

Table 1 Example application rates of CRS-2P for standalone chip seal projects as compared to fog seal over chip seal projects.

Agency	Standalone Chip Seal Projects	Fog Seal over Chip Seal Projects
Houston County	0.30 to 0.32 gal/sy	0.27 gal/sy
Otter Tail County	0.30 gal/sy	0.25 gal/sy

1.6 CHIP SEAL AGGREGATE APPLICATION RATES

There were varying aggregate sizes used across the agencies, which include FA-2, FA-2 (modified 1/8-inch), FA-2.5, and FA-3. For fog seal over chip seal projects, the application rate of the aggregates ranges from 17 to 25 pounds per square yard. One agency specified the application rate varies depending on the pavement condition and another agency stated that they bid and pay by the square yard with the contractor determining application rate from a chip seal design.

For standalone chip seal projects, one agency employs similar application rate (18 pounds per square yard) of FA-3 with or without a fog seal. Another agency specifies similar application rate (25 pounds per square yard) but with different type of aggregates used (FA-3 modified rocks for fog seal over chip seal projects and pea rocks for standalone chip seal projects). There is one agency which uses a higher application rate (22 pounds per square yard) of FA-2 aggregates for standalone chip seal projects, as opposed to 18 pounds per square yard of FA-2 modified aggregates for fog seal over chip seal projects.

1.7 PROJECT COSTS

The project costs gathered for fog seal over chip seal projects are based on recent project information, and assume a two-lane, 24-foot-wide pavement (unless noted otherwise). A breakdown of the components that the project costs are comprised of can be found in **Appendix A**. The average costs ranged between $16,000 to $35,000 per mile for a standard project.

The two agencies that have performed both standalone chip seal projects and fog seal over chip seal projects have provided the project costs as summarized in **Table 2.**

Table 2 Project costs for standalone chip seal projects as compared to fog seal over chip seal projects.

Agency	Standalone Chip Seal Projects	Fog Seal over Chip Seal Projects	Cost Difference
Houston County	$20,000 per mile	$22,000 per mile	$0.15 per square yard
Stearns County	$14,000 per mile	$24,000 per mile	$0.71 per square yard

1.8 LIFE EXPECTANCY AND PERFORMANCE

Many of the agencies responded that the fog seal over chip seal applications are performing well. However, in the aspect of life expectancy, four agencies stated that the applications were recent, so the life expectancy has not been determined. Four agencies are expecting between six to ten years of life extension. It shall be noted that the life expectancy is not performance based, and it is the expectations of the agencies on the applications.

Most agencies specify the re-applications to be carried out between six to twelve years after the first application. The re-applications are based on pavement condition, maintenance schedules, or the availability of funds. A few agencies responded the applications were recent, so they have not planned for the re-applications. One agency is considering to just re-apply the fog seal application if the granite is still in place. If the roadways are in satisfactory condition but the granite has chipped away, then the agency will re-apply chip seals followed by fog seals. Agencies have specified that they typically would not perform the re-applications if the roads are scheduled for paving or a mill and overlay within the next three years.

For standalone chip seal projects, agencies have specified the re-applications to be conducted between five to twelve years after the first application. The aspects that the agencies have considered for re-applications are:

- Condition of the pavement (structural defects, ride quality); and
- Prior sealcoat condition (aggregate retention, damage caused by plow).

1.9 PROS AND CONS AND/OR LESSONS LEARNED

The lessons learned obtained from various agencies for fog seal over chip seal projects are summarized below.

- Seven of 13 agencies have observed better chip retention and embedment.

- Three of 13 agencies stated with a layer of the fog seal application, the surface of the roads appear to me more aesthetically pleasing.
- If the fog seal over chip seal applications are applied earlier in the year, traffic and heat will help to knead the fog seal into the aggregate.
- Weather and road conditions come into play, shade and cooler temperature lead to a longer cure time.
- Applying fog seals on chip sealed roadways keeps the pavement from drying or wearing out prematurely and becoming brittle.
- On urban streets, higher volume of turning movements causing the oil to rise to the pavement (usually within the first year of application and lessen the year after), which caused safety concerns.
- Fog seal appears to reduce the amount of chip loss due to plowing as compared to standalone chip seal.

The lessons learned obtained from various agencies for standalone chip seal projects are summarized below.

- There is public perception that chip seals cause windshield damage. Chip seal application has lower rock retention thus there are complaints of loose rocks on the adjacent lawns.

1.10 FEEDBACKS FROM CONSTITUENTS AND/OR MAINTENANCE CREWS

The feedbacks obtained from constituents and/or maintenance crews for fog seal over chip seal projects are summarized below.

- Two agencies stated less sweeping is needed due to better chip retention.
- There are less complaints on windshield damage.
- There are a few areas exhibiting stripping issues.

The feedbacks obtained from constituents and/or maintenance crews for standalone chip seal projects are summarized below.

- One agency stated that their current practice of applying a heavier tack coat (CRS-2) chip seal has done more to extend pavement life as compared to the fog seals over new chip seals they conducted in the past.

CHAPTER 2: ANALYSIS OF FINDING

2.1 COST COMPARISON OF FOG SEAL OVER CHIP SEAL VS. STANDALONE CHIP SEAL

To determine a cost difference comparison of the projects that had fog seal over chip seal to the projects that were standalone chip seals a few assumptions had to be made unless specifically noted otherwise. Most project costs gathered were assumed to be performed on two-lane, 24-foot-wide pavement sections. There were other factors that had to be considered when analyzing the data; for instance, if there was work done by the municipality to create cost efficiency on the projects they bid out. All the factors that were included with the data returned from the surveys and interviews were carefully analyzed to determine the most accurate cost comparisons. Additionally, the considerations for traffic volume and speed were removed from consideration because these factors were found to have little to no effect on the application.

To accurately compare the cost difference between fog seal over chip seal to that of a standalone chip seal project, there were two methods applied. First, if data came back as an overall project cost or lump sum item, then those projects were compared to the overall cost per mile of a similar standalone chip seal project. The second method used to determine a cost difference was used on projects with itemized costs. From those projects, individual costs of fog sealing a chip seal project were chronicled. There were many project parameters to consider when coming up with a value. In the end, all the results gathered were broken down into a cost difference per square yard. These values were then used to calculate a median cost of fog sealing a chip seal. The median value best illustrates the additional cost of performing a fog seal over a chip seal because it is not skewed by a small proportion of extremely large or small values, and therefore provides a better representation of a "typical" value.

The data in this study was specifically collected from cities and counties on roads with less than 1,000 AADT. The histogram shown below is a breakdown of the prices that were pulled from the survey data. Within this data are a variety of application rates, but we feel the median number is the best representation of the general cost for fog seal over chip seal projects. The median value of the data set was $0.29 per square yard to apply a fog seal over a chip seal. This value should be used as a starting point when considering if fog sealing a chip seal is going to provide value to a chip seal project. There are several additional factors to consider, such as application rates as well as size and scope of the project, that can affect the price of a fog seal.

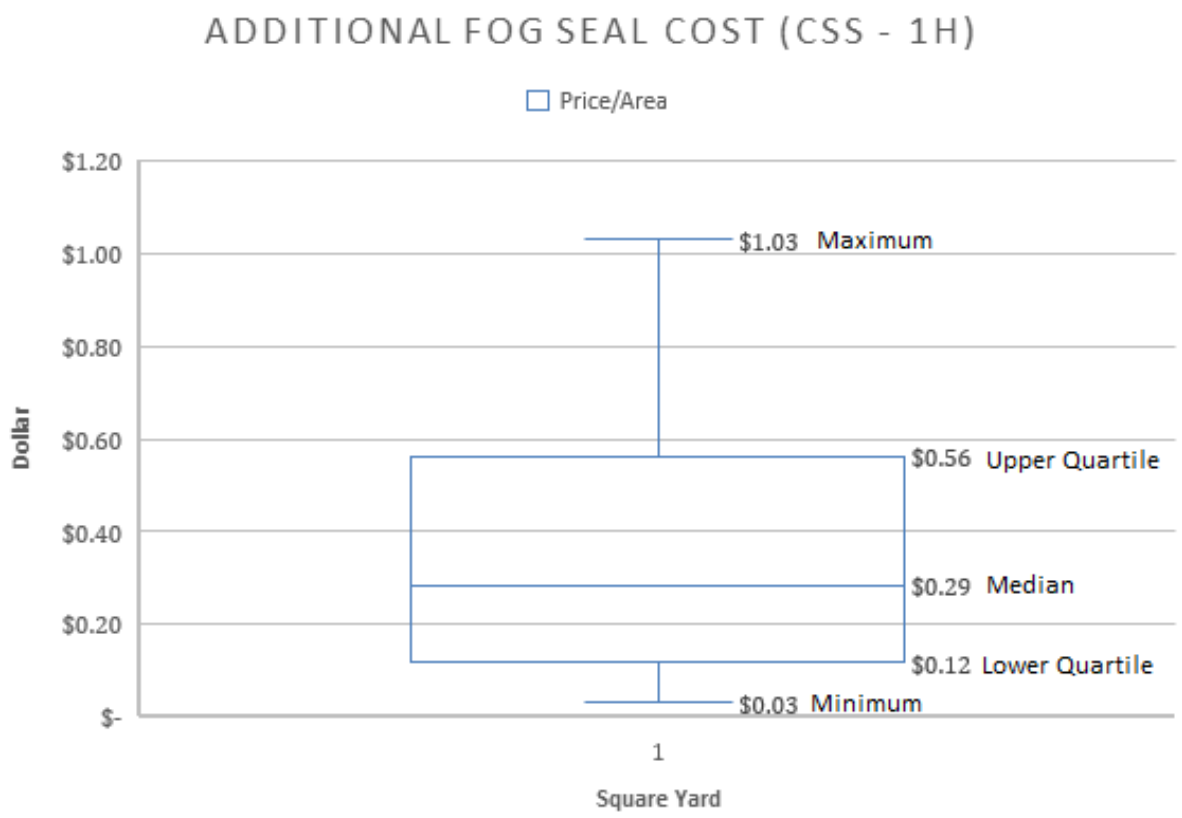

Figure 1 Histogram of Fog Seal Price Results from Survey

2.2 LIFE EXPECTANCY AND PERFORMANCE

To understand if there is a benefit in the additional cost of fog seal over chip seal, the additional pavement performance needs to be analyzed. From the results of the surveys and interviews, a true-life expectancy was not able to be determined because there was not enough long-term data on these types of fixes. Therefore, to analyze the cost effectiveness of fog seal over chip seal an assumed life of 7 years was considered when applying a standalone chip seal to a pavement in good to fair condition. This assumption was derived from assumptions used in previous LRRB studies, in addition to the feedback we received from this survey. From that assumption the "per year" value of a chip seal project was determined. Then taking the cost difference of the fog seal over chip seal was applied to determine how many additional years of pavement life a municipality would want to achieve to receive a benefit from fog sealing over chip seal.

From the survey data it was determined that the average bid price for the municipalities to deliver a chip seal only project was $1.55 per square yard. If that price is converted into a price per year based on the assumed extension of pavement life of 7 years provided by chip sealing, then it is $0.22 per square

yard per year. This value can then be compared to the additional price of fog sealing a chip sealed road to determine if there is value in fog sealing your project.

2.3 ADDITIONAL CONSIDERATIONS

2.3.1 Aesthetics and Public Perception

Through several responses received during this study, there has been feedback indicating that the public perception of chip seals is that they cause vehicle damage and the tracking of rocks onto adjacent properties can be an annoyance. With fog seal over chip seal, many of these issues for the public have been reduced or eliminated. Since there are more rocks retained on the pavement surface with the fog seal application, there is the notion that there are less vehicle damage claims and rocks tracking outside of the project limits. Additionally, there is a public opinion that the project looks more aesthetically pleasing because of the black surface finish of fog sealing. The public tends to look at it more like a new pavement surface, similar to what would be seen from a mill and overlay project. This can lead to fewer complaints, reduced costs related to processing public concerns and damage claims and potentially a better public image.

2.3.2 Maintenance Considerations

There are considerations for maintenance during construction that should be evaluated when deciding on which project type to implement. One benefit of fog sealing is the higher chip retention that leads to reduced sweeping hours. Other maintenance factors that should be considered pertain to the extended life of the fog sealed chip seal when compared to the traditional chip seal. Multiple agencies indicated that applying fog seal kept the pavement from drying or wearing out prematurely. Additionally, there were comments that benefits were seen on the reduced chip loss from snowplowing when the fog seal was applied. Since there was evidence of reduced snowplow damage to the chip seal treatment it can be concluded that a fog seal makes the chip seal more durable and resistant to abrasion leading to less maintenance over its life. Several maintenance crews indicated that there were fewer stripping issues when a fog seal was applied, which contributed to a considerable cost savings when comparing the total project cost of the two project types. This study was inconclusive in determining if it eliminated the stripping issue, but it did seem to help. The condition of the existing road surface appears to be the most significant factor contributing to stripping of the chip seal. Municipalities that were surveyed also indicated that pavement markings are more visible and last longer because of the texture and additional color contrast that the dark fog seal provides.

2.4 OVERALL ASSESSMENT

There are several factors to consider when looking into the value of fog sealing over a chip seal project. This project attempted to filter the data down into more absorbable figures by breaking the cost per square yard of a chip seal project into a price per year of future life of pavement. It was determined

that the price per year of a standalone chip seal was $0.22 per square yard per year and the fog seal over a chip seal was determined to be $0.29 per square yard of additional initial cost. Therefore, based on the data provided in this report, if fog sealing over chip seal provided just over one additional year of life to the project there would be value added as it is 1.3 times the value of the yearly square yard price of the standard chip seal. Not having the long-term data on fog seal over chip seal from the municipalities surveyed yet, it is difficult to conclusively state that it will provide the additional life compared to a chip seal. However, based on the responses from this survey, the fog sealed product is much more durable and provides greater protection for the road surface. Therefore, it can be deduced that the fog sealed chip seal will provide additional pavement life justifying its additional cost. There are also the ancillary considerations that can provide additional value to fog sealing such as the public's positive perception and reduced maintenance of a fog sealed project. Additionally, it could also be argued that there is less disruption to the traveling public due to reduced maintenance activities and extending the timeline to do another chip seal or maintenance project.

2.4.1 Pros and Cons Breakdown When Comparing Fog Seal on Chip Seal to Standalone Chip Seal

2.4.1.1 Pros:

- Added durability
- Extended treatment life leading to extended pavement life
- Aesthetical/Public appeal
- Better chip retention
- Reduction in damage claims
- Better striping visibility with added color contrast
- Additional protection from weathering
- Reduced damage from snowplow operations
- Reduced future maintenance

2.4.1.2 Cons:

- Median additional cost of $0.29 per square yard
- Added cure time of fog seal that can cause tracking issues

CHAPTER 3: BEST PRACTICES MANUAL

3.1 WHY FOG SEAL A CHIP SEAL?

3.1.1 How to Determine if a Chip Seal Project Should be a Fog Sealed Chip Seal

When considering if fog sealing a chip seal is the correct project for a certain pavement segment there are several factors to consider. One of the most discussed benefits is the additional chip retention that is achieved when the chips are fully embedded in the asphalt emulsion. This is achieved because the additional top coating of asphalt emulsion covers the remaining surfaces of the aggregate chips that weren't coated by the chip seal emulsion. This creates a very durable product that has increased resistance to chip loss due to plowing and greater resistance to stripping or raveling. A future benefit of this increase durability is a reduction in frequency of future maintenance projects with the added protection from oxidation and infiltration. All these factors lead to an extended pavement life when compared to a standalone chip seal project.

Fog-sealed Chip Seal in Curb and Gutter Section

There are several other characteristics that a fog sealed chip seal will provide beyond that of increased durability. Almost every municipality surveyed through this research project has indicated that they have seen a reduction in damage claims associated with a fog sealed project. This can be attributed to the improved chip retention. There is also feedback indicating that the public is more receptive to a fog sealed chip seal when compared to a standalone chip seal. There are many factors that could lead to this public perception but a few that were frequently mentioned indicated that the product appeared to be a new road surface, similar to a mill and overlay, yet much cheaper and that there was less tracking of rock chips onto private properties. With the black/like new surface that a fog sealed chip seal provides there are also positive implications for pavement markings. There is an added contrast for the white and yellow pavement markings on a fully black surface compared to the lighter colored surface of the chip seal.

The black surface of the fog sealed chip seal does come at some additional cost. There is added cure time for the additional process of fog sealing. This means a slightly longer duration of project impact to the road users and additional traffic control. These construction process impacts do lead to slightly increased project costs due to additional project materials and labor. The cost effectiveness will be discussed in further detail later in this section.

The fog sealing of a chip seal will not address all the limitations that a standard chip seal might have and there are times when other alternatives should be considered. The addition of a fog seal doesn't provide any additional strength to the pavement structure. It should not be considered when the pavement is experiencing medium to high severity distresses or if there are subgrade failures identified in the road segment. Since the fog sealed product does not add any structural value to the surface it is still not advised to be used in areas where there will be significant turning movements because the chips can be displaced with strong lateral forces. Examples of locations with high turning movements could be a cul-de-sac or a new development where a contractor is still using equipment like a skid steer to load materials from the street. If a chip seal is still chosen as the pavement fix a fog sealed chip seal will still provide the more durable product in these locations with frequent lateral forces.

Fog sealing over a chip seal is a good choice when trying to extend the life of pavements that have started to oxidize and become weathered. This happens over the span of just a few years, because of the oxidation processes, the asphalt will turn lighter shades of black and eventually becomes gray. During this period is when cracks develop and when heavier vehicular traffic can cause failures in asphalt by finding weak points in the sub-structure of the pavement. One of the most common reasons for the pavement sub-structure to develop points of weakness is from water percolating through cracks in the pavement. Fog sealing over a chip seal is a great choice for pavements that have reached this stage or to be proactive and protect pavement from oxidation and infiltration before the pavement has even started to show noticeable signs of distress. This type of project will seal off cracks that have started to form and restore the waterproof barrier that is necessary to protect the structure of flexible pavements essentially rejuvenating the pavement.

Example of Size and Coverage of an FA-2 Fog-sealed Chip Seal

3.1.2 How Cost Effective is Fog Sealing a Chip Seal?

We have already discussed several of the factors that will determine if there is value in fog sealing a chip seal. One of the biggest factors for this decision however will be the cost effectiveness of the product and if there is a value provided by the extension of pavement life. In

the Task 2 report for this research project, it was determined that the price of a standalone chip seal was $0.22 per square yard per year and the fog seal over a chip seal was determined to be $0.29 per square yard of additional initial investment. Therefore, based on the data provided in that report, if fog sealing over chip seal provided just over one additional year of life to the project there would be value added as it is 1.3 times the value of the yearly square yard price of the standard chip seal. Not having the long-term data on fog seal over chip seal from the municipalities surveyed yet, it is difficult to conclusively state that it will provide the additional life compared to a chip seal. However, based on the responses from this survey, the fog sealed product is much more durable and provides greater protection for the road surface. Therefore, it can be deduced that the fog sealed chip seal will provide additional pavement life justifying its additional upfront investment.

3.2 ADDITIONAL DESIGN AND PLANNING CONSIDERATIONS

3.2.1 Traffic Control Plan

Depending on the road segment, a flagging or pilot car operation that conforms to the current Minnesota Temporary Traffic Control Manual shall be implemented. Requiring the utilization of a pilot car is encouraged to maintained slow speeds on the new pavement surface. If possible, speeds of 25 mph or less can aid in reducing the chance of vehicle damage from rocks. Traffic must remain off the new pavement that has been chip sealed or fog sealed until after the emulsified asphalt has completely set. The contractor should take care not to back up, turn sharply, or apply heavy breaking on the new surface while it is still curing.

Verify that traffic control personnel are trained and qualified in accordance with contract documents and agency requirements. Attention to traffic control at road intersections is critical to not hold traffic for extended periods and be able to effectively direct traffic on to the proper lane as to not damage the new pavement surface. Additional flaggers may be needed to control the traffic at entrances to private drives as well to ensure traffic isn't driving on the new surface until it has cured.

Only a Temporary Raised Pavement Marking (TRPM) Type 4 is approved to be used for a chip seal application. These markers are designed to be placed prior to the sealing operation with a clear protective cover that is removed after the seal coat is applied. For a fog sealed chip seal make sure that there are two layers of protective coating so that the second layer of protective coating can be removed after the fog seal operation.

An additional factor to consider with traffic control is to reach out and familiarize the residents along the project about what to expect during construction. Several municipalities have seen improved product and fewer complaints when successful outreach has been implemented. In general, it's beneficial to the project to have informed residents who know what to expect for traffic control and at what point they can safely drive on the surface without damaging the product or their property.

3.2.2 Fog Seal Application

Example of Rural Section with Fog -sealed Shoulder

Common fog seal application rates range from 0.08 to 0.15 gallon per square yard of diluted CSS-1h emulsion (depending on the size and type of chip used). A higher rate of application is used for coarser chips with the rate lowering as the chips become finer. Minnesota requires a dilution rate of one-part emulsion done at the location which the emulsion was manufactured. MnDOT Specification table 2355.3-1 indicates that a CSS-1h or CRS-2Pd for fog seal can be applied at rates ranging from 0.05 to 0.20 gallon per square yard.

Through a survey of several MN cities and counties it was found that the standard starting rate or an assumed design rate for fog seal application on a chip seal is 0.10 gallons per square yard of CSS-1H emulsion for all rock types. CSS-1h was the most prevalently used emulsion to apply to a chip sealed road among the municipalities that were surveyed. Its benefit is that it is slow setting to allow it more time to adequately coat and adhere to the aggregates. Once cured it creates a harden surface that seals out water and resists abrasion. The cured surface delivers a strong bond that won't track.

Electrostatic testing of chip seal aggregate source can be done before chip design to ensure that the emulsion selected for the project is compatible with the potential sources of aggregate. This will verify that a fog seal will adhere properly to the chip seal.

3.2.3 Determine Application Width

Fog sealing over a chip seal can be highly modifiable to suit the exact needs of the road segment that it is being applied to. This isn't only limited to the application design rates that are discussed in the previous section but also the ability to independently vary the widths of chip and fog seals. An evaluation of the existing pavement section needs to be done to determine a typical surfacing cross section for each segment. By taking the time to thoughtfully develop typical surfacing cross sections and segments, the proper surface treatments can be applied, and cost efficiencies achieved. Common pavement features to assess during design are as follows:

Ground-in pavement features (rumble strips and pavement markings)

- To avoid having to regrind rumble strips, it is not recommended to apply a chip seal to this area of the pavement surface. If the rumble strip is on a pavement joint, it is strongly encouraged to apply fog seal to prevent water infiltration.

Pavement markings to preserve

- If a fog seal isn't being recommended for the shoulder, consider stopping the chip seal at the fog line to provide a raised thru-lane surface to protect the fog line from damage caused by snowplows.
- Significant pavement features such as railroad crossings, turn lanes messaging, stop bars and crosswalks shall be noted to be covered and preserved to provide a depressed surface. The existing surface will be more protected from wear being below the level or the fog sealed chip seal surface.

Shoulder pavement condition

- Shoulders can exhibit different distresses than a traveled lane because it is subject to less loading and wear. Therefore, it needs to be determined if a fog sealed chip seal (added protection and surface friction), fog sealing (pavement protection), or no treatment is needed.
- Turn lanes and bypass lanes should be explicitly called out in the plans as receiving the fog sealed chip seal to insure they receive the same treatment as the driving lane.

3.3 CONSTRUCTION

3.3.1 Critical Points of Inspection

Construction is the most critical point of a fog sealed chip seal life cycle. A study by the National Cooperative Highway Research Program (NCHRP) has found that proper construction practices can be instituted to help improve the reliability of this product. Below is a list of key items to pay attention to and is by no means exhaustive:

- Weather – temperature and rain (MnDOT Spec. 2356.3.A)
- Calibration – 200-foot test section (MnDOT Spec. 2356.3.J)
- Cleanliness of roadway (MnDOT Spec. 2356.3.C)
- Total square yards to be paved (Plan)
- Temperature of emulsion (MnDOT Spec. 2355.3.C & 2356.D.2)S

Example of How to Handle Rumble Strips

- Application rate of emulsion (Project Specifications or plan)
- Amount of emulsion used (Project Specifications or plan)
- Square yards of aggregate placed (Project Specifications or plan)
- Timeliness of emulsions and aggregate laydown (MnDOT Spec. 2356.3.E)
- Timeliness of rolling (MnDOT Spec. 2356.3.F)
- Proper signage and traffic control (MN Temporary Traffic Control Field Manual)
- Quality of both emulsion and aggregate

3.3.2 Weather Considerations

Given the extreme volatility of asphalt emulsions, atmospheric conditions have the potential to cause serious problems and will play a big role in the ultimate success of the project. The temperature affects the breaking of the asphalt emulsion and the subsequent bond that can be achieved between the emulsion and the aggregate. Even if everything is done perfectly, a day that is too hot or too cold can have disastrous effects on a fog sealed chip seal product. When temperatures are below 60°F, the asphalt will cool too fast and when the cold aggregate is applied, it will not bond to the emulsion properly. Moisture retention is not a problem, but the emulsion stays liquid too long and the bond never really breaks. The asphalt tends to migrate to the top of the aggregate and bleeding will occur. This will affect the rate at which the fog seal can be applied and can create excessive tracking of asphalt off the project.

An important factor in the cure time for this project type is the tree canopy along the road. If there is a lot of shade created from the trees along a segment of road there will be slower cure times and should be something to keep in mind when trying to open the road to traffic. Be sure to check areas of pavement that are shaded to determine when to allow traffic on the new surface as these will be the last sections to cure. Ideal project conditions would be a dry forecast, Temps below 40 degrees should not be anticipated for at least 24 hours, sustained winds are less than or equal to 10 mph, and application should be at least 2 hours before sunset.

MnDOT standard specification 2356.3.A can be referenced for several limitations for weather time and dates.

3.3.3 Rain or Moisture

Excessive moisture in the form of rain or high humidity is the primary culprit for most chip and fog seal failures. The added presence of water during production can cause the pavement to bleed. Afternoon showers have the potential to cause the asphalt to release its bond from the aggregate and float to the surface. The asphalt can then run off the road onto the shoulder and onto driveways along the side of the road, turning driveways black with asphalt. If there are any ruts or depressions in the road surface asphalt can get trapped, pool up, and splash up on vehicles which is difficult to remove. This is the worst-case scenario, but it has happened. Cleanup from this event is both difficult and expensive. With

careful attention to the weather, incidents like this can be avoided. Understanding that this potential exists, it is very important to allow adequate time for the pavement to cure before a rain event.

The other extreme is an absence of moisture. In situations where the atmosphere is hot and dry. The ability of the asphalt to bind to the surface of the aggregate is reduced because the aggregate is excessively dry. The bond becomes localized to the first point of contact rather than coating the entire surface of the aggregate face. Water can be infused into the aggregate at the stockpile to help prevent this problem. However, care should be taken not to saturate the aggregate to the point of free water flowing onto the pavement.

3.4 EQUIPMENT

3.4.1 The Distributor

The distributor must employ the use of computerized controls. Flow from each nozzle in the asphalt distributor must be within ± 10 percent of the average flow of all nozzles. All nozzles shall be the same size, provide the same flow rate, be oriented in the same direction and be the same elevation from the pavement. The application of emulsified asphalt must be done uniformly in all directions (transverse and longitudinal) up to 15 ft wide. The distributor shall be equipped with the following: an accurate volume measuring device with tachometer, pressure gauges, power operated pump, and full circulation spray bars with lateral and vertical adjustments. The asphalt distributor shall have a ground speed control device interconnected with the emulsified asphalt pump such that the specified application rate will be supplied at any speed. The distributor shall be capable of maintaining the emulsified asphalt at the specified temperature. The spray bar nozzles shall produce a uniform double lap application fan spray, and the shutoff shall be instantaneous, with no dripping.

A Typical Distributor Truck Operation

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

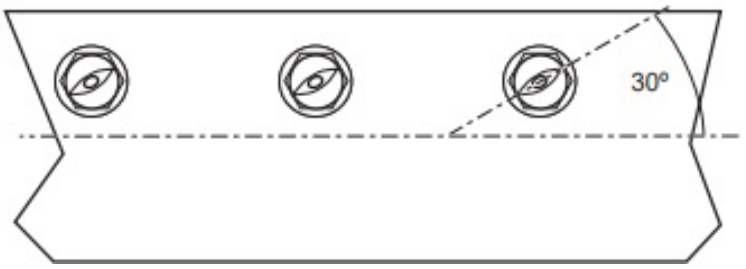

Figure 2 Spray Nozzle Positioning

The spray bar height shall be adjusted so that the emulsified asphalt provides exactly two or three overlaps across the entire spray width. If it is set too high or too low streaking will occur because of uniform application. As the distributor empties its tank during spraying the bar height will rise. This change in height from the reduced load is usually not enough to cause significant streaking that would warrant adjustment of the spray bar.

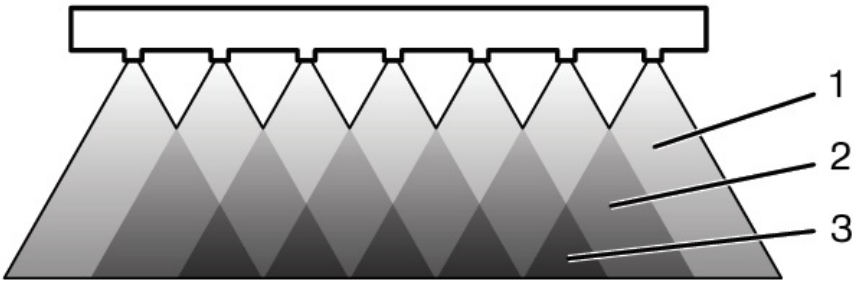

Figure 3 Spray Pattern Illustration

3.5 EVALUATE APPLICATION RATES

3.5.1 Verifying Application in the Field

The ability to adjust both emulsion and aggregate application rates in the field is critical to delivering a quality product. The application rates provided in the design and contract requirements should be considered as starting points and should be fine-tuned in the field to account for site conditions. The speed and pressure settings for the asphalt distributor must be adjusted for the type of emulsion being applied. In addition to using the appropriate settings on the asphalt distributor and aggregate spreader, records of daily application quantities will be required to verify actual production rates. MnDOT Spec.

2356.3.D.2 requires the construction of a 200-foot-long test strip to ensure bituminous material application rate is adequate for the existing field conditions. After applying the bituminous material test strip, place the aggregate at the design application rate. After a chip seal has cured and been swept, follow MnDOT Spec. 2355.3.C to perform yield check to assess the fog seal application rate after the first 1,000 feet. The following techniques provide additional guidance for the inspectors to observe the proper rates and adjust if necessary.

The two factors that affect uniform applications are the nozzle angle and the height of the spray bar. The nozzles should be between 15 and 30 degrees. Some distributors used in other asphalt applications turn the end nozzles to a 60-to-75-degree angle for better coverage at the pavement edges. This will leave the emulsion thin just inside the outside edges, which will reduce aggregate retention in these areas and could cause bleeding on the edges and at the centerline. It is recommended that half-spray end-nozzles are used to ensure even distribution at the pavement edges. The spray bar on the distributor should be adjusted prior to running a test strip for the emulsion. It is recommended that the emulsion be applied at a spray bar height that provides double coverage. This adjustment can be made by turning off the even nozzles and adjusting the pressure so that the spray from each individual nozzle will match up evenly with the adjacent spraying nozzle. When uniform coverage is being obtained with the even nozzles turned off, turn the even nozzles back on for the double coverage. The distributor is now ready for the 200-foot test section.

The rate of emulsion application is measured in gallons per square yard (gal/yd^2). A 200-foot test strip is used to determine the quantity of emulsion needed. The quantity of emulsion in the distributor will be recorded at the beginning and end of the test section. The 200 linear feet of the test trip is multiplied by the width of spray to determine the area in square feet. Dividing the total square feet by nine converts the measurement to square yards. Divide the gallons used by the area to obtain gallons per square yard. Observe the pull to make sure the emulsion is covering evenly. Also, check that the spray bar height and the individual nozzle spray widths are, at a minimum, double covering the existing road. Depending on the type of distributor used, the pressure or RPM's required to provide the desired rate should be recorded. The temperature of the emulsion will affect the spray pattern so be sure to have the emulsion within the operating range of 160 to 170 degrees Fahrenheit.

A fog seal can be applied as soon the chip seal is cured and swept. A 1 to 2 day wait period after construction was applied by several municipalities before fog sealing. The Ring Test can be a useful tool to dial in the fog seal application rates that will yield the best product on the chip sealed surface. The steps are outlined below and should be used if application rates need to be evaluated. The Ring Test shall be carried out using the emulsified asphalt to be used on the job site or from equivalent material from the same source and having substantially the same material properties

Ring Test:

1. Sweep the section of road to be fog sealed clean of debris and dust.

2. Draw three 6-in. diameter circles on the swept pavement.

3. Select three target application rates and translate them to the required volume of emulsified asphalt from Table 2.

4. Label each circle with its application rate.

5. Use a 10-mL graduated cylinder to pour the required amount of emulsified asphalt into the center of each circle. Evenly distribute the material within the circle.

6. The ideal application rate will evenly and completely cover the pavement within the circle, with no emulsified asphalt draining outside.

7. Record the optimal application rate.

Ring Test fog seal application rates

Amount of Emulsified Asphalt for Ring Test	
gal/yd^2	mL (6-in circle)
0.05	4.2
0.06	5.0
0.07	5.8
0.08	6.6
0.09	7.4
0.1	8.3
0.11	9.1
0.12	10.0
0.13	12.8

3.6 ADDITIONAL CONSIDERATIONS

3.6.1 Cure Time and Traffic

Traffic control is required to protect the integrity of the application. The curing time for the fog seal material will vary depending on the pavement surface conditions and the weather conditions at the time of application. Under ideal conditions, including increasing air and surface temperatures, it is suggested that traffic be kept off the fog seal material for at least two hours, but this should only be used as starting point. Each day will provide different weather conditions that affect the cure time of emulsion. This cure time is going to impact the length of time that traffic should be prevented from driving on the fog seal. This is to protect the product and additionally to prevent damage claims from getting asphalt product on vehicles as well. It's wise to keep an eye on how the emulsion is curing throughout the day and adjust traffic control as needed to avoid any issues. Pay close attention to areas with heavy shade as this will prolong the cure time compared to sections in direct sunlight.

3.6.2 Pavement Markings

Interim pavement markings can be placed after the fog seal cures. Place interim pavement markings after the fog seal cures and before removal of traffic control. Do not place permanent pavement markings using latex paint within 3 days of placing the fog seal. Place all other types of permanent pavement marking at least 14 days after placement of the fog seal. In cases where permanent pavement

markings are to be ground-in it is recommended to plan a follow-up project for the following season with temporary pavement marking installed in the meantime.

3.6.3 Future Maintenance Plan

In order to achieve the maximum life out an asphalt pavement it is imperative to have a quality pavement management plan in place in order to plan funds when the next pavement fix is anticipated. Most agencies have planned for re-applications to be conducted on a six to ten-year cycle from the first application. It is only recommended to do this type of surface treatment twice before considering a mill and overlay. A reapplication of only the fog seal may be considered if the rock chips are still in place. If the roadway is in decent condition but significant surface roughness has been lost due to the loss of chips, then the recommendation would be to apply a second chip seal followed by fog seal. Having a pavement management plan allows the right maintenance at the right time to get the maximum life out of the pavement. When considering a fog sealed chip seal consult the pavement management plan to check when they next major pavement fix like a mill and overlay is planned. It would not be cost effective to apply a fog sealed chip seal when a major pavement fix is planned within the next few years.

REFERENCES

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Ulring, Joel D., and Wood, Thomas J. *Minnesota Seal Coat Handbook 2021*. Minnesota Department of Transportation, March 2021. http://www.dot.state.mn.us/materials/pavementpreservation/manualsandguides/documents/MN%20Seal%20Coat%20Handbook_March2021.pdf

APPENDIX A
[SURVEY DETAILS]

3.7 PRELIMINARY SURVEY OF PRACTICE

A preliminary online survey was distributed to 450 agencies within the state of Minnesota; 52 agencies responded to the survey:

1. Beltrami County
2. Benton County
3. Carver County
4. Chisago County
5. City of Albert Lea
6. City of Andover
7. City of Austin
8. City of Chanhassen
9. City of Chisholm
10. City of Coon Rapids
11. City of Crystal
12. City of Detroit Lakes
13. City of Eden Prairie
14. City of Elk River
15. City of Golden Valley
16. City of Hastings
17. City of Hutchinson
18. City of Little Falls
19. City of New Hope
20. City of Roseville
21. City of Shakopee
22. City of Spring Lake Park
23. City of West St. Paul
24. City of Woodbury
25. Clay County
26. Cottonwood County
27. Dodge County
28. Fillmore County
29. Goodhue County
30. Houston County
31. Kandiyohi County
32. Koochiching County
33. Lac Qui Parle County
34. Lake of the Woods County
35. Marshall County
36. McLeod County
37. Meeker County
38. Mower County
39. Nicollet County
40. Nobles County
41. Olmsted County
42. Otter Tail County
43. Pennington County
44. Pipestone County
45. Pope County
46. Redwood County Highway Department
47. Rock County Highway Department
48. St. Louis County
49. Sherburne County
50. Stearns County
51. Wabasha County
52. Watonwan County

Below are the preliminary survey questions intended to obtain information on the experience of agencies in the application of fog seal on chip sealed low volume roads.

- Does your agency perform chip seals?
- Has your agency ever applied fog seal over a newly constructed chip seal?
- How many years have you fog sealed over chip seals?
- Do you have a control section?
- Do you have any in-place fog seals without chip seals underneath?
- What products do you use for fog sealing or chip sealing?
- How has the performance been in these applications?

3.7.1 Experience on Fog Seal over Chip Sealed Low Volume Roads

Based on the preliminary survey results, 32 agencies responded that they have performed the application of fog seal over chip sealed low volume roads. Half of these respondents (16 agencies) stated that they have at least five years of experience in these applications.

3.7.2 Type of Products

Table 3.1 shows a summary of products used for each type of application.

Table 3.1. Products used for fog seal and chip seal applications.

Type of Application	Type of Emulsion	Aggregate Size
Fog Seal	CSS-1h	
Chip Seal	CRS-2, CRS-2P	FA-2, FA-2.5, FA-3

3.7.3 Performance of Preventive Maintenance

This section includes the performance of chip seals, fog seals, and fog seals on chip sealed low volume roads from the survey. 44 agencies responded and below is a summary of the performance.

- 33 respondents (75 percent) responded satisfactory, good, or excellent
- 5 respondents (11 percent) responded poor performance due to chip seal stripping or fog seal wears off quickly
- 4 respondents (9 percent) responded not enough performance data
- 2 respondents (5 percent) responded no concerns or no issues

3.8 FOLLOW-UP INTERVIEWS (FOG SEAL ON LOW VOLUME CHIP SEALED ROADWAYS)

Follow-up interviews were conducted to gather more in-depth information regarding the applications of fog seals on chip sealed low volume roads.

Below is a list of agencies who participated in the follow-up interviews:

1. Beltrami County
2. Chisago County
3. City of Eden Prairie
4. City of Hutchinson
5. Houston County
6. Lac Qui Parle County
7. Lake of the Woods County
8. McLeod County
9. Meeker County
10. Nicollet County
11. Otter Tail County
12. St. Louis County
13. Stearns County

Below are the interview questions for the application of fog seals on chip sealed low volume roads.

- Can you provide some background information on the project?
  - What is the roadway volume and speed limit?
  - What is the length of time between the chip seal application and fog seal application?

    - What was the pavement condition of the road, was it old and the intent was to hold the pavement together or was this a new roadway and the intent was to lower the environmental impacts?
    - Any idea on the distress types present?
- What were the application rates used for fog sealing and chip sealing?
- What was the cost of the project?
- What was the life expectancy of chip sealed pavements that are fog sealed?
    - What are the factors that prompted the decision of re-applying the application? When does that usually occur?
- Do you have performance criteria/standards established for fog seal on chip sealed pavements? If so, what are they?
    - Do you have pavement management data of the roadway (before and after application)?
- What are the pros and cons of the project? What worked and what didn't?
    - What are some of the lessons learned?
- Have your maintenance crews commented on the performance?
    - If there has been maintenance performed, would you mind sharing the costs associated with it?

3.8.1 Background Information

This section summarizes the background information of the projects performed (**Table 3.2**), which includes traffic volume, speed limit, and condition of the pavements at the time of application. In this project, low volume roads are defined as roadways with an Annual Average Daily Traffic (AADT) under 1,000 or from the pavement design standpoint, less than one million Equivalent Single Axles Loads (ESALs) or MnDOT traffic level 2.

Table 3.2. Background information on fog seals on chip sealed low volume roads.

Agency	Traffic Volume (AADT)	Speed Limit (mph)	Condition of the Pavements	Time Interval between Applications
Beltrami County	See Notes[1]	-	▪ Recent applications were on new pavements in good condition. The applications were performed within one to two years after paving. ▪ First few years of the applications were on old pavements and the intent was to hold the pavements together.	Varies depending on the contractor, within a few days up to a week
Chisago County	400 to 9,500	30 to 55	Majority placed on newer pavements (within 3 years of pavement age)	A few days, usually within a week

Table 3.2 (continued). Background information on fog seals on chip sealed low volume roads.

Agency	Traffic Volume (AADT)	Speed Limit (mph)	Condition of the Pavements	Time Interval between Applications
City of Eden Prairie	Residential and collector roads	30	• New pavements (paved 4 years ago) • Old pavements (up to 12 years after preservation projects such as a mill and overlay), with typical distress of cracking exhibited but crack sealing and patching were done prior to the applications of fog seals and chip seals	Typically, between one to three weeks. In recent two years, the time interval has been around one week
City of Hutchinson	Low	30	Existing old pavements with most of the roadways in good or excellent condition, following localized repairs conducted by the City staff a year or two before the applications. Primary distress was transverse cracks and they were addressed prior to seal coating with crack filling, spray injection patching or milling/patching, depending on their severity	Approximately 2 days

Table 3.2 (continued). Background information on fog seals on chip sealed low volume roads.

Agency	Traffic Volume (AADT)	Speed Limit (mph)	Condition of the Pavements	Time Interval between Applications
Houston County	Rural roadways with AADT under 700 (typically between 250 to 700 AADT)	55	• Majority of the projects were placed on roadways paved less than a year • One project was placed on a roadway that is about 30 years old in 2013 with the purpose of holding the pavement together due to the extra oil from the fog seal application. Different types of cracking exhibited including alligator cracking	In accordance with the standard MnDOT specifications, usually a couple of days to within a week
Lac Qui Parle County	Rural (180 to 800 AADT)	55	New pavements (6 years old) with majority of the distresses observed were thermal cracking, no crack sealing done prior to the applications	48 hours to 2 weeks (The chip seal operation takes a few weeks)
Lake of the Woods County	300	60	A combination of newer pavements (one year old) and older pavements (4 years old). Low severity cracking is present on older pavements	2 to 3 weeks
McLeod County	Rural	55	Newer overlays within 2 to 3 years of paving	Usually within a week

Table 3.2 (continued). Background information on fog seals on chip sealed low volume roads.

Agency	Traffic Volume (AADT)	Speed Limit (mph)	Condition of the Pavements	Time Interval between Applications
Meeker County	Between 200 and up to 3,000	30 to 55	Since summer 2019, projects were placed on roadways one year after paving. Prior to that, projects have been placed on roadways 5 to 6 years after paving. The applications have been used as reactive maintenance applied on older streets that have been patched and crack filled	Usually within 3 to 7 days [2]
Nicollet County	Less than 500	50 to 55	• New bituminous overlay. Applications were performed during the construction season, in the event of late paving applications were performed the following year. • Placed on existing pea rock and FA-2.5 Quartz chip sealed pavements	One to four weeks after chip sealing
Otter Tail County	See Notes[3]	See Notes[3]	Depending on the tiered system[4]; roadways that fall under the platinum, gold, and silver categories were fog sealed and chip sealed 3 years after major repairs.	Usually performed the next day or within a week depending on the Contractor
St. Louis County	Between 300 and up to 800	55	Newer streets within one year of paving	Usually within 2 days

Table 3.2 (continued). Background information on fog seals on chip sealed low volume roads.

Agency	Traffic Volume (AADT)	Speed Limit (mph)	Condition of the Pavements	Time Interval between Applications
Stearns County	See Notes[5]	See Notes[5]	Newer overlays within 2 to 3 years of paving	Usually within one to 2 days, depending on the weather

Notes:

[1] Beltrami County has performed applications over 30 miles of roadways per year. Majority of the applications were on roads with over 1,000 AADT and a several of them are on roads under 1,000 AADT.

[2] Meeker County used to require a minimum of wait time of 7 days, but the County has not seen any issue with allowing the Contractor to apply the fog seal sooner.

[3] Otter Tail County has performed applications on roadways with 170 to 850 AADT with a speed limit of 55 mph and roadways with 920 AADT with a speed limit of 30 mph.

[4] The tiered system is based on two criteria, which are the average daily traffic and freight routes. The system includes classifications ranking from platinum, gold, silver, to bronze. Roadways under higher tiered have higher average daily traffic and higher freight movements.

[5] Applications were typically in urban setting where the traffic volume is low and curb and gutter are present. Otherwise, the applications were on higher speed roadways with over a 1,000 AADT.

3.8.2 Application Rates

This section summarizes the application rates used for fog seals and chip seals. The emulsions used for fog seals and chip seals are CSS-1H and CRS-2P or CRS-2 respectively, and the aggregate sizes (FA-2, FA-2.5, and FA-3) vary depending on the agencies (**Table 3.3**).

Table 3.3. Application rates implemented by agencies across the state of Minnesota.

Agency	CSS-1H Emulsion (gal/sy)	Emulsion (gal/sy)	Aggregate (lbs/sy)
Beltrami County	See Notes[1]		
Chisago County	0.10	0.25 gal/sy CRS-2P	Paid by the square yard
City of Eden Prairie	0.12	• 0.34 gal/sy CRS-2P (FA-2, Class A aggregates) • 0.24 gal/sy CRS-2P (FA-2, modified Class A 1/8-inch trap rock)	20 lbs/sy FA-2, Class A gray or black rock; or FA-2, modified Class A 1/8-inch trap rock
City of Hutchinson	The City bid and pay by the square yard		
Houston County	0.08	0.27 gal/sy CRS-2P	• 18 lbs/sy of FA-2 on new pavements • 18 lbs/sy of FA-3 on old pavements
Lac Qui Parle County	0.04 to 0.05 residual rate	0.2 to 0.25 gal/sy CRS-2 or CRS-2P depending on the bid received	18 to 22 lbs/sy

Table 3.3 (continued). Application rates implemented by agencies across the state of Minnesota.

Agency	CSS-1H Emulsion (gal/sy)	Emulsion (gal/sy)	Aggregate (lbs/sy)
Lake of the Woods County	0.10	0.34 gal/sy CRS-2P	-
McLeod County	0.10	0.27gal/sy CRS-2P	17 lbs/sy FA-2 (1/4-inch)
Meeker County	0.10	0.30 gal/sy CRS-2P	Use 3/8-inch rocks
Nicollet County	0.10	0.32 gal/sy CRS-2 on new pavement; 0.33 gal/sy to 0.43 gal/sy CRS-2 on past chip sealed surface	18 lbs/sy FA-3 granite
Otter Tail County	0.10	0.25 gal/sy CRS-2P	18 lbs/sy FA-2 modified rocks
St. Louis County	0.12	0.33 gal/sy CRS-2P	25 lbs/sy FA-2.5 rocks
Stearns County	0.12 to 0.15	0.25 gal/sy CRS-2P	25 lbs/sy FA-3 modified rocks

Notes:

[1] The application rates vary depending on the condition of the pavements but the rates are in accordance with the MnDOT specifications. The Contractor would submit the chip seal design. Older pavements typically require a higher rate of application, but the application rates are generally reduced for re-application.

3.8.3 Project Costs

This section summarizes the project costs obtained from various agencies. Project costs presented in **Table 3.4** are provided in per-mile costs based on recent bid prices or historical information and assume a two-lane, 24-foot-wide pavement (unless noted otherwise).

Table 3.4. Per-mile project costs, with the assumption of a two-lane, 24-foot-wide pavement (unless noted otherwise).

Agency	Project Cost ($ per mile)	Notes
Beltrami County	$25,000	Entire project costs.
Chisago County	$16,200 to $17,600	$1.15 to $1.25 per square yard for half-million square yard project including striping, mobilization, marking, and materials.
City of Eden Prairie	$25,100	2020 costs including fog seal emulsion, chip seal emulsion, and aggregates.
City of Hutchinson	$21,700	2018 costs including material costs but not pavement markings. City operators will follow up with street sweeping after the fog seal sets up, typically a few weeks after the operations have been completed, but the City usually does not charge that to the project since the cost is usually less than $1,500 for labor and equipment.
Houston County	$22,000	Average entire project costs including mobilization, pavement markings (latex paint), and labor.
Lac Qui Parle County	$9,000	2016 costs including material costs, labor, and equipment. The County partnered with Chippewa County to perform the applications (the County owns a distributor and the Chippewa County owns a chip spreader).

Table 3.4 (continued). Per-mile project costs, with the assumption of a two-lane, 24-foot-wide pavement.

Agency	Project Cost ($ per mile)	Notes
Lake of the Woods County	$25,000	Entire project costs.
McLeod County	$21,650	2020 average costs including material costs, traffic control, and temporary marking.
Meeker County	$18,000	Average 24- to 26-foot-wide pavements, costs including labor, equipment, and material. The costs did not include pavement marking.
Nicollet County	$16,800	2019 costs including fog seal emulsion, chip seal emulsion, and aggregates.
Otter Tail County	$17,000	2020 project costs including only the material costs. The total project costs including material costs plus miscellaneous costs such as traffic marking and control, and sweeping are $20,000 per mile.
St. Louis County	$35,000	Entire project costs including pavement marking, labor, equipment, mobilization, and material costs.
Stearns County	$24,000	2020 project costs with approximately $1.70 per square yard with total project amount roughly $900,000 to $975,000. The costs include all costs, including temporary raised pavement marking, mobilization, labor, and material costs. The pavement marking is done by the County forces after.

3.8.4 Performance and Life Expectancy of the Applications

This section summarizes the performance and life expectancy of fog seals on chip sealed low volume roads (**Table 3.5**). However, due to the limited number of years of experience, majority of the agencies are not able to determine the life expectancy of the applications, but they are satisfied with the applications to date.

Table 3.5. Performance of the applications to date.

Agency	Performance	Re-Application
Beltrami County	Applications on new pavements are performing well	Applications on old pavements are scheduled for re-applications every 6 to 7 years
Chisago County	Applications are performing well	Every 7 years, two applications on pavement life before performing a mill and overlay
City of Eden Prairie	Applications are performing well, and the City is expecting 8 to 10 years of life	Projects were recent so the City has not performed any re-application
City of Hutchinson	The City plans for 6- to 8-year life	Some of the streets were seal coated 6 to 8 years prior, so this was scheduled re-application in most cases
Houston County	Applications on both new pavements and old pavements (one project applied in 2013) are performing well	Too early to determine but the County usually would not apply surface treatments on roadways that will be paved within the next 5 years
Lac Qui Parle County	-	Every 6 years (2 applications over the pavement life and an overlay at year 18)
Lake of the Woods County	-	-

Table 3.5 (continued). Performance of the applications to date.

Agency	Performance	Re-Application
McLeod County	Approximately 7 to 10 years of life based on visual inspections and industry standards	Every 7 years when the pavements are oxidized and/or there is aggregate loss
Meeker County	Applications are performing well	Not determined
Nicollet County	Applications are performing well	10 to 12 years after the first application
Otter Tail County	-	Platinum- and gold-tiered pavements are scheduled for re-application 7 years after the first application, while silver-tiered pavements are scheduled for re-application 10 years after the first application
St. Louis County	Too early to determine with approximately 5 to 7 years of experience	The County might consider re-applying in one to 2 years
Stearns County	Generally, the County would not look at seal coating the roadway again for at least ten years, so the County is hoping to get 10 years life out of the first application, but the County bases that decision on the roadway surface – does it look like the aggregates have been exposed or popping out in areas, etc.	Within the next 5 years, the County is looking to re-apply just the fog seals for desired outcome

3.8.4.1 Factors that Prompted Re-Application

NICOLLET COUNTY

The fog seal over chip seal applications have been performing well thus the County has not performed any re-applications. However, the factor that would prompt the County to re-apply fog seals and chip seals are when there is distinct loss of chip seal aggregates.

LAC QUI PARLE COUNTY

Based on a 6-year fix schedule and how the roads are wearing out and funding available. If the pavement surface exhibited raveling and alligator cracking is present, it will be planned for an overlay. If the fog seal over chip seal applications are still performing well, the re-application will be delayed for another few years.

STEARNS COUNTY

The damage from ultraviolet exposure and plowing prompts the re-applications. However, if the granite is still in place, the County will just apply fog seals over the existing applications. If the roadways are in decent condition but the granite has chipped away, then the County will re-apply chip seals followed by fog seals.

3.8.5 Lessons Learned

Below are the lessons learned from agencies across the state of Minnesota.

3.8.5.1 Beltrami County

For older pavements, moisture within the pavements might have caused the presence of shallow potholing and there was loss of rocks. Issues are substantial on edge-line striping. Some of the paints and shallow depths of pavements were peeled off. However, there were applications, which applied on older pavements, that held up well.

3.8.5.2 Chisago County

Fog seal applications help to seal up the road and the surface of the road looks more aesthetically pleasing. If the applications are applied earlier in the year (in June), traffic and heat will help to knead.

3.8.5.3 City of Eden Prairie

The City has been satisfied with pairing fog seal and chip seal applications and have been performing them together for the past 2 years. The City has seen better chip retention and less loss of chips into the gutter and there are fewer complaints from the residents. From the aesthetic point of view, the product has a darker finishing thus the residents perceive the roads as newer pavements.

One of the cons of fog sealing on chip sealed roads is that it is time consuming as fog sealing is weather dependent. When applied under shade, fog seal applications take a longer time to cure.

For higher volume collector roads, the City has been avoiding performing fog seal applications on the roads due to the added cure time and impacts to traffic. Unlike Counties, the Cities generally do not have the capabilities to detour the traffic.

3.8.5.4 City of Hutchinson

Applying a fog seal following a chip seal results in significantly less rock loss and less problem with rocks tracking onto driveways, into houses, and onto the boulevards. However, there are traffic constraints as there is no access for the streets until the fog seal emulsions have cured.

3.8.5.5 Houston County

Applying fog seals on chip sealed roadways keeps the pavement from drying or wearing out prematurely and becoming brittle.

On urban streets, higher volume of turning movements causing the oil to rise to the pavement (usually within the first year of application and lessen the year after), which caused safety concerns.

3.8.5.6 Lac Qui Parle County

Fewer chip loss and positive public perceptions. The County is considering if the first applications should be applied earlier in pavement life, similar to what Chippewa County has implemented which the first applications are applied in the first 3 years.

3.8.5.7 McLeod County

Better chip retention and embedment. Low-cost preventive maintenance as the extra oil from fog sealing serves as good insurance and the public perceives the applications as new pavement due to the darker shade from fog sealing.

3.8.5.8 Meeker County

Fog seal over chip seal applications are performing well with perfect chip retention and there are no issues of loose rocks. The County had used pea rocks with no fog seal in the past and after the County has switched to granite rocks with a fog seal, there is better chip retention observed.

3.8.5.9 Nicollet County

The County looks for oil that is just bleeding through the chip seal aggregates at tire tracks to know they have the right application rate. Some roads that have a steeper crown tend to have the rocks plowed off an approximately 6-inch-wide strip on the crown of the road. CSAH 3 was tested in 2013 with and without fog seals. The rock on the crown of the road plowed off faster on the portion of the road without the fog seal application, thus the plow truck operator doesn't apply as much pressure on the underbody plow. Majority of roads that are not overlayed before sealcoating are mastic crack filled

before sealcoating with either Nuvo 201 or now the County uses Right Pointe Pave Patch Black "no box". Large-sized rocks last longer from being same size on entire road surface, thus avoiding larger rocks from being "plowed" off. FA-3 aggregates make roads less susceptible to black ice conditions.

3.8.5.10 Otter Tail County

Fog seal over chip seal applications extend the life of pavements. The applications are cost-effective as the applications are relatively cheap. However, from aesthetic point there are marks left on fog sealed surface from the horse carriages.

3.8.5.11 St. Louis County

The applications have been performing well with chip retention and less accumulation of snow and ice from the rocks. However, there is public perception that the chip seal contributes to damaging tires.

3.8.5.12 Stearns County

If financially allowed, the County would fog seal all the chip sealed pavements as they provide better chip retention as compared to standalone chip seal with pea rocks. The County would use polymer modified emulsions for roadways with higher traffic volume.

3.8.6 Feedbacks from Residents and/or Maintenance Crews

Below are the feedbacks from residents and/or maintenance crews obtained from agencies across the state of Minnesota.

3.8.6.1 Beltrami County

Patching has been performed on shallow potholing. Crack leveling has been performed as well. These maintenance activities have been conducted prior to the re-application. One of the reasons the County has decided to perform fog seal on chip sealed roadways is that there are no concerns on loose rocks.

3.8.6.2 City of Eden Prairie

Less sweeping is needed due to better chip retention from pairing chip sealing with fog sealing.

3.8.6.3 City of Hutchinson

Performance of these streets, in general, has been acceptable. However, there are a few areas that have exhibited significant stripping. The estimated costs of addressing the stripping in the few areas were $7,500 to $10,000 for materials, labor, and equipment.

3.8.6.4 Houston County

There have not been complaints as the applications have been beneficial to the County.

3.8.6.5 Meeker County

There are no complaints except when the County was using pea rocks initially.

3.8.6.6 Nicollet County

Since the implementation of applying fog seals on chip sealed roads in 2014, the County has received less complaints from the constituents on the aggregates causing windshield damage.

3.9 FOLLOW-UP INTERVIEWS (STANDALONE CHIP SEALED ROADWAYS)

Follow-up interviews were conducted to gather more in-depth information regarding the applications of standalone chip sealed low volume roads. In this project, low volume roads are defined as roadways with an Annual Average Daily Traffic (AADT) under 1,000 or from the pavement design standpoint, less than one million Equivalent Single Axles Loads (ESALs) or MnDOT traffic level 2.

The list of agencies participated in the follow-up interviews is the same as listed in **Section 3.2**, however, only a few of the agencies are still applying standalone chip seals:

1. City of Eden Prairie
2. Cottonwood County
3. Houston County
4. Nicollet County
5. Otter Tail County
6. Stearns County

Below are the interview questions for the application of standalone chip sealed low volume roads and the application of standalone chip seals.

- Can you provide some background information on the project?
    - What is the roadway volume and speed limit?
    - What was the pavement condition of the road, was it old and the intent was to hold the pavement together or was this a new roadway and the intent was to lower the environmental impacts?
    - Any idea on the distress types present?
- What was the application rate used for chip sealing?
- What was the cost of the project?
- What was the life expectancy of the standalone chip sealed pavements?
    - What are the factors that prompted the decision of re-applying the application? When does that usually occur?
- Do you have performance criteria/standards established for standalone chip sealed pavements? If so, what are they?
    - Do you have pavement management data of the roadway (before and after application)?
- What are the pros and cons of the project? What worked and what didn't?
    - What are some of the lessons learned?
- Have your maintenance crews commented on the performance?
    - If there has been maintenance performed, would you mind sharing the costs associated with it?

3.9.1 City of Eden Prairie

3.9.1.1 Background Information

Similar to fog seals on chip sealed roads, standalone chip seals were in the City's preventive protocol prior to implementing fog sealing over chip sealing two years ago.

3.9.2 Cottonwood County

3.9.2.1 Background Information

CSAH 7 from CSAH 13 to north county line has an ADT between 550 and 840 depending on the segment. The speed limit is 55 mph on the rural segments and 30 mph in Westbrook.

Pavement surface age is 16 years old, overlaid in 2004. The Pavement Quality Index (PQI) ranges from 3.0 to 3.3. The intent of the crack fill, mastic, and chip seal is to slightly improve the ride quality and to extend the usable life of the pavement. In this case, it was to keep the PQI above 3.0 for 5 to 10 years.

Existing distress present was minor alligator cracking and a lot of transverse cracking. The County crack performed crack filling on the entire road with a 3405 rubber before chip sealing. The County also used mastic in areas where there was cupping of the transverse cracks.

The County also applies chip seals on new pavement surface to help prevent pavement from aging.

3.9.2.2 Application Rate

The application rate used for chip sealing was 0.28 gallon per square yard of CRS-2.

3.9.2.3 Project Cost

The material cost was roughly $9,000 per mile for the chip seals.

3.9.2.4 Performance and Life Expectancy

The life expectancy is 8 to 12 years, which is when previous chip seal has lost enough chips that the County determines a new chip seal is necessary to protect the new crack seal or mastic and to protect the underlying pavement and provide a new wear surface.

The CSAH 7 project would not be scheduled for another chip seal since it would be planned for a mill and overlay when the pavement is 25 to 30 years old.

In cases where chip seals are placed on new pavements (0 to 3 years old), the County would schedule crack fill, mastic, and chip seal when the pavements are 10 to 15 years old, followed by re-applications at 25 to 30 years old.

3.9.2.5 Performance Criteria/Standards Established

There is no set criteria or standards since budget and available funding affect project selection. As a rule of thumb, the County would like to keep the pavements at above 3.0 PQI. As the pavements are approaching the end of their life, the County would let the pavements deteriorate to 2.0 PQI before reconstructing them. The County has data from 2017 to 2019 on other roads that showed about a 0.2 increase in PQI after a crack fill, mastic, chip seal project.

3.9.2.6 Lessons Learned

For a reasonable price, the County was able to extend the life of CSAH 7 for another 10 years. The County firmly believes using allotted dollars on a heavier tack coat for chip sealing is a better investment than fog sealing. The County performed fog seals on chip sealed roads and standalone chip seals 12 years ago and there is no noticeable difference between the two applications. The County is fortunate to have an excellent aggregate source.

By applying heavier tack coat after rolling the roads turns a tinge black and is susceptible to streaking. This has zero impact on the chip seal and helps chip retention. However, it will never look as nice as a fog seal.

3.9.2.7 Feedbacks from Residents and/or Maintenance Crews

The County's staff has definitely noticed how well the heavier tack coat chip seals are holding up as compared to the fog seals in the past. The County anticipates there will be zero pavement maintenance cost on the CSAH 7 segment for the next 5 to 7 years.

The County strongly believes that a fog seal is mostly for aesthetic purpose. The County works in the constraint of an annual budget and in order to utilize the funding is to apply a heavier tack coat of CRS-2 emulsion or to perform several more miles of chip sealing in lieu of a fog seal. However, the public might confuse a fog seal with an overlay.

3.9.3 Houston County

3.9.3.1 Background Information

Prior to 2016, chip seals have been applied on both rural and urban roadways with AADT up to 8,000. Typically, the AADT is between 250 and 1,000 with a speed limit of 55 mph for rural roadways and 30 mph for urban roadways. Chip seals were usually placed within a year after newly paved roads.

3.9.3.2 Application Rate

The application rate used for chip sealing was 0.30 to 0.32 gallon per square yard of CRS-2P, and 18 pounds per square yard of FA-2 (new pavements) or FA-3 (old pavements) aggregates.

3.9.3.3 Project Cost

The cost was roughly $20,000 per mile for the chip seals. Average costs include all costs, including mobilization, pavement markings (latex paint), and labor.

3.9.3.4 Performance and Life Expectancy

The life expectancy is 5 to 7 years. Life expectancy is primarily based on past performance through visual inspections of the roadways, but the County also reviews pavement data collected every 2 to 4 years as well to see how the road conditions have changed over time. The County looks at the condition of the pavement (structural defects, ride quality), prior sealcoat application condition (aggregate retention), and if the pavement surface appears "dry" or oxidized.

7 to 10 years is what the County's program typically allows for the County to go back and apply a fresh sealcoat if warranted. In an ideal world, this would be done in the 5- to 7-year range as that is when the County begins seeing more drastic condition changes begin. The pavements are usually scheduled for re-application every 7 years unless the pavements had been selected for improvement projects within the next 5 years.

3.9.3.5 Lessons Learned

There was no concern on oil bleeding. The County did not have concern on loose rocks since there would be two sweepings after the chip seal applications.

3.9.4 Nicollet County

The County stopped standalone chip seal projects since 2014. Past chip seal projects used FA-2.5 Quartz aggregates and were scheduled for first application 5 to 7 years after an overlay, followed by re-applications every 5 to 7 years.

3.9.5 Otter Tail County

Prior to 2017, chip seals were applied every other year and tiered system was not established. The application rates were 0.30 gallon per square yard of CRS-2P emulsion and 22 pounds per square yard of FA-2 rocks.

3.9.6 Stearns County

3.9.6.1 Background Information

Standalone chip seals are typically placed in rural setting on roadways with lower than 1,000 AADT. The speed limit is 45 mph and less with lower traffic volume.

Chip seals are typically placed on original construction within 3 to 5 years of paving.

3.9.6.2 Application Rate

The application rate used for chip sealing is 0.25 gallon per square yard of CRS-2P emulsion and 25 pounds per square yard of pea rocks.

3.9.6.3 Project Cost

The 2020 cost was roughly $14,000 per mile ($1 per square yard) for the chip seals using pea rocks.

3.9.6.4 Performance and Life Expectancy

The life expectancy varies depending on the plow and rutting, but it is expected to last 7 to 10 years. If the roadways are still in decent condition the County will schedule the re-application in another 10 to 12 years.

3.9.6.5 Lessons Learned

There is public perception that chip seals cause windshield damage. Chip seal application has lower rock retention thus there are complaints of loose pea rocks on the adjacent lawn.