Minnesota Seal Coat Handbook

Revised March 2021

MINNESOTA
SEAL COAT HANDBOOK 2021

Revised March 2021 by:

Joel D. Ulring
Pavement Preservation Engineer
MnDOT Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Thomas J. Wood
Andrea Blanchette
Sheue Torng Lee
WSB
701 Xenia Avenue South, Unit 300
Golden Valley, MN 55416

Revised June 2006 by:

Thomas J. Wood Engineering Specialist
MnDOT Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Originally prepared December 1998 by:

David W. Janisch
MnDOT Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

Frank S. Gaillard City of Savage
6000 McColl Drive
Savage, MN 55378-2464

Published by:

Minnesota Department of Transportation
Office of Materials and Road Research
1400 Gervais Avenue
Maplewood, MN 55109

TABLE OF CONTENTS

FOREWORD

This is the second revision of this handbook which was originally written in 1996. This update to the handbook, although still titled ***Minnesota Seal Coat Handbook***, has changed all references of Seal Coat to Chip Seal, better aligning it with other state Department of Transportation's (DOT's), Federal Highway Administration (FHWA), and industry. Minnesota Department of Transportation (MnDOT) specifications will eventually be updated to reflect this change. As preventive maintenance and preservation of bituminous pavements continues to evolve, this version of the handbook has been expanded to include a brief discussion on spray applied bituminous surface seals and additional similar types of thin bituminous pavement surface treatments which are often referred to as BSTs.

Although information on the BSTs discussed above have been brought into this handbook, the intent is still the same, to provide guidance in the design and construction of high-quality chip seal surface treatments for bituminous pavements. Applying this treatment to the right pavement at the right time while paying attention to the quality of materials used and workmanship will result in better performing, longer lasting bituminous pavements.

This revision of the handbook was sponsored by the MnDOT Pavement Section with assistance from WSB Consulting Engineers and input from a Technical Advisory Panel made up of MnDOT, City and County Engineers. Their time spent reviewing and providing constructive comments to this latest update is greatly appreciated.

DEFINITIONS

Aggregate Flatness	Particles which are long and skinny which pass through a slotted steel plate. Used to determine FI- Flakiness Index.
Alligator Cracking	A form of load related fatigue cracking in a bituminous pavement consisting of closely spaced interconnected cracks which have an appearance of the back of an alligator.
Asphalt Binder	An asphalt emulsion used in chip sealing to seal and bind aggregate to a bituminous pavement.
Asphalt Emulsion	An asphalt blended into very fine droplets mixed with an emulsifier and suspended in water. Can be cationic (positive electrical charged), anionic (negative electrical charge) or non-ionic (neutral, no electrical charge). Also referred to as Engineered Asphalt Emulsion.
Asphalt Emulsion Breaking	The process of asphalt particles separating from the water in an engineered asphalt emulsion. The asphalt, which is heavier than water, drops down and the water rises to the surface and evaporates. The asphalt emulsion goes from a brown color to black.
Asphalt Emulsion Curing	Occurs after the asphalt emulsion breaks and water is evaporating from it.
Average Least Dimension	Is the expected chip seal thickness in the wheel paths after chips have been orientated on their flat side by traffic. It is calculated from the Median Particle Size (M) and Flakiness Index (FI).
Bleeding or Flushing	Occurs when excess asphalt binder in the wheel path rises above the top of the cover aggregate.
BSTs	Bituminous Surface Treatments. A combined binder-aggregate system that provides protection to the bituminous pavement surface against the environmental effects that sun, water and air have on it.
Chip Seal	A thin bituminous pavement surface treatment constructed by placing a layer of emulsified asphalt to seal the pavement surface and then covered with a one stone thick aggregate layer.
Cover Aggregate	Aggregate placed over an asphalt emulsion in the chip sealing process.
CQS-1h	Cationic quickset emulsion binder.
CRS-2	Cationic rapid-setting type 2 emulsion binder.
CRS-2P	Cationic rapid-setting type 2 emulsion polymer modified binder.

Flakiness Index – FI	A measure of the percent, by weight, of flat particles by testing in accordance to the Central Federal Lands Highway Division (CFLHD) DFT-508.
Fog Seal	A diluted asphalt emulsion spray applied as a surface treatment to bituminous pavements.
High-float Emulsion	An asphalt emulsion having chemicals added to it providing a thicker asphalt film on the cover aggregate particles.
Interlayer	A thin bituminous surface treatment, geotextile or other material placed between two bituminous pavement layers to seal the pavement surface and act as a stress relief layer to minimize reflective cracking.
Median Particle Size	The theoretical size where half of the stones are larger and half smaller within an aggregate gradation. It is determined by extending a horizontal line at 50 percent passing mark on the gradation graph until it intersects the gradation curve. A vertical line is then projected downward which gives the Median Particle Size.
Oxidation	The reaction of oxygen with the asphalt binder resulting in hardening of a bituminous pavement leading to reduced durability and cracking.
Pavement Preservation	A program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations. These practices in general do not increase pavement capacity or strength but reduce the effects of aging (environmental and traffic loading) and restore serviceability.
PM-CQS-1h	Polymer modified cationic quickset emulsion.
Polymer Modified Emulsion	An asphalt emulsion with polymer added which raises the softening point of the base asphalt. Their use improves cover aggregate retention and less potential for bleeding.
Poorly-graded Aggregate Gradation	An aggregate gradation in which the particles are various sizes, but not evenly distributed.
Preventive Maintenance	A planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system without significantly increasing the structural capacity.
Raveling	Progressive disintegration of a bituminous pavement from the surface downward as a result of the dislodgement of aggregate particles.

Rejuvenator Seal	A spray applied asphalt emulsions or biobased product containing a rejuvenating additive applied directly to the pavement surface. Sometimes includes a fine cover aggregate such as sand if friction is a concern.
Rutting	Surface depression in the wheel path of a bituminous pavement.
Scrub Seal	A thin bituminous pavement surface treatment constructed by placing a layer of an emulsified asphalt modified with an asphalt rejuvenating additive which is "scrubbed" into pavement cracks and other distresses with a broom trailer to seal the pavement surface and then covered with a one stone thick aggregate layer.
Seal Coat	A thin bituminous pavement treatment constructed by placing a layer of emulsified asphalt to seal the pavement surface and then covered with a one stone thick aggregate layer. Also called a chip seal.
Single-sized Aggregate Gradation	An aggregate gradation in which the particles are predominantly one size.
Surface Seal	Either an asphalt emulsions or biobased product spray applied directly to the pavement surface. Sometimes includes a fine cover aggregate such as sand if friction is a concern.
Underseal	A chip seal placed as an interlayer within a bituminous pavement. It is constructed before placing a new bituminous overlay.
Well-graded Aggregate Gradation	An aggregate gradation in which the particles are various sizes, and are evenly distributed from fine to coarse.

CHAPTER 1. INTRODUCTION TO BITUMINOUS SURFACE TREATMENTS

Bituminous Surface Treatments - BSTs consist of a combined binder-aggregate system that provide a durable preventive maintenance surface benefitting the bituminous pavements treated. They are constructed by placing a layer of emulsified asphalt (commonly polymer modified) to seal the pavement surface and then covered with a one-stone thick aggregate layer. Common BSTs used in Minnesota are bituminous chip seals, underseals, and scrub seals. Spray applied surface seals are also common practice in Minnesota. Although these treatments are well suited for certain situations and are generally less expensive than BSTs, they are less durable and require more frequent application.

Both spray applied bituminous surface seals and BSTs benefit bituminous pavements in resisting the effects that sun, water, and air have on them. Therefore, oxidation of the asphalt binder and loss of fine aggregate at the pavement surface is significantly reduced or eliminated by their use.

BSTs provide the following benefits to a bituminous pavement:

- A waterproof membrane layer to protect the underlying pavement.
- Protects the pavement surface from the effects of sun (oxidation).
- Improve skid resistance.
- Seal micro cracks.
- Fill existing cracks.
- Fill and stabilize raveled surfaces.

Historically, BSTs have been used since the 1920s, initially on low volume gravel roads and residential streets. Today they are increasingly being used and are most effective as preventative maintenance treatments on bituminous pavements that are in good condition. Well-constructed BSTs have extended the service life of these pavements by several years.

CHAPTER 2. TYPES OF BSTs AND SURFACE SEALS

As the world of pavement preservation has evolved over the years, several types of Bituminous Surface Treatments (BSTs) are now being used in preventative maintenance of bituminous pavements. The most common are chip seals, underseals, and scrub seals. In addition, numerous spray applied surface seals have been developed and are being used too. Following are brief descriptions of each of these treatments.

2.1 Chip Seal

A chip seal is comprised of a layer of asphalt cement covered with single particle thick layer of aggregate. It is constructed by spraying asphalt cement on the pavement surface immediately followed by application of a cover aggregate. The asphalt cement is usually modified with a polymer and emulsified (suspended in water) allowing it to be applied without the addition of extreme heat. The cover aggregate is commonly natural occurring gravel or crushed aggregate such as granite, quartzite or trap rock. Common practice in Minnesota is to fog seal the chip seal a few days to a week after the treatment is placed. This has been proven to increase aggregate retention, improve resistance to snowplow damage and lengthen life expectancy of the chip seal treatment. A chip seal is estimated to provide five to seven years of life extension to a bituminous pavement (1).

2.2 Scrub Seal

Scrub seals are best utilized on pavements which are more distressed with surface oxidation, minor raveling, and block cracking, making them less desirable as a chip seal candidate. This treatment is constructed just like a chip seal. The asphalt emulsion used is often modified with a rejuvenator additive to soften the more brittle pavement surface and reverse the effects of oxidation. The distributor pulls a broom sled as the emulsion is applied. The broom sled has multiple brooms mounted at various angles to it. The brooms create a small wave of emulsion ahead of them scrubbing the emulsion into the cracks and other pavement distresses, ensuring the pavement surface is sealed. Aggregate is immediately applied as in a chip seal. Common practice in Minnesota is to fog seal the scrub seal a few days to a week after the treatment is placed. This has been proven to increase aggregate retention, improve resistance to snowplow damage and lengthen life expectancy of the scrub seal treatment. A scrub seal is estimated to provide six to seven years of life extension to a bituminous pavement (1).

2.3 Underseal (Interlayer)

An underseal is a chip seal placed as an interlayer within a bituminous pavement (2). This treatment has also been referred to as a “Texas Underseal” as it was developed in Texas where it has been used extensively.

The typical underseal application involves placing the chip seal prior to overlaying a bituminous pavement. An underseal serves two purposes; primarily as a waterproof seal to stop water intrusion within the pavement structure, secondly it acts as a stress relief layer helping retard or delay reflective cracking in the new bituminous pavement placed over it. Experience has shown the treatment is better at delaying reflective cracking of non-thermally active cracks.

Often the pavement is milled prior to construction of the underseal. The rougher milled surface typically requires higher application rates of emulsion and lower application rates of aggregate cover. Because the underseal will be overlaid, it is not necessary to fog seal it. Additionally, it is not recommended to tack the underseal prior to paving. It is possible that tack sticking to construction equipment tires could dislodge chips during the paving process.

2.4 Surface Seal

Surface seals are either asphalt emulsions or biobased products that are typically spray applied to the pavement surface just like a fog seal. They may be modified with rejuvenator additives to improve the flexibility of the pavement and restore the oxidized surface of bituminous pavements. Because of these traits, surface seals and rejuvenator seals can be applied to many types and ages of bituminous pavements. Surface seals are typically applied to newer pavements less than two to three years old. They are promoted to penetrate the surface of the bituminous pavement, filling air voids and reducing moisture intrusion. Rejuvenator seals are applied to older pavements that are structurally sound and generally in good condition, but require corrective action to treat minor surface cracks, minor surface raveling and surface oxidation. Reapplication of these seals is typically every four to six years depending on the product and roadway it is applied to.

Some products may temporarily reduce pavement friction or affect reflectivity of pavement markings. Pavement friction can be reduced for a period of a few hours to a few days as the surface seal cures. Sand or a similar material is typically applied immediately after application to negate this loss of friction. In general surface seals do not have long-term impacts on pavement marking reflectivity so restriping of pavements may not be required with these treatments. A surface seal is estimated to provide two to four years of life extension to a bituminous pavement (1).

CHAPTER 3. CHIP SEAL

Chip sealing is a common preventive maintenance activity in Minnesota performed by most cities, counties and rural MnDOT districts (3). It involves spraying asphalt cement on the surface of an existing pavement followed by the application of a cover aggregate. The asphalt cement is usually emulsified (suspended in water) to allow for it to be applied without the addition of extreme heat. The cover aggregate is normally either naturally occurring gravel or crushed aggregate such as granite, quartzite, or trap rock (basalt).

3.1 OVERVIEW

BENEFITS OF CHIP SEALING

The primary reason to chip seal an asphalt pavement is to protect the pavement from the deteriorating effects of sun and water. When an asphalt pavement is exposed to sun, wind and water, the asphalt hardens, or oxidizes. This causes the pavement to become more brittle. As a result, the pavement will crack because it is unable to bend and flex when exposed to traffic and temperature changes. A chip seal combats this situation by providing a waterproof membrane which not only slows down the oxidation process but also helps the pavement to shed water, preventing it from entering the pavement itself and underlying base material.

A secondary benefit of chip sealing is an increase in the surface friction it provides. This is accomplished by the additional texture the cover aggregate adds to the pavement. With time, traffic begins to wear the fine material from the surface of the asphalt pavement. This results in a condition referred to as raveling. When enough of the fine material is worn off the pavement surface, traffic is driving mostly on the coarse aggregate. As these aggregate particles begin to become smooth and polished, the roadway may become slippery, making it difficult to stop quickly. A chip seal increases the pavement texture and improves surface friction properties.

CONDITIONS CONDUCIVE TO LONG LASTING CHIP SEALS

In most cases, chip sealing is done on roadways with low to moderate traffic volumes (up to several thousand vehicles per day). This is because of the increased chance of windshield damage to vehicles during and immediately after construction as traffic volume and speed limits increase. While it is possible to successfully chip seal high speed, high traffic roads (Average Annual Daily Traffic - AADT greater than 10,000) such as interstate highways, special precautions must be taken when chip seals are placed on these types of roadways to minimize the chance of problems occurring. Refer to Section 3.11 Special Considerations of this handbook for more details.

Chip seals are affected greatly by weather conditions, especially during construction. The ideal conditions are a warm, sunny day with low humidity. High humidity and cool weather will delay the curing time and cause the chip seal to be tender for a longer period of time making it more susceptible to damage by traffic. Rain can cause major problems when chip sealing. If the asphalt binder has not cured, it can become diluted and rise above the top of the cover aggregate. After the water evaporates, asphalt may cover the entire surface causing tires to pick up aggregate or track the binder across the surface. Chip sealing should **never** be done when showers are threatening. For information on what to do if it begins to rain during construction, refer to Section 3.9 – Common Problems and Solutions of this handbook.

Roadways to be chip sealed should be in relatively good condition. This means that there should be no pavement structure or weak subgrade related distresses such as alligator cracking, rutting and potholes. If these conditions exist, the road should not be sealed until proper repairs are completed.

In summary, chip sealing is a good maintenance technique for pavements with the following distresses:

- Low to moderate block cracking.
- Low to moderate raveling.
- Low to moderate transverse and longitudinal cracking.
- A smooth surface with low friction numbers.

MATERIALS USED IN CHIP SEAL CONSTRUCTION

The two main materials used in chip seal construction are the asphalt binder and the cover aggregate. The asphalt binder is normally an asphalt emulsion. The cover aggregate can be either natural or crushed.

Asphalt Binder

The most common asphalt binder used for chip seals in Minnesota is an asphalt emulsion. Typical asphalt binders used in Minnesota are CRS-2 and a polymer modified alternative, CRS-2P.

Asphalt Emulsion

An asphalt emulsion consists of the following components:

- Asphalt Cement
- Water
- Emulsifying Agent (surfactant)
- Polymers

The asphalt cement makes up about two-thirds of the volume of the emulsion. The base asphalt used to make the emulsion typically has similar characteristics to the asphalt cement used in hot mix production. This is the same PG range for most asphalt cements used in hot mix production. It has become increasingly popular to add latex or polymer to asphalt emulsions. These modified emulsions have improved early chip retention and durability of chip seals.

Water is the second largest ingredient in the emulsion. It provides a medium for the suspension and transfer of the asphalt particles. When the asphalt and water separate from each other, the color of the emulsion will change from brown to black. When this process has occurred, the emulsion is said to have broken. The aggregate chips must be applied and rolled before this occurs, normally only a few minutes after the emulsion is applied.

The emulsifying agent, or surfactant, has two primary roles. First, it causes the asphalt particles to form tiny droplets which are suspended in water. This is accomplished by the surfactant's ability to lower the surface tension between the asphalt and water. Having the asphalt particles suspended in the water allows the asphalt to be applied at much lower temperatures than it otherwise could be. Secondly, the emulsifying agent determines the electrical charge of the emulsion (cationic (+), anionic (-) or nonionic). It is important to choose an emulsion with an electrical charge that is opposite that of the aggregate. Since like charges repel, the emulsion will not bind well to aggregates with the same charge. Since most aggregates have a negative charge (4), Cationic (+) emulsions, such as CRS-2P, are used almost exclusively in Minnesota.

When an emulsion breaks, the asphalt particles separate from the water. Since the asphalt is heavier than the water, the water will rise to the top and eventually evaporate, leaving only the asphalt cement on the roadway.

Cover Aggregate

The cover aggregate should be **clean and dust free**, uniform in size and hard so that it provides a tight, durable surface able to withstand the abuse of snowplows and vehicles. In Minnesota, the gradation of chip seal aggregate is referred to as either FA-1, 2, 2½ or 3 (5). The larger the number, the larger the aggregate. The FA stands for Fine Aggregate. By far, the most common used sizes are FA-2 and FA-3. An FA-2 (Figure 3.1.1) consists mainly of particles smaller than 1/4 inch. An FA-3 (Figure 3.1.2) consists mainly of the chips smaller than 3/8 inch.

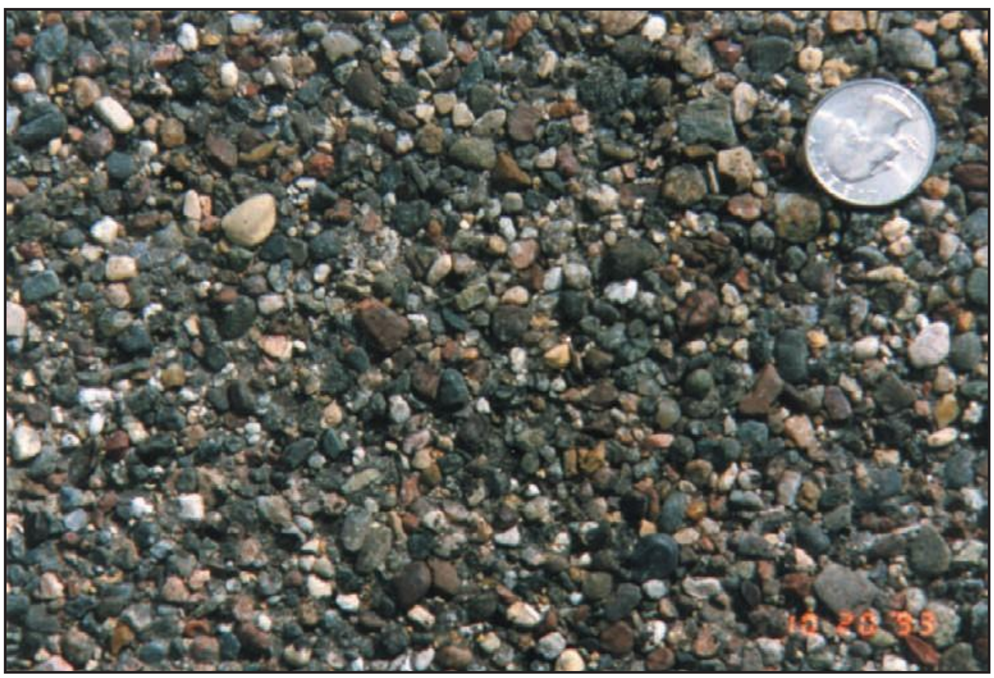

Figure 3.1.1 Example of an FA-2 Pea Rock (buckshot)

Figure 3.1.2. Example of an FA-3 Granite

A more detailed discussion of both the asphalt binders and cover aggregate can be found in Chapters 2 and 3 of this handbook.

EQUIPMENT USED IN CHIP SEAL CONSTRUCTION

There are several different types of equipment normally used to construct a chip seal. The exact type and size may vary depending on the situation and roadway width. The list of equipment is as follows:

- Power Brooms
- Asphalt Distributor
- Chip Spreader
- Pneumatic Tire Rollers
- Haul Trucks
- Front End Loader
- Asphalt Tanker
- Miscellaneous Hand Tools.

Power Brooms

There are two different types of power brooms used in chip sealing. Chip seals constructed in rural settings typically use front mounted rotary sweepers (Figure 3.1.3) whereas those constructed in urban settings use pick-up sweepers (Figure 3.1.4). The brooms are used prior to application of the chip seal to clean any dirt or debris from the existing pavement surface. This provides a clean surface for the asphalt binder to adhere to. Once the chip seal has been constructed, the brooms are used to remove any excess aggregate not embedded into the binder.

Figure 3.1.3. Rotary sweeper typically used in rural areas

Figure 3.1.4. Pick-up sweeper typically used in urban areas

Asphalt Distributor

One of the key pieces of equipment on a chip seal project is the asphalt distributor. It must be able to apply a uniform layer of asphalt binder at the correct depth and width. If the binder is applied too heavily, flushing of the asphalt in the wheel paths will result. If applied too thin, excessive chip loss will result. Most distributors used today have computerized controls which can regulate the pressure of the material to compensate for the speed of the vehicle. This results in a constant application rate, regardless of travel speed. Two distributors are normally used on a chip seal project. This allows one to continue to work while the other is being refilled by the tanker.

Figure 3.1.5. Computer controlled asphalt distributor

Figure 3.1.6. Computer control console of an asphalt distributor

Chip Spreader

Another important piece of equipment is the aggregate chip spreader. It must apply a uniform, even layer of aggregate across the entire width being sealed. As such, it must be calibrated properly and in good working order. A self-propelled chip spreader is desirable. This type of spreader pulls the aggregate trucks as it travels down the road. When the truck is empty, it is released by the spreader and another backs into place. If done correctly, almost no work stoppage occurs while refilling the spreader.

The newer chip spreaders are now equipped with computerized controls that allow the gates to open and close hydraulically, to compensate for the speed of the spreader. This ensures a constant application rate, regardless of travel speed.

Figure 3.1.7. Self-propelled chip spreader

Pneumatic Rollers

Perhaps the most overlooked pieces of equipment are the pneumatic tired rollers. Their primary function is to embed the aggregate into the asphalt binder and orient the chips on their flat side. It is important to have enough rollers to complete the rolling quickly. The chips need to be embedded into the binder before it breaks. Normally, a minimum of three rollers will be required. The first two rollers, drive side-by-side rolling the pavement outer edges. The third roller then follows closely behind, rolling the center of the lane. It is very important for the rollers to travel slowly, no more than 5 mph (8 km/hr), so the chips are correctly embedded into the binder.

Figure 3.1.8. Pneumatic tired rollers (Ohio DOT)

Haul Trucks & Front-End Loaders

A standard front-end loader is required to load the aggregate from the stockpile into the delivery trucks. The one exception to this would be if the aggregate is being obtained directly from an aggregate supplier. In that case, the trucks would be loaded at the pit or quarry.

Asphalt Tanker

Another piece of equipment used on chip seal projects is an asphalt tanker. While this is not normally supplied by the agency or the contractor, the foreman/supervisor needs to be aware of how many will be needed, where they should be located, and when to schedule them to arrive. Proper placement and delivery of asphalt binder is essential for good production. Without it, workers will be continually waiting for material to be delivered.

Miscellaneous Hand Tools

Hand tools are often used to touch up areas where the chip seal does not fully cover the pavement surface, such as cul-de-sacs and corners of parking areas, particularly where curb and gutter is present. Tools such as push brooms, shovels and squeegees are normally used. It is very common to find these tools on the rollers since the roller operators will typically be the ones who do the touch up work.

SUMMARY

In summary, chip sealing is a common, cost-effective, preventive maintenance activity involving several different types of equipment, each playing a unique role in the process. Attention must be paid to the type and quality of materials as well as the condition and operation of the equipment. The experience of the equipment operator is of utmost importance. Even new, well-calibrated equipment, using the finest materials, will not produce a quality chip seal project without experienced and qualified operators.

3.2 AGGREGATE

Thanks to its geological history, Minnesota has an abundant supply of good quality aggregate. Consequently, there are many choices available when considering which aggregate to use for a chip seal project.

AGGREGATE TYPES

The MnDOT specification 3127, "Fine Aggregate for Bituminous Chip seal" (6) identifies the following three classes of aggregate:

> ***Class A*** aggregate consists of crushed quarry or mine trap (basalt, diabase, gabbro or other related igneous rock types), quartzite or granite. These are primary granites from the St. Cloud and Ortonville areas, quartzite from the New Ulm area and trap rock (basalt) from Dresser, Wisconsin.
>
> ***Class B*** aggregate consists of all other crushed quarry or mine rock such as limestone, dolomite, rhyolite and schist. Primary, limestones available near the Rochester area have been used.
>
> ***Class C*** aggregate consists of natural or partly crushed gravels obtained from a natural gravel deposit.

As with most any type of construction material, chip seal aggregates are chosen based on several factors such as availability, cost, the type of road being sealed and traffic volume and movement.

Some guidelines include:

> ***Resistance to Traffic Wear and Snowplow Damage:*** Class A aggregates are the hardest and can withstand the pounding by traffic better than either Class B or Class C aggregates. In addition, crushed aggregate, such as Class A and B, lock together better than Class C aggregates due to their shape. For Class C aggregates, require particles to have 80% one face crushed. This will provide better protection against snowplow damage.
>
> ***Effect on Asphalt Binder Quality:*** Class B and C aggregates will generally require more asphalt binder because they are much more absorptive than Class A aggregates.

AGGREGATE APPLICATION RATE

When constructing a chip seal, the cover aggregate should be applied so it is only one-layer thick, unless a double or choke seal is being constructed (see Section 3.10). Applying too much aggregate not only increases the chance of windshield damage to passing vehicles but can also dislodge properly embedded stones. The exception to this is in areas where extensive stopping and turning movements take place, such as intersections and turn lanes. Using a light excess of aggregate, about 5 or 10 percent, can help reduce the scuffing caused by vehicle tires turning on the fresh, uncured, chip seal.

AGGREGATE SHAPE

The shape of an aggregate is characterized by the following:

- Flat or cubical; and
- Round or angular.

Impact of Aggregate Flatness

Traffic plays an important role in determining the chip orientation of chip seals constructed with flat and elongated aggregate. The flatter the aggregate, the more susceptible the chip seal will be to either bleeding in the wheel paths or excessive chip loss in the non-wheel path area. This is because traffic causes any flat chips in the wheel path to lie on their flattest side. This results in a thinner chip seal in the wheel path than in the non-traffic areas as shown in Figure 3.2.1. If the binder is applied too thick in the wheel paths, bleeding will result when the chips lie on their flat side. If the binder is applied to thin, the chips in the non-traffic areas will be dislodged by traffic and snowplow blades.

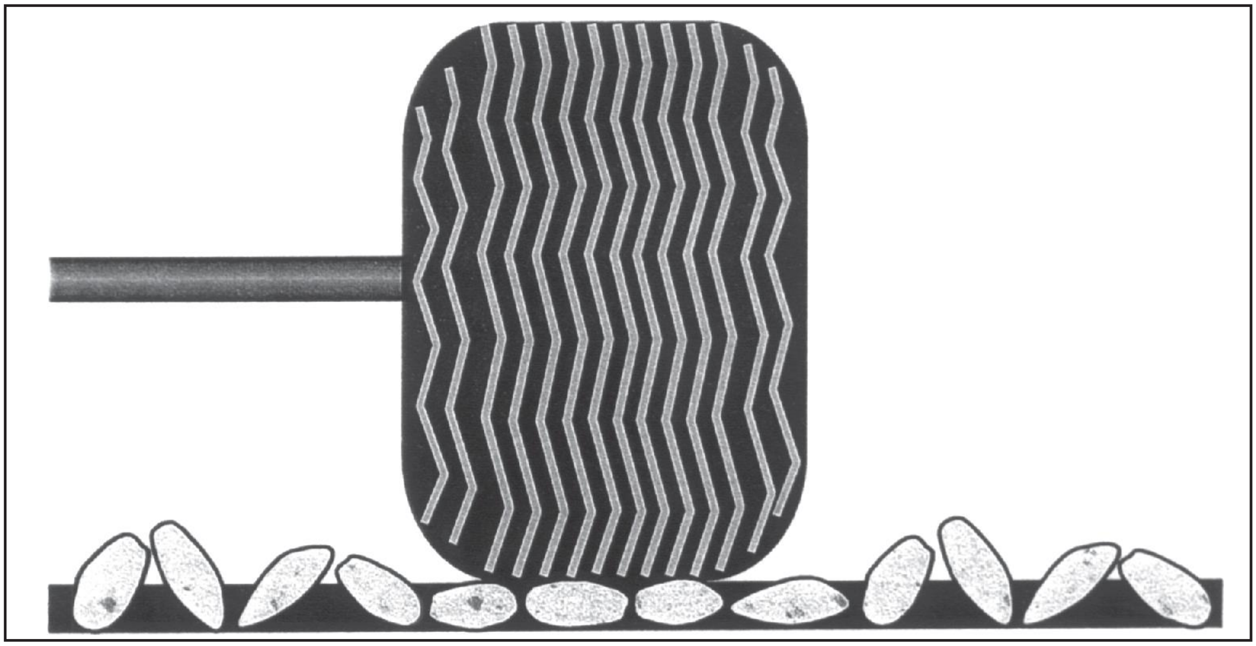

Figure 3.2.1. Traffic causes flat chips in the wheel path to lay down on their flattest side

For low volume roadways and parking lots, this difference in chip seal thickness may not be a problem because it requires repeated applications of traffic to re-orient the chips on their flattest side. If the traffic volume is low enough, or not confined to a specific area, such as a wheel path, there may not be a large enough difference in chip height to cause a problem.

With cubical aggregate, traffic will not have a pronounced effect on chip orientation. No matter how the chips are oriented, the chip seal height will be essentially the same and chip embedment will be uniform.

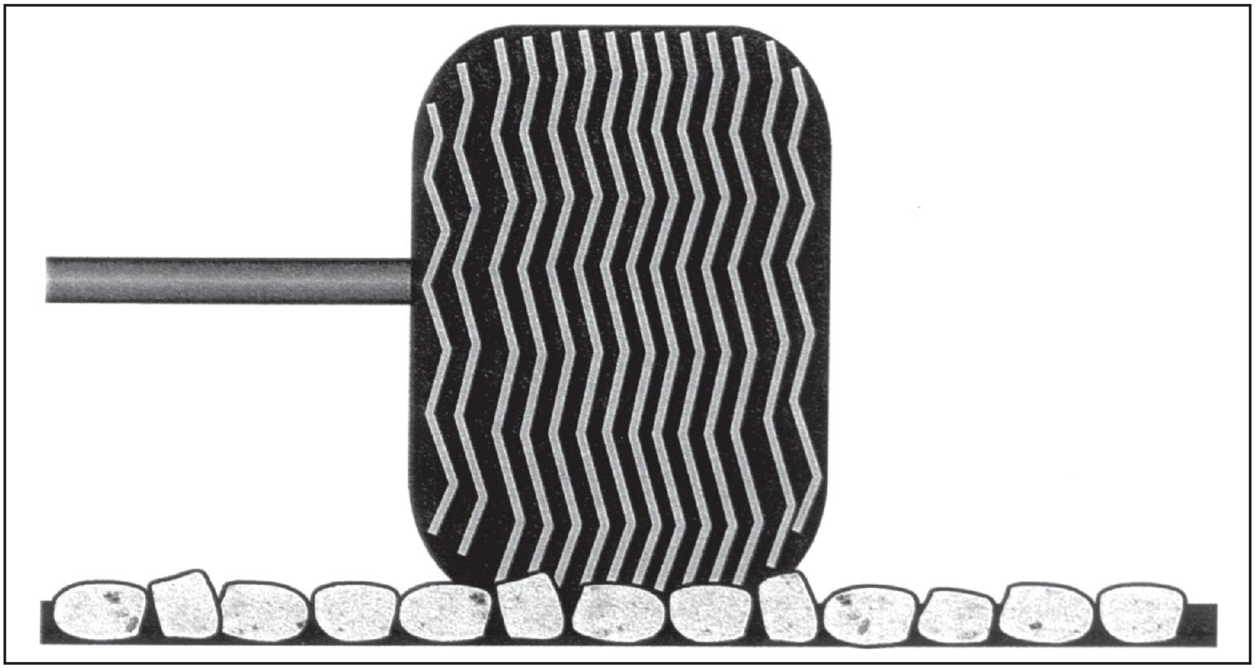

Figure 3.2.2. Traffic has little effect on cubical aggregate

The way to measure the flatness of an aggregate is the Flakiness Index (see Section 3.4 - Design). This index is the percentage, by weight, of the aggregate that consists of flat and elongated pieces. Most Class A and B aggregate in Minnesota have a Flakiness Index between 18 and 30 percent. Class C aggregates have lower Flakiness Indices, typically between 9 and 20 percent. Aggregate with Flakiness Indices over 25 percent should not be used for chip sealing.

Tips for using flat aggregate:

- In the binder design process, calculate the amount of binder required for both the wheel path and non-wheel path areas. This will give you a feel for the difference in the chip seal thickness between these two areas.

- Flat aggregate should not be used on high volume roadways. There will either be too much binder in the wheel paths or not enough between them. For a high volume roadway, a cubical aggregate having a Flakiness Index of 25 percent or less is recommended.

- Use a little extra aggregate (5-10%) in the wheel paths to prevent the flat chips from sticking to the tires of the chip spreader and dump trucks while the binder is curing. This can be done by increasing the opening of the chip spreader gates in these areas. Remember, if enough binder is applied to hold onto the tall chips in the non-traffic areas, the flat chips in the wheel path will likely be covered with the binder. The excess aggregate will help to prevent them from sticking to vehicles.

Impact of Aggregate Roundness

The roundness of the aggregate will determine how resistant the chip seal will be to turning and stopping movements. A round aggregate is defined as an aggregate that is not crushed. They are much more susceptible to rolling and displacement by traffic than crushed aggregate. MnDOT requires natural gravel chip seal aggregates to meet 80 percent one face crushed or fractured (MnDOT 1214 references ASTMD 5821).

Tips for using round aggregate:

- Use a one-size gradation. Round aggregates are more easily dislodged by snowplows, because of their inability to lock together. Using a single-size aggregate will help prevent the plow blade from dislodging the taller/larger stones.

- Extra care must be taken to ensure proper embedment is achieved. Chip seals constructed with round aggregate are more susceptible to snowplow damage. The chips need to be deeply embedded into the binder to minimize this damage.

- A double chip seal is a good option when using round aggregate, particularly on high volume roads. This type of seal involves placing two separate applications of chip seal layers, one on top of the other. The aggregate used for the top layer should be roughly half the size of the aggregate on the bottom layer. The second application of binder embeds the initial layer of aggregate 100 percent within the chip seal structure. The smaller stones in the top layer settle into the first layer, better locking them into the overall seal structure. The surface layer of smaller stones are less likely to dislodge and are typically too small to cause windshield damage. The double chip sealed surface is often smoother than a single seal, which also minimizes snowplow damage.

AGGREGATE GRADATION

Aggregate gradation plays an important role in chip seal design, construction, and performance. Gradation refers to the distribution of the various sized stones that make-up the aggregate matrix. Aggregates used in chip seal construction are normally classified as either one-size or graded.

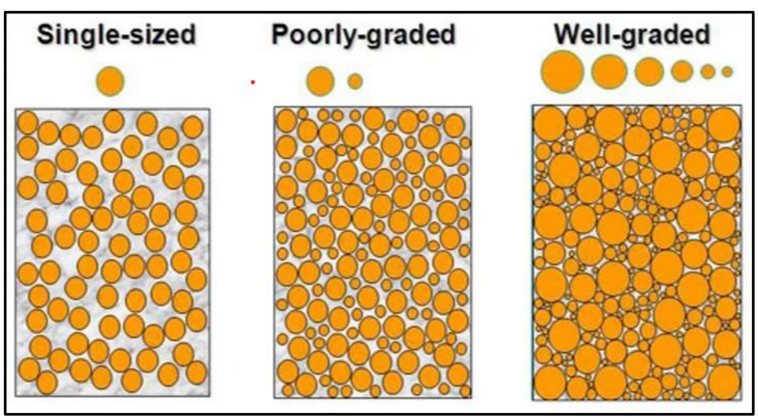

Figure 3.2.3 Aggregate grading

One-Size Aggregate

The best chip seal gradations are those that are single or one-size. An aggregate is considered one-size if nearly all the material is retained on two consecutive sieves. This results in most of the stone pieces being in a narrow range of sizes as shown in Figure 3.2.3.

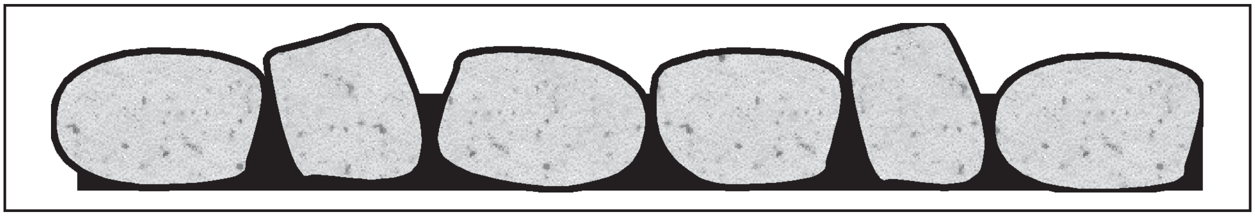

Figure 3.2.4. Cross section of a one-size chip seal aggregate

Figure 3.2.4 shows a typical one-size aggregate chip seal application. Notice that the chips are similar in size and the large amount of space (voids) that exists between each stone. This is the space available for the asphalt binder to fill and a key component in determining the amount of binder required for good performance.

Some of the advantages of using a one-size aggregate are:

- Maximum friction is obtained between vehicle tires and the pavement surface because more chips are in contact with the tires.
- Checking for adequate binder can be determined quickly and accurately and there is less chance of bleeding. Reasoning if one particle is embedded properly, the others should be also.
- Better drainage is obtained by better defined surface channels between the aggregate particles, which allows for rapid and positive removal of water.

Graded Aggregate

Graded aggregates cover a wide range of possibilities from single-sized (poor) graded to well graded (Figure 3.2.3). The more well graded an aggregate is, the less desirable it is for chip seal construction. This is because well graded aggregates have lower air voids and therefore, less room for binder between the chips (Figure 3.2.5). As a result, there is a fine line between applying too much binder (bleeding) and not enough (loss of aggregate). Failure to account for the aggregate's gradation increases the chance of one of these failure modes occurring.

Figure 3.2.5. Cross section of a graded chip seal aggregate

Some problems with using graded aggregate are:

- Some of the larger particles project so far above the average thickness of the chip seal they are torn out of the surface by vehicle tires and snowplow blades.
- Some of the smaller particles are so small they are completely submerged into the asphalt binder which can cause bleeding.

- Because of the considerable range in particle sizes, vehicle tires make firm contact with fewer particles at a time resulting in less friction.

- It is difficult to determine the proper quantity of binder that will be both sufficient to hold onto larger particles and yet not submerge too many of the smaller particles.

The most often used chip seal aggregate gradations in Minnesota are MnDOT FA-2, FA-2½, and FA-3. These are considered poorly graded (one-sized) aggregates. However, the gradation bands are broad enough that there is the possibility of a well graded material meeting the aggregate specification.

Figure 3.2.6. Example of a one-size FA-4 chip seal aggregate

Figure 3.2.7. Example of a poorly graded round chip seal aggregate

DUSTY AGGREGATE

Dusty aggregates have been responsible for many chip seal failures. Aggregates containing dust should not be used for chip sealing unless certain precautions are taken. To avoid dusty aggregate, the specified aggregate gradation should have one percent or less passing the #200 sieve (75µm). Dust coating the outside of the aggregate particles prevents the emulsion from bonding with the chip. Consequently, extensive chip loss will occur.

If clean, dust-free, aggregate is not available, one of the following **must** be done before the aggregate is used:

- Wash the aggregate to remove the dust. The washing process, which should be done with clean, potable water, involves screens which allow the unwanted fines to be removed. A conveyor is then used to stockpile the material where it can drain and dry.

- A high-float emulsion, such as HFMS-2 should be used. This type of binder can be used with aggregates having as much as 5 percent passing the #200 sieve. The wetting agents used in this type of binder can cut through the dust coating and provide a good bond between the binder and the chips.

Figure 3.2.8. Evidence of a dusty aggregate

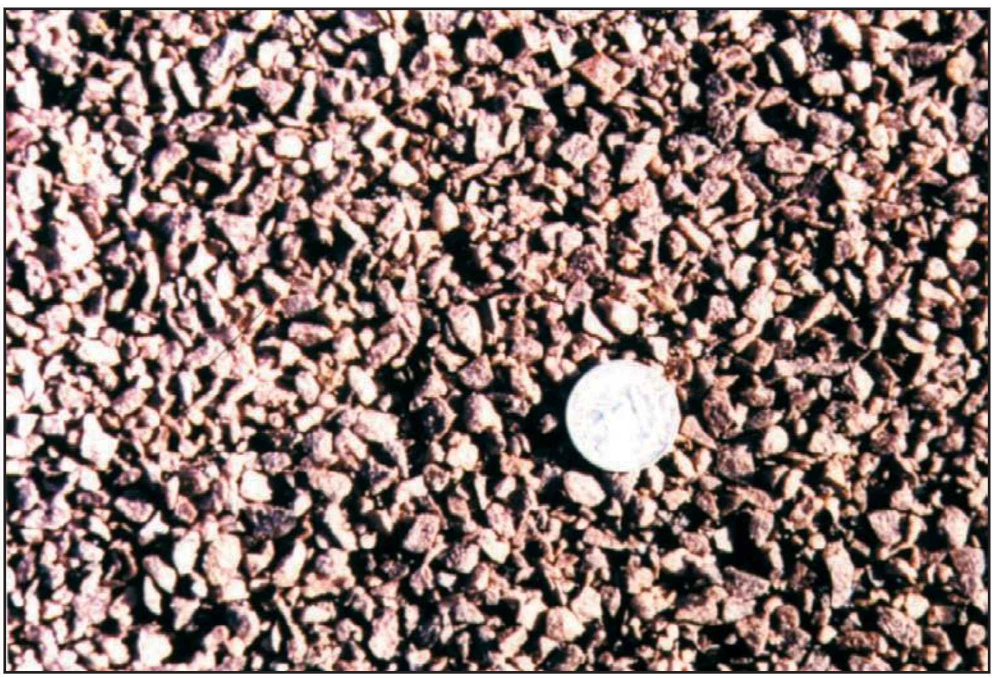

Figure 3.2.9. Dusty aggregate before sweeping

Figure 3.2.10. Dusty aggregate after sweeping (notice most of the large aggregate is missing)

This page intentionally left blank.

3.3 ASPHALT BINDERS

Asphalt binder is used in road applications primarily because it is waterproof and adheres to stone. At room temperature, most asphalts are very stiff, too stiff to apply to a roadway. To get it into a form that can be applied requires the viscosity to be reduced. This can be done by heating the binder or making an asphalt emulsion. The binder most often used for constructing chip seals is an asphalt emulsion.

ASPHALT EMULSIONS

Emulsions are all around us in our daily lives. Common examples of emulsions are milk, margarine, butter, beer, and paint. Emulsions are made up of two components with one dispersed in the other. An asphalt emulsion is created by mixing two incompatible components together, asphalt (oil) and water. Maintaining the dispersion of the two components requires some way of overcoming the incompatibility. The methods that have been found to work for asphalt emulsions are high shear blending and chemical treatment. An asphalt emulsion consists of asphalt particles dispersed in water and chemically stabilized as shown in Figure 3.3.1.

As molten asphalt is blended into fine droplets, the asphalt is brought into contact with a chemical solution (emulsifier) which provides the stabilization. After discharge, the emulsion consists of water with fine particles of asphalt dispersed in it. The only thing between the asphalt particles is water and the emulsifier. Since asphalt is not naturally soluble in water, keeping it dispersed as fine droplets in water is a significant challenge.

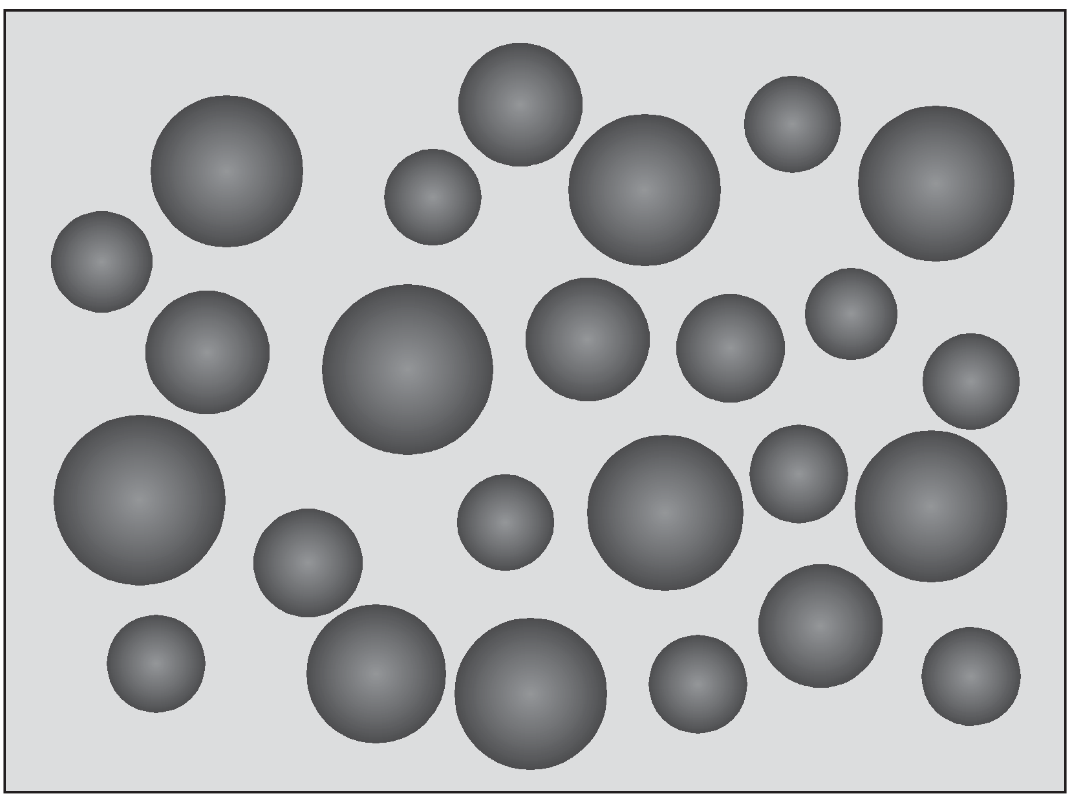

Figure 3.3.1. Asphalt emulsion

Emulsion Classification

Emulsions are divided into three grades for classification based on their electrical charge: cationic, anionic and non-ionic. In practice, only the first two are used in roadway construction and maintenance. The cationic and anionic designation refers to the electrical charge of the emulsifier surrounding the asphalt particles. Cationic emulsions have a positive (+) electrical charge surrounding the asphalt particles while anionic emulsions have a negative (-) electrical charge.

Since opposite electrical charges attract, anionic emulsions should be used with aggregates having a positive (+) charge. Similarly, cationic emulsions should be used with aggregates having a negative (-) charge. Failure to use materials with opposite electrical charges may result in the materials repelling each other, causing failure.

In addition to being classified by their electrical charge, emulsions are further classified according to how quickly they revert back to asphalt cement. The terms RS, MS and SS have been adopted to simplify and standardize this classification. They are relative terms only and stand for Rapid-Setting, Medium-Setting and Slow-Setting. As the emulsifier is drawn toward aggregate surfaces with an opposite electrical charge, the asphalt particles begin to settle to the bottom of the emulsion. The speed at which this occurs is indicated by the RS, MS and SS designation.

Five grades of high-float emulsions are also available. High-float emulsions, so designated because they pass the Float Test (AASHTO T-50 or ASTM D-139), have a quality imparted by the addition of certain chemicals that permit a thicker asphalt film on the aggregate particles with a minimum probability of drainage. This property allows high-float emulsions to be used with somewhat dusty aggregate with good success.

Finally, emulsions are subdivided by a series of numbers that relate to the viscosity of the emulsion and the hardness of the base asphalt cement. The numbers “1” and “2” are used to designate the viscosity of the emulsion. The lower the number, the lower the viscosity and the more fluid the emulsion is. If the number is followed by the letter “h”, the emulsion has a harder base asphalt. The letter “d” refers to diluted.

Emulsifiers

Emulsifiers are the chemical solutions that give the asphalt particles the ability to stay suspended in water. The two types of emulsifiers; cationic and anionic are both comprised of salts.

a) Anionic Emulsifiers are comprised of acids reacted with a base such as caustic potash or caustic soda to form a salt. It is this salt that is the active emulsifier. The emulsifier attaches itself to the asphalt particles. The number and density of these emulsifier molecules determine how much negative (-) charge is on the surface of the asphalt particles. Figure 3.3.2 shows an anionic emulsified asphalt particle.

b) Cationic Emulsifiers are also made of acid salts. Cationic emulsifiers give a positive (+) charge to the asphalt particles. The most often used emulsifiers in Minnesota, by a wide margin, are cationic. This is because most aggregates have a negative charge and thus attract cationic emulsifiers, causing a good bond. Figure 3.3.3 shows a cationic emulsified asphalt particle.

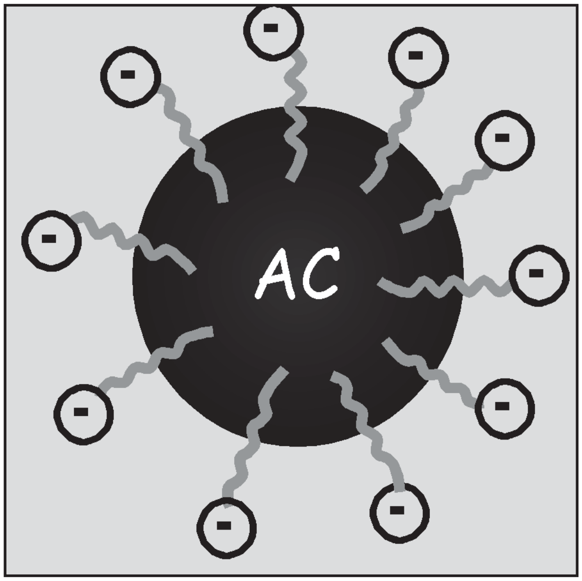

Figure 3.3.2. Anionic (-) Emulsion

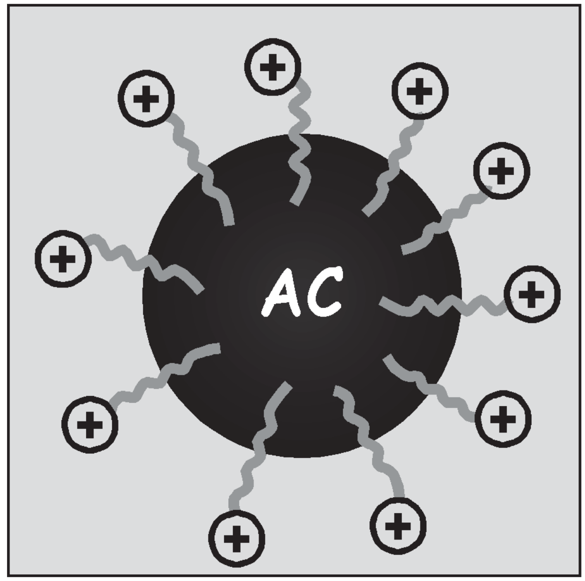

Figure 3.3.3. Cationic (+) Emulsion

Cationic Versus Anionic

Overall, cationic emulsions perform more reliably in the field and set up more quickly than anionic emulsions, provided the correct handling and application procedures are used.

In addition:

- Cationics are less sensitive to weather because they have a chemical break.
- Cationics can be stabilized without making break times longer.
- Cationics are more critical in handling.
- Cationics need close attention to storage procedures.
- Cationics are more suitable for aggregates, silica aggregates included.
- No precoat is required for a cationic emulsion if aggregate is clean and dust-free.

Properties of Emulsions

All the properties of emulsions and their behavior under various conditions are directly related to the type and strength of emulsifier used.

Breaking refers to the event when the asphalt and water separate from each other. This occurs as the emulsifier leaves the surface of the asphalt particles as it is attracted to the surface of the aggregate. Since asphalt is heavier than water, the asphalt particles will settle to the bottom of the solution.

Curing refers to when the emulsion has set. Humidity can slow the cure time. On hot and humid days, this process can be performed overnight.

Since ***anionic emulsions*** have a negative charge, as does almost every mineral, there will be no electrostatic attraction between the emulsion and the aggregate surface since like charges repel each other. For an anionic emulsion to break, the particles must get so close to each other that the repulsion forces are overcome by the attractive forces that exist between all things. This occurs by forcing the particles together in some way. During chip sealing, this occurs as the water evaporates out of the emulsion. In Minnesota, the most common used anionic emulsion for chip sealing is HFMS-2.

Cationic emulsions have a positive charge and since opposite charges attract, they are drawn toward most aggregate particles. Thus, a direct and very rapid reaction between the emulsion and an aggregate or pavement is possible as shown in Figures 3.3.4 and 3.3.5. The size of the charge, affects stability, i.e. the larger the charge, the more rapid the reaction. The other mechanism which affects curing is evaporation. After the chemical break is completed, the water must still be completely evaporated for the residual asphalt to achieve full strength. In Minnesota, the most common used cationic emulsion is CRS-2.

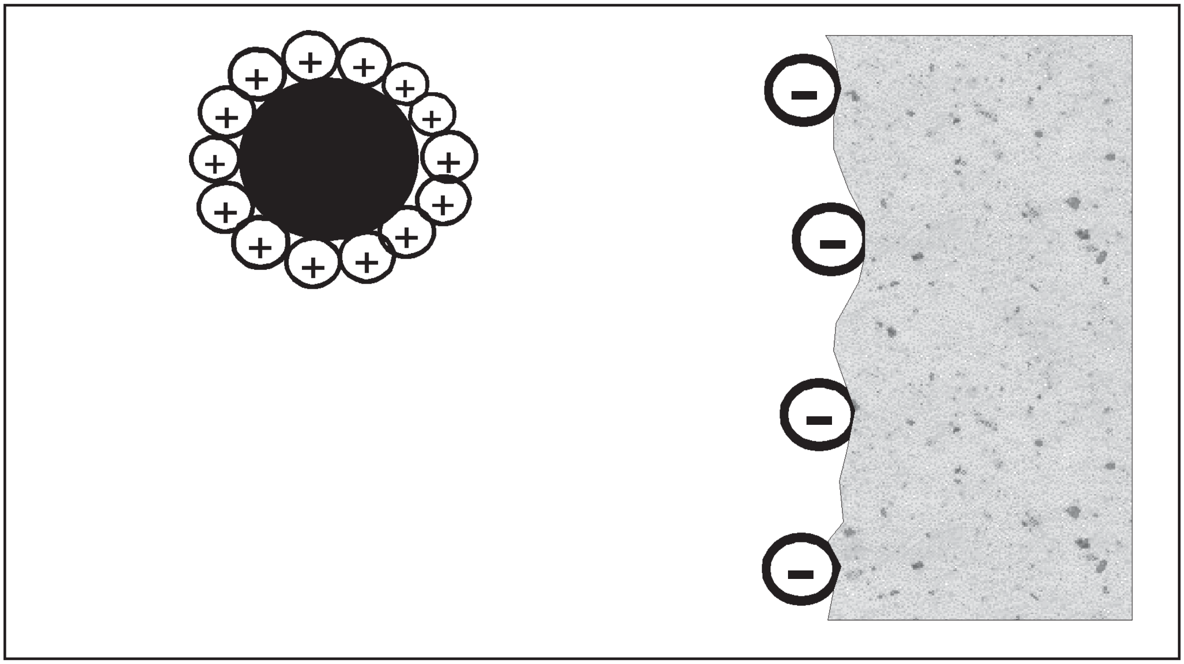

Figure 3.3.4. Cationic Emulsion before breaking

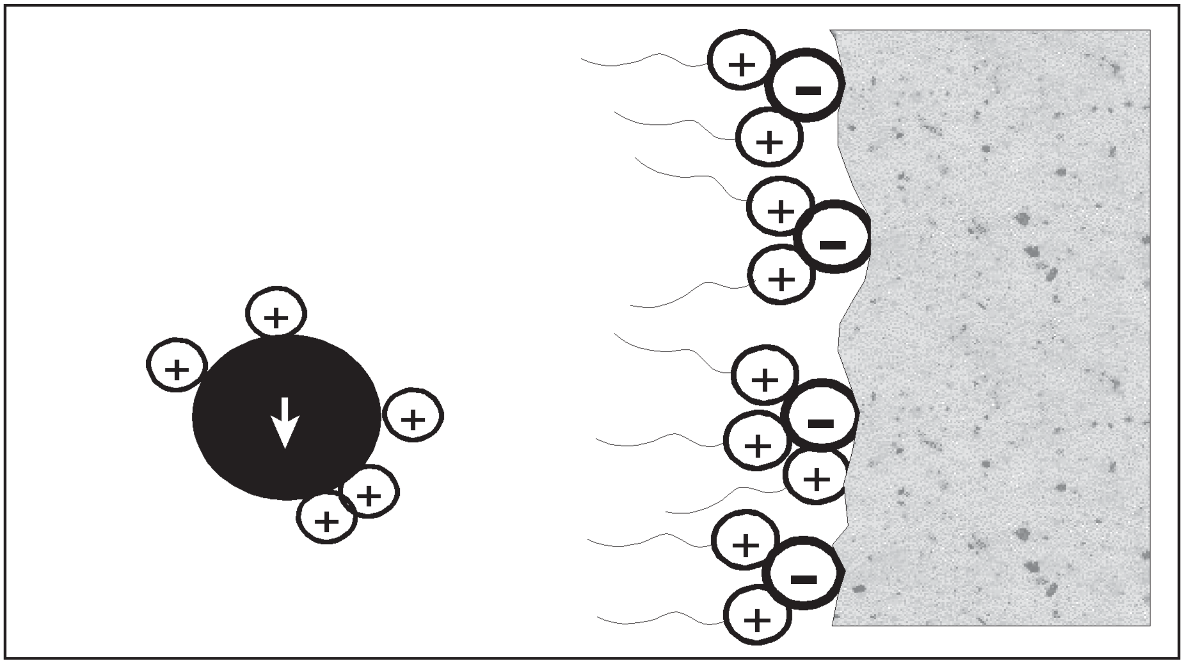

Figure 3.3.5. Cationic emulsion beginning to break

Polymer Modified Emulsion

Certain properties of asphalt emulsions can be enhanced by the addition of polymers. Common polymers used in emulsions are natural and synthetic latex, SBR and SBS polymers that are paving grade asphalt binders. Emulsions are typically modified by adding about 2.5 to 3 percent polymer, by weight.

Advantages of using polymers are:

1. **Early chip retention:** Using polymers allows same day sweeping versus having to wait until the next morning.

2. **Raises the softening point of base asphalt:** The residual asphalt from a CRS-2 has an average softening point (temperature) of 108º F versus the residual asphalt from CRS-2p softening point of 128º F. This allows the user to be more aggressive with their application rate without the fear of bleeding. The more asphalt binder placed on the roadway the longer the chip seal will perform.

3. **Greater protection of the chip seal:** The elastomeric characteristics of the polymer-modified asphalt protect the chips from impact shock from stopping and turning traffic, and snow removal equipment.

4. **Flexibility:** Polymer modified emulsions are available both in Cationic and Anionic (High Floats) emulsions.

5. **Less waste of materials:** With a polymer-modified emulsion, there is less chance of loose aggregate after final sweeping because of the ability of the asphalt to stretch and rebound. The polymer provides the emulsion a rubber band type characteristic, causing it to spring back to its original position when pulled and released.

STORAGE AND HANDLING OF ASPHALT EMULSIONS

Safety

Emulsions are water based, they have no flash point and are not flammable or explosive. Drums of emulsion kept in the sun will not expand or burst. Being water based, emulsions do not pose any health risk to workers. Since they can be used at cooler temperatures (125 - 185° F., 52 - 85° C.), the likelihood of severe burns is also much less. The binder material should be accompanied by a Material Data Safety Sheet (MSDS).

As discussed earlier, there are advantages of using emulsions compared to hot asphalt cement and cutbacks. There are a few simple rules for successful use of asphalt emulsions. They are simple if one remembers how emulsions are made. **Suppliers, most often, are the best source of information on storage and handling of specific products.** General best practices for storing and handling asphalt emulsions are summarized below.

Pumping

Pumps compress or shear the material that they pump. This results in the emulsion being compressed. If this happens too severely or often, the emulsion will become coarse and may go back to asphalt cement. Pumps should be selected carefully. Centrifugal pumps and some types of positive displacement pumps may be used.

Temperature

When materials get cold, they typically shrink. With emulsions, this means that the asphalt droplets get closer together. If the emulsion gets too cold, the asphalt particles can get too close together causing the emulsion to break and return to asphalt cement.

When materials get hot, they expand. Heating an emulsion is useful. However, when water gets hot its evaporation rate increases significantly. If the water leaves the emulsion, the asphalt droplets get closer together which can return the emulsion to asphalt cement. This can occur if any part of the emulsion gets hotter than 200° F (95° C).

Following are several important temperature related items to remember when storing and handling emulsions:

- When heating emulsion, do it gently and only in accordance to specification.
- Use agitation.
- Warm pumps before use.
- On bulk tanks in cold areas, electrical tracing is advisable.
- Do not apply direct heat to an emulsion with fire or a blow torch.

Cleaning

For emulsions, cleanliness is very important. A sloppy operation will produce problems. When an emulsion is exposed to air it can begin to break. When a cationic emulsion is exposed to metal it can also begin to break. If a pump is not flushed after use, it will clog. If lines are left partially full of emulsion they will clog. The higher the performance of the emulsion, the more critical cleaning is. Thorough cleaning of equipment should be done immediately after use and before storage.

The cleaning procedure is the responsibility of the contractor. The distributor manufacturer's recommendations should be followed.

3.4 DESIGN

Chip seals should be designed to ensure that the proposed materials are of sufficient quality and have the desired properties required for a successful chip seal project. In addition, the design will determine the proper amount of cover aggregate and bituminous binder to apply. The design procedure recommended in this handbook is based on the one first presented in the late 1960's by Norman McLeod (7). This procedure was later adapted by the Asphalt Institute (8) and the Asphalt Emulsion Manufacturers Association (9). It was also the design procedure used by the Strategic Highway Research Program (SHRP) for designing the Special Pavement Study chip seal sections constructed across the United States (10).

ASPHALT BINDER CONSIDERATIONS

An asphalt emulsion is comprised of a mixture of asphalt and water. The water in the emulsion will evaporate as the binder cures. This results in collapse of the asphalt film; effectively reducing the height of the binder. In designing a chip seal, it is important to know the *residual asphalt content* of the binder. The residual asphalt is the glue that remains on the roadway after the water has evaporated out of the binder.

For aggregate particles to remain on the roadway, they need to have approximately 70 percent of their height embedded into the *residual asphalt*. To accomplish this with an asphalt emulsion, the binder must rise near the top of the aggregate particles. This is demonstrated in Figure 3.4.1. If the emulsion rises just below the top of the aggregate (voids ~ 100 percent filled), the voids will be roughly two-thirds filled after curing since about one-third of the binder will evaporate. Failure to allow emulsions to rise this high will result in insufficient embedment and loss of the cover aggregate as soon as the chip seal is exposed to snowplows and traffic.

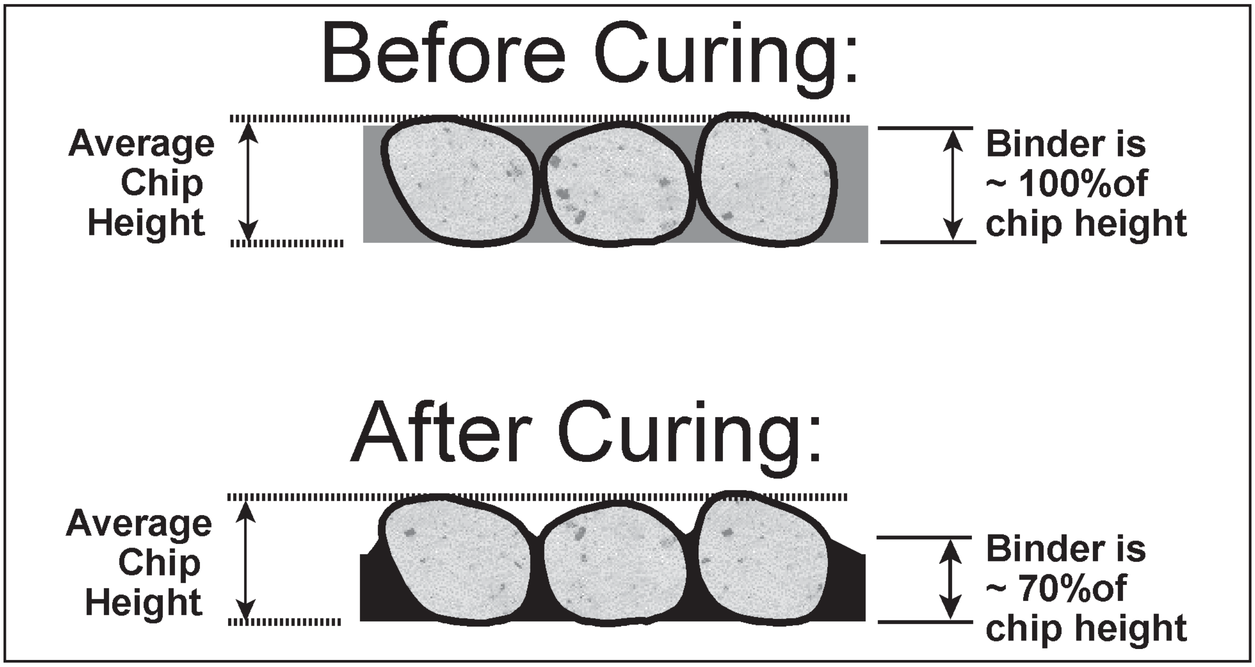

Figure 3.4.1. Change in volume after emulsion has cured

Refer to section 3.3 Asphalt Binders of this handbook for more details on asphalt binders used in chip seal construction.

COVER AGGREGATE CONSIDERATIONS

When designing a chip seal, there are several factors concerning the aggregate that must be considered. They all play a role in determining how much aggregate and binder should be applied to the roadway.

Gradation

The gradation of the cover aggregate is important not only for determining its application rate, but also the binder application rate. The more graded the aggregate is, the closer the particles will be to each other on the roadway. This leaves very little room for the asphalt binder, which can cause bleeding. The best gradation for a chip seal aggregate is one size. This means that most every chip is the same size. A one-size aggregate gradation has lots of room between the particles for filling with the binder. In addition, inspection is much easier because each chip is embedded approximately the same amount.

Particle Shape

The shape of the aggregate particles can be round or angular, flat, or cubical. Their shape will determine how they lock together on the roadway. The more they lock together, the chip seal is better able to withstand turning and stopping of vehicles as well as snowplows.

Bulk Specific Gravity

The specific gravity, or unit weight, of the aggregate also plays a role in determining how much aggregate to apply to the roadway. Specific gravities of chip seal aggregate in Minnesota can differ by as much as 20 percent. The lower the specific gravity, the lighter the aggregate. It will take more pounds of a heavy aggregate, such as trap rock, to cover a square yard of pavement than it will for a light aggregate such as limestone.

Aggregate Absorption

The amount of binder applied to the roadway not only needs to compensate for absorption into the existing pavement but also into the cover aggregate itself. Sedimentary aggregates such as limestone can have ten times the absorption of igneous aggregate such as granite or trap rock. Failure to recognize this fact and correct for it can lead to excessive chips loss because of lack of embedment.

THE McLEOD DESIGN PROCEDURE

Minnesota uses the McLeod procedure in designing chip seals. In this procedure the aggregate application rate depends on the aggregate gradation, shape, and specific gravity. The binder application rate depends on the aggregate gradation, absorption and shape, traffic volume, existing pavement condition and the residual asphalt content of the binder.

The McLeod design procedure has been modified by the Minnesota DOT to apply slightly more binder to improve resistance against snowplow damage in the non-wheel path areas. This will be discussed later in this chapter.

The McLeod procedure is based on two basic principles:

1. The application rate of a given cover aggregate should be determined so that the resulting chip seal will only be ***one-stone thick***. This amount of aggregate will remain constant, regardless of the binder type or pavement condition.

2. The voids in this aggregate layer need be **70 percent filled with asphalt cement** for good performance on pavements with moderate levels of traffic.

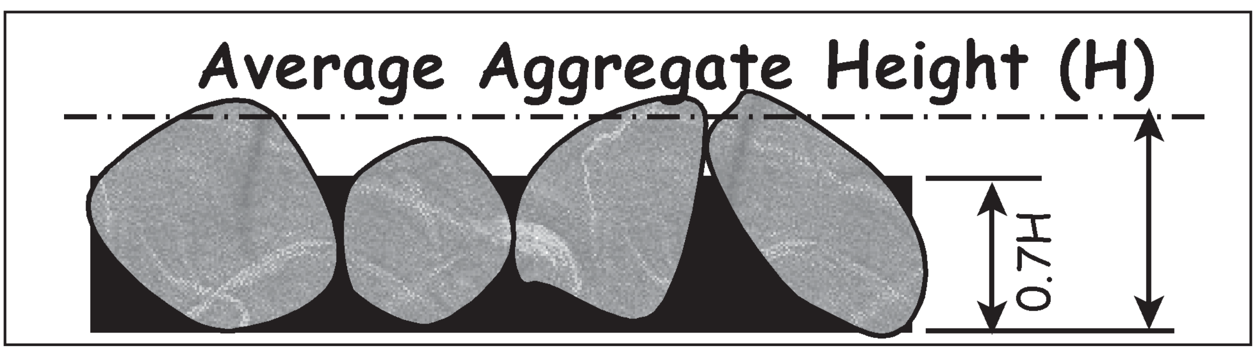

Figure 3.4.2. McLeod design: One-stone thick & proper embedment (70%).

Figure 3.4.3 shows an inspector checking for proper chip embedment. Notice that the chip is embedded about 70 percent into the residual asphalt. This will help to ensure good chip retention.

Figure 3.4.3. Proper embedment (~70%) into the residual asphalt

Key components of the McLeod design procedure are as follows:

Median Particle Size

The Median Particle Size (M) is determined from the gradation chart. It is the theoretical sieve size through which 50 percent of the material passes (50 percent passing size). The gradation is determined using the following sieves:

Table 3.4.1. Sieve nest for chip seal gradations

Sieve Name	Opening U.S. Customary Units	Opening S.I. Metric Units
1 inch	1.000 in.	25.0 mm
3/4 inch	0.750 in.	19.0 mm
1/2 inch	0.500 in.	12.5 mm
3/8 inch	0.375 in.	9.5 mm
1/4 inch	0.250 in.	6.3 mm
No. 4	0.187 in.	4.75 mm
No. 8	0.0937 in.	2.36 mm
No. 16	0.0469 in.	1.18 mm
No. 50	0.0117 in.	300 µm
No. 200	0.0029 in.	75 µm

Figure 3.4.4. Chip seal Sieve Nest

Flakiness Index (FI) is a measure of the percent, by weight, of flat particles. It is determined by testing a small sample of the aggregate particles for their ability to fit through a slotted plate (Figure 3.4.5).

There are five slots in the plate for five different size fractions of the aggregate. If the chips can fit through the slotted plate, they are considered flat. If not, they are considered cubical. The lower the Flakiness Index, the more cubical the material is. The test is run according to Central Federal Lands Highway Division (CFLHD) DFT-508 (12).

The five slots in the plates are for the following:
- Slot 1: Material passing the 1 in. sieve (25 mm) but retained on the 3/4 in. sieve (19 mm).
- Slot 2: Material passing the 3/4 in. sieve (19 mm) but retained on the 1/2 in. sieve (12.5 mm).
- Slot 3: Material passing the 1/2 in. sieve (12.5 mm) but retained on the 3/8 in. sieve (9.5 mm).
- Slot 4: Material passing the 3/8 in. sieve (9.5 mm) but retained on the 1/4 in. sieve (6.3 mm).
- Slot 5: Material passing the 1/4 in. sieve (6.3 mm) but retained on the No.4 sieve (4.75 mm).

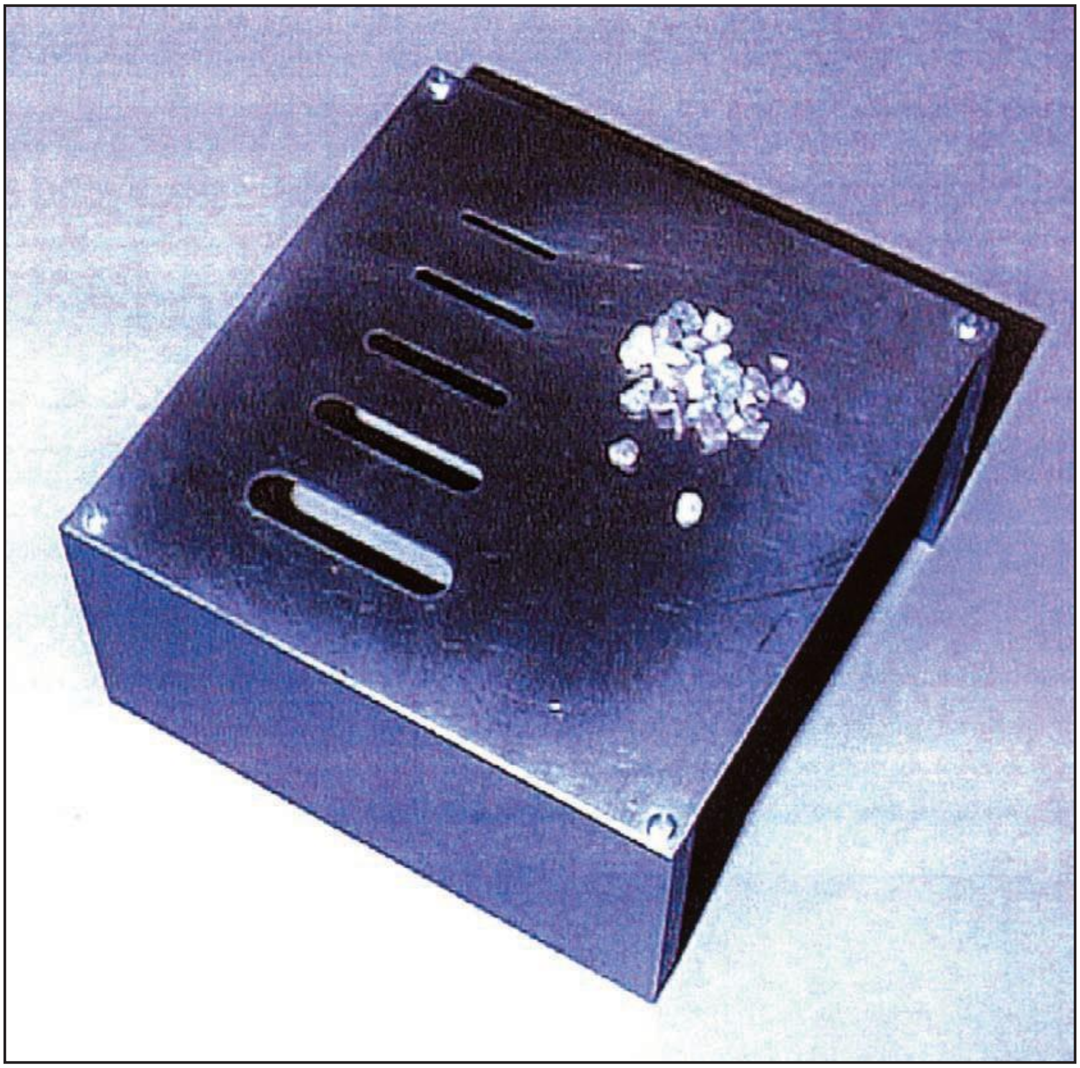

Figure 3.4.5. Flakiness Index Testing Plate

For most chip seal aggregate in Minnesota only the smallest three slots are used. This is because most chip seal projects do not use 1, 3/4 or 1/2-inch (25, 19 or 12.5 mm) stone. The weight of material passing all the slots is then divided by the total weight of the sample to give the percent flat particles, by weight, or Flakiness Index.

Average Least Dimension

The Average Least Dimension, or ALD (H), is determined from the Median Particle Size (M) and the Flakiness Index (FI). It is a reduction of the Median Particle Size after accounting for flat particles. It represents the expected chip seal thickness in the wheel paths where traffic forces the flat chips to lie on their flattest side.

The Average Least Dimension is calculated as follows:

$$H = \frac{M}{1.139285 + (0.011506)(FI)} \qquad (1)$$

Where:

H = Average Least Dimension, inches or mm
M = Median Particle Size, inches or mm
FI = Flakiness Index, in percent (i.e. 20 not 0.20)

Loose Unit Weight of the Cover Aggregate

The loose unit weight (W) is determined according to ASTM C 29 and is needed to calculate the voids in the aggregate in a loose condition. The loose unit weight is used to calculate the air voids expected between the chips after initial rolling is performed. It depends on the gradation, shape, and specific gravity of the aggregate. Well-graded aggregate and aggregate with a high dust content will have the highest loose unit weight because the particles pack together tightly leaving little room for air. This air space between the aggregate particles is the only space available to place the binder.

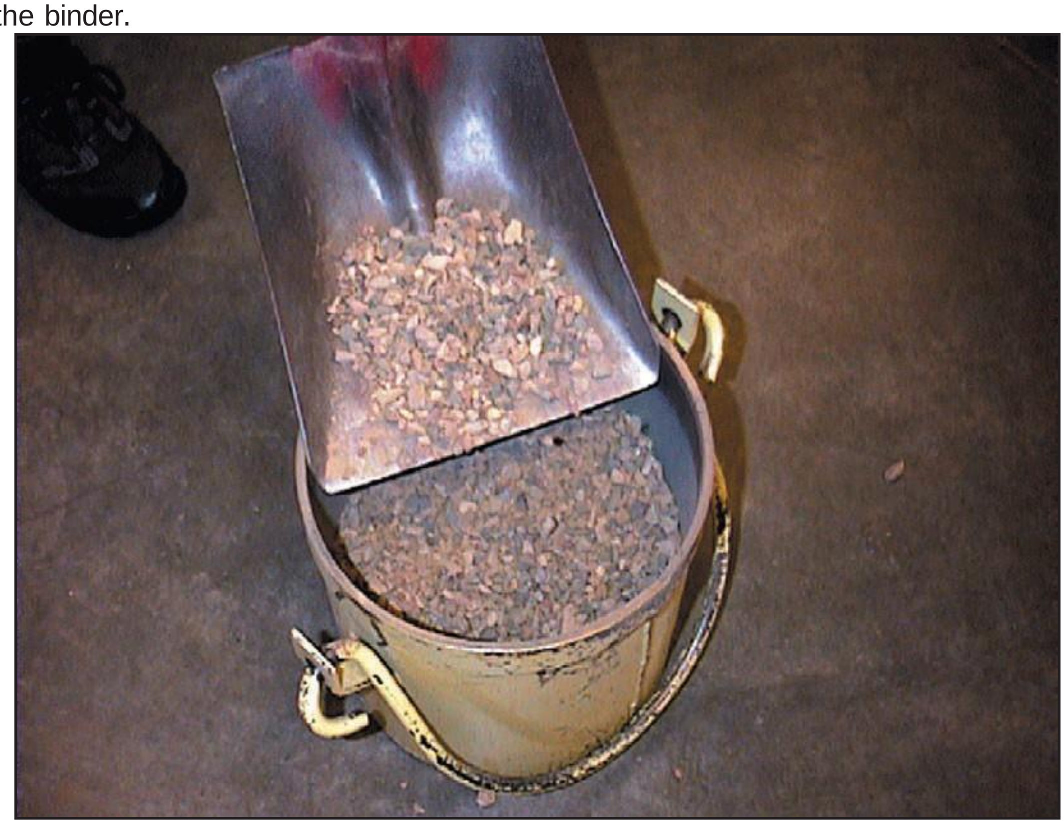

Figure 3.4.6. Loose Unit Weight Test

Voids in the Loose Aggregate

The voids in the loose aggregate (V) approximate the voids present when the chips are dropped from the spreader onto the pavement. Generally, this value will be close to 50 percent for one-size aggregate and less for graded aggregate. After initial rolling, the voids are assumed to be reduced to around 30 percent and eventually about 20 percent after sufficient traffic has oriented the stones on their flattest side. If the traffic volume is low, the voids will remain around 30 percent and the chip seal will require more binder to ensure good chip retention. The following equation (select for units desired) is used to calculate the voids in the loose aggregate:

U.S. Customary Units:

$$V = 1 - \frac{W}{62.4G} \qquad (2)$$

Where:

V = Voids in the Loose Aggregate, in percent expressed as a decimal
W = Loose Unit Weight of the Cover Aggregate, ASTM Method C 29, $lbs./ft^3$
G = Bulk Specific Gravity of the Aggregate

S.I. Metric Units:

$$V = 1 - \frac{W}{1000G} \qquad (3)$$

Where:

V = Voids in the Loose Aggregate, in percent expressed as a decimal
W = Loose Unit Weight of the Cover Aggregate, ASTM Method C 29, kg/m^3
G = Bulk Specific Gravity of the Aggregate

Bulk Specific Gravity

Different aggregates have different specific gravities or unit weights. This value must be accounted for in the design procedure because it will take more pounds of a heavy aggregate to cover a square yard of pavement than it will for a light aggregate. Table 3.2 can be used as a guideline for determining the specific gravity of typical chip seal aggregates in Minnesota.

Table 3.4.2. Typical Bulk Specific Gravity of Common Chip seal Aggregates in Minnesota

Aggregate type		**Class A**			**Class B**		**Class C**
		Granite	Quartzite	Trap Rock	Limestone	Red Rock	Pea Rock
Bulk Specific Gravity	Min.	2.60	2.59	2.95	2.40	2.50	2.55
	Max.	2.75	2.63	2.98	2.67	2.52	2.66
	Avg.	**2.68**	**2.62**	**2.97**	**2.61**	**2.51**	**2.62**

Aggregate Absorption

Most aggregates absorb some of the binder applied to the roadway. The design procedure must be able to correct for this condition to ensure enough binder will remain on the pavement surface. Table 3.3 can be used as a guideline. A good rule of thumb is that Class A aggregates generally do not require a correction for absorption, whereas Class B and C aggregates generally do. McLeod suggests an absorption correction factor, A, of 0.02 gal/yd^2 (0.09 L/m^2) if the aggregate absorption is around 1 percent. The author recommends using this correction if the absorption is 1.5 percent or higher.

Table 3.4.3. Typical Absorption of Common Chip seal Aggregates in Minnesota

Aggregate type		**Class A**			**Class B**		**Class C**
		Granite	Quartzite	Trap Rock	Limestone	Red Rock	Pea Rock
Percent Absorption	Min.	0.40	0.61	0.31	1.75	no data	1.14
	Max.	0.92	0.72	0.59	5.44	no data	2.32
	Avg.	**0.59**	**0.67**	**0.43**	**2.80**	**-**	**1.69**

Traffic Volume

The traffic volume on the pavement surface, in terms of the number of vehicles per day, plays a role in determining the amount of asphalt binder needed to sufficiently embed the chips. In general, the higher the traffic volume, the lower the binder application rate. At first glance this may not seem correct. However, remember that traffic forces the chips to lay on their flattest side. Consequently, the greater the traffic volume the greater the chance the chips will be laying on their flat side. If a roadway had no traffic, the chips would be laying in the same orientation as when they were first rolled during construction. As a result, they would stand taller and need more asphalt binder to achieve the desired 70 percent embedment. With enough traffic, the chips will be laying as flat as possible causing the chip seal to be as thin as possible. If this is not accounted for, the wheel paths will likely bleed. The McLeod design procedure uses Table 3.4 to estimate the required embedment, based on the number of vehicles per day on the roadway.

Table 3.4.4. Traffic Correction Factor, T

Traffic Factor *The percentage, expressed as a decimal, of the ultimate 20 percent void space in the cover aggregate to be filled with asphalt*				
Traffic - Vehicles per day				
under 100	*100 to 500*	*500 to 1000*	*1000 to 2000*	*Over 2000*
0.85	*0.75*	*0.70*	*0.65*	*0.60*

Note: *The factors above do not make allowance for absorption by the road surface or by absorptive cover aggregate.*

Traffic Whip-Off

The McLeod procedure also recognizes that some of the cover aggregate will get transported to the side of the roadway by passing vehicles as the chip seal cures. The degree to which this will occur is directly related to the speed and number of vehicles driving on the new chip seal. To account for this, a traffic whip-off factor (E) is included in the aggregate design equation. A reasonable value to assume is 5 percent. The traffic whip-off factor is shown in Table 3.5

Table 3.4.5. Aggregate Wastage Factor, E (Source: Asphalt Institute MS-19, March 1979)

Percentage Waste* Allowed For	Wastage Factor, E
1	1.01
2	1.02
3	1.03
4	1.04
5	1.05
6	1.06
7	1.07
8	1.08
9	1.09
10	1.10
11	1.11
12	1.12
13	1.13
14	1.14
15	1.15

*Due to traffic whip-off and handling

Existing Pavement Condition

The condition of the existing pavement plays a major role in the amount of binder required to obtain proper embedment. A new smooth pavement with low air voids will not absorb much of the binder applied to it. Conversely, a dry, porous, and pocked pavement surface can absorb a tremendous amount of the binder. Failure to recognize when to increase or decrease the binder application rate to account for the pavement condition can lead to excessive chip loss or bleeding. The McLeod procedure uses the descriptions and factors in Table 3.4.6 to add or reduce the amount of binder to apply in the field.

Table 3.4.6. Surface Correction Factor, S

Existing Pavement Texture	***Correction, S***	
	S.I. Metric (L/m²)	*U. S. Customary (gal/yd²)*
Black, flushed asphalt	*-0.04 to -0.27*	*-0.01 to -0.06*
Smooth, non-porous	*0.00*	*0.00*
Slightly porous & oxidized	*+0.14*	*+0.03*
Slightly pocked, porous & oxidized	*+0.27*	*+0.06*
Badly pocked, porous & oxidized	*+0.40*	*+0.09*

The inspector needs to be aware if the pavement surface conditions change within the project limits as adjustments in application rates of binder and cover aggregate may be required.

Most agencies chip seal roadways built during different years by different contractors with different materials as part of a single contract. Included may be new pavements, old pavements, porous pavements, flushed pavements, etc. For this reason, ***it is not practical to assume that all roadways to be chip sealed will need the same amount of asphalt binder.***

Examples of some of these pavement conditions are shown in Figures 3.4.7 to 3.4.10.

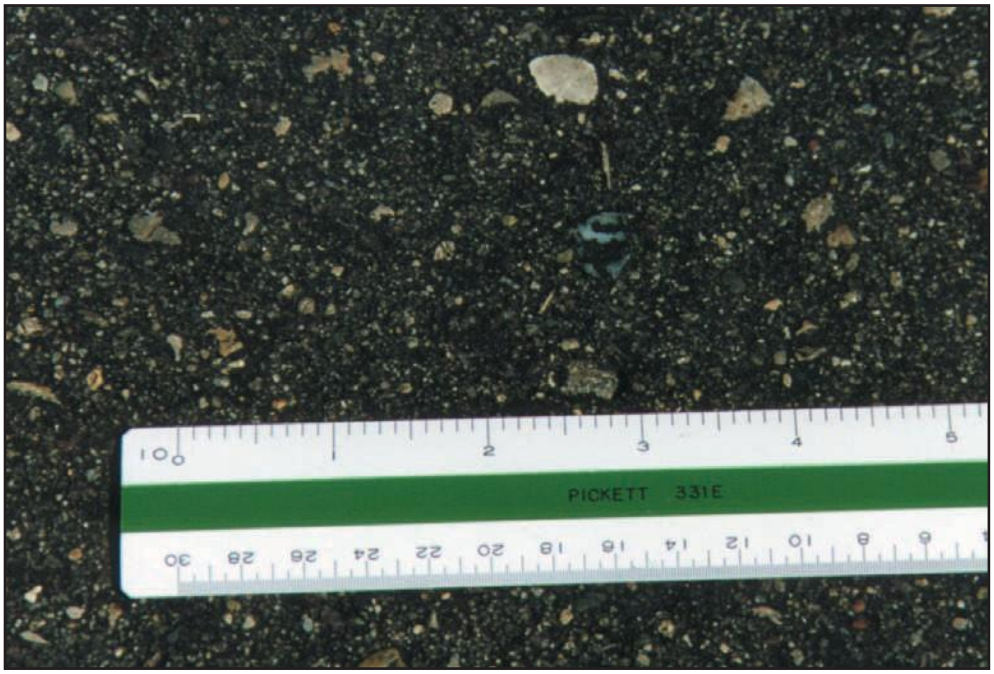

Figure 3.4.7. Example of a smooth, non-porous surface

Figure 3.4.8. Example of a slightly porous and oxidized surface

Figure 3.4.9. Example of a slightly pocked, porous, and oxidized surface

Figure 3.4.10. Example of a highly pocked, porous, and oxidized surface

McLEOD CHIP SEAL DESIGN EQUATIONS

Once all the lab tests have been completed, the following equations are then used to determine the aggregate and binder application rates. While the results may need to be adjusted in the field, especially the binder application rate, they have shown to provide a close approximation of the correct quantity of materials.

Aggregate Design Equation

The aggregate application rate is determined from the following equations:

U.S. Customary Units:

$$C = 46.8(1-0.4V)HGE \qquad (4)$$

Where:

C = Cover Aggregate Application Rate, lbs./yd^2
V = Voids in the Loose Aggregate, in percent expressed as a decimal (Equation 2)
H = Average Least Dimension, inches
G = Bulk Specific Gravity of the Aggregate
E = Wastage Factor for Traffic Whip-Off (Table 4.5)

S.I Metric Units:

$$C = (1-0.4V)HGE \qquad (5)$$

Where:

C = Cover Aggregate Application Rate, kg/m^2
V = Voids in the Loose Aggregate, in percent expressed as a decimal (Equation 3)
H = Average Least Dimension, mm
G = Bulk Specific Gravity of the Aggregate
E = Wastage Factor for Traffic Whip-Off (Table 3.5)

Binder Design Equation

U.S. Customary Units:

$$B = \frac{(2.244)(H)(T)(V) + S + A}{R} \qquad (6)$$

Where:

B = Binder Application Rate, gallons/yd^2
H = Average Least Dimension, inches
T = Traffic Factor (based on expected vehicles per day, Table 3.4)
V = Voids in Loose Aggregate, in decimal percent (Equation 2)
S = Surface Condition Factor, gal/yd^2 (based on existing surface, Table 3.6)
A = Aggregate Absorption Factor, gallons/yd^2
R = Residual Asphalt Content of Binder, in percent expressed as a decimal

S.I. Metric Units:

$$B = \frac{(0.40)(H)(T)(V) + S + A}{R} \qquad (7)$$

Where:

B = Binder Application Rate, liters/m^2
H = Average Least Dimension, mm
T = Traffic Factor (based on expected vehicles per day, Table 3.4)
V = Voids in Loose Aggregate, in decimal percent (Equation 3)
S = Surface Condition Factor, liters/m^2 (based on existing surface, Table 3.6)
A = Aggregate Absorption Factor, liters/m^2
R = Residual Asphalt Content of Binder, in percent expressed as a decimal

One additional calculation has been made to the McLeod design to account for snowplow damage. After the binder design equation is done using the ALD, it is recalculated using the Median Particle Size in place of the ALD. This will determine the binder required if none of the chips lay flat. The average of these two values is then used as the starting point for the field test sections discussed in Chapter 7 of this manual. It had been found that if this is not done, insufficient binder will exist in the non-traffic areas and snowplows will shave off the stones in these areas.

The following example is given to demonstrate how to use the design equations to determine binder and cover aggregate application rates.

CHIP SEAL DESIGN EXAMPLE

A 150-pound (68kg) sample of an FA-3 granite chip seal aggregate has been submitted for design. The traffic on the road to be sealed is 850 vehicles per day. The pavement surface is slightly pocked, porous, and oxidized. The binder will be a CRS-2 emulsion with 67% residual asphalt.

Step 1: Determine the aggregate gradation, bulk specific gravity, and percent absorption

Gradation results:

Sieve Name	Sieve Opening		Percent Passing
	U.S. Customary	**S.I. Metric**	
1/2 inch	0.50 in.	12.5 mm	100
3/8 inch	0.375 in.	9.5 mm	92
1/4 inch	0.25 in.	6.3 mm	85
No. 4	0.187 in.	4.75 mm	18
No. 8	0.0937 in.	2.36 mm	6
No. 16	0.0469 in.	1.18 mm	3
No. 50	0.0117 in.	300 µm	1
No. 200	0.0029 in.	75 µm	0.4

- Based on AASHTO T 84-94 the bulk specific gravity of was determined to be 2.71.
- Based on AASHTO T 84-94 the aggregate absorption was determined to be 0.3 percent.

Step 2. Determine the Median Particle Size

The gradation results in the table above are then plotted on a gradation chart. The Median Particle Size is determined by extending a horizontal line at 50 percent passing mark until it intersects the gradation curve. A vertical line is then projected downward which gives the Median Particle Size. This is the theoretical size where half of the stones are larger and half smaller. It is considered theoretical because there may not be any stones of that size present.

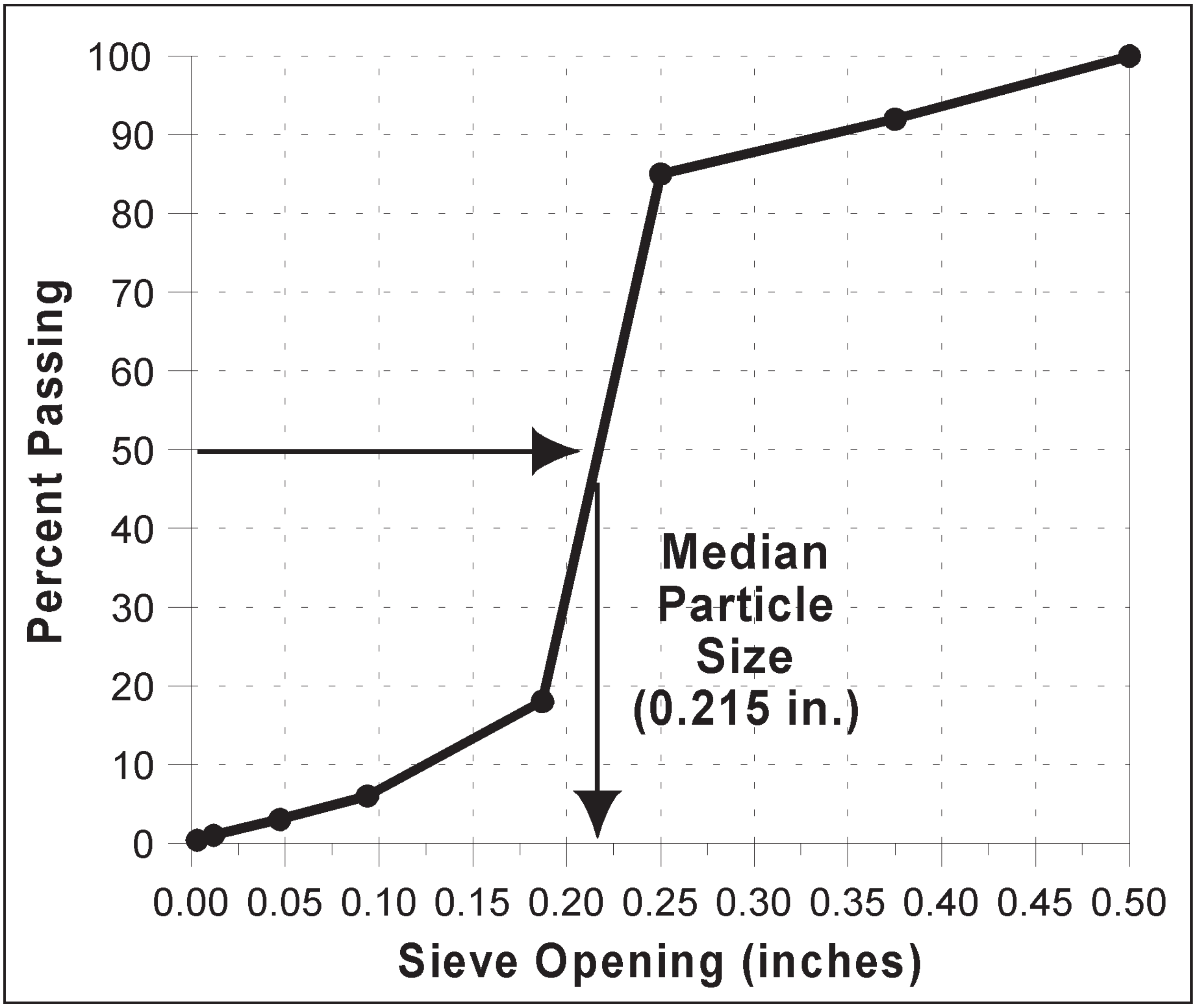

Figure 3.4.11 Gradation Chart for the Design Example showing the Median Particle Size

Step 3. Determine the Flakiness Index (FI)

The aggregate used to determine the gradation is then broken down into the following fractions:

(1) Passing the 1 in. sieve but retained on the 3/4 in. sieve
(2) Passing the 3/4 in. sieve but retained on the 1/2 in. sieve
(3) Passing the 1/2 in. sieve but retained on the 3/8 in. sieve
(4) Passing the 3/8 in. sieve but retained on the 1/4 in. sieve and
(5) Passing the 1/4 in. sieve but retained on the No. 4 sieve.

Since all of the material passed the 1/2 in. sieve, only the last three fractions are used. The aggregate particles in each fraction are tested to see if they fit through the slotted plate (Figure 3.4.5). The results are shown in the following table, “Flakiness Index Test Results”.

Flakiness Index Test Results

Size Fraction	Weight Retained on Slot (grams)	Weight Passing Slot (grams)
1/2 to 3/8 in.	54.2	12.3
3/8 to 1/4 in.	123.3	43.5
1/4 in. to No.4	184.4	89.5
Totals	**361.90**	**145.3**

The Flakiness Index is calculated as follows:

$$FI = \frac{\textit{(Weight of Flat Chips)}}{\textit{(Weight of Sample)}} = \frac{(145.3)}{(361.90 + 145.3)} = \frac{(145.3)}{(507.2)} = 28.6 \text{ percent} \qquad (8)$$

Step 4. Determine the Average Least Dimension (H)

The Average Least Dimension, or ALD, is the expected thickness of the chip seal in the wheel paths after any flat chips have been oriented on their flattest side by traffic. It is calculated from the Median Particle Size (M) and the Flakiness Index (FI) as follows:

U.S. Customary Units:

$$H = \frac{M}{1.139285 + (0.011506)(FI)} = \frac{0.215 \text{ in.}}{1.139285 + (0.011506)(28.6)} = 0.146 \text{ inches} \qquad (9)$$

S.I. Metric Units:

$$H = \frac{M}{1.139285 + (0.011506)(FI)} = \frac{5.50 \text{ mm}}{1.139285 + (0.011506)(28.6)} = 3.75 \text{ mm} \qquad (10)$$

Step 5. Determine the Loose Weight of the Aggregate (W)

A metal cylinder with the volume of 0.50 ft^3 ($0.014m^3$) was loosely filled with aggregate (as shown in Figure 3.4.6) until full. The weight of the aggregate was then determined. This was repeated three times with results shown in the following table. The average of the three is then used to determine the Loose Unit Weight of the aggregate.

Loose Weight Test Results

Test Number	Weight of the Aggregate in the Cylinder (lbs.)	Weight of the Aggregate in the Cylinder (kg)
1	45.25	20.57
2	45.32	20.60
3	45.29	20.59
Average	**45.29**	**20.59**

The Loose Unit Weight (W) is calculated as follows:

U.S. Customary Units:

$$W = \frac{\textit{Weight of aggregate}}{\textit{Volume of cylinder}} = \frac{45.29 \text{ lbs.}}{0.50 \text{ ft}^3} = 90.58 \text{ lbs./ft}^3 \qquad (11)$$

S.I. Metric Units:

$$W = \frac{\textit{Weight of aggregate}}{\textit{Volume of cylinder}} = \frac{20.59 \text{ kg}}{0.014 \text{ m}^3} = 1{,}471 \text{ kg/m}^3 \qquad (12)$$

Step 6. Determine the Voids in the Loose Aggregate (V)

Using Equations 13 and 14, the voids in the loose aggregate are calculated. The higher the voids, the more room for the asphalt binder and the more one-size the aggregate is.

U.S. Customary Units:

$$V = 1 - \frac{W}{62.4G} = 1 - \frac{90.58 \text{ lbs./ft}^3}{(62.4)(2.71)} = 0.46 \qquad (13)$$

S.I. Metric Units:

$$V = 1 - \frac{W}{1000G} = 1 - \frac{1{,}471 \text{ kg/m}^3}{(1000)(2.71)} = 0.46 \qquad (14)$$

Since 0.46 is fairly close to 0.50, this is a fairly one-size aggregate.

Summarizing the above information:

Test	U.S. Customary Units	S.I. Metric Units
Median Particle Size	0.215 inches	5.50 mm
Flakiness Index	28.6 percent	28.6 percent
Average Least Dimension	0.146 inches	3.75 mm
Loose Unit Weight	90.58 lbs./ft^3	1,470 kg/m^3
Voids in the Loose Aggregate	0.46	0.46
Traffic Volume	500 - 1000 vehicles/day Uses 5% whip-off	500 - 1000 vehicles/day Uses 5% whip-off
Surface Condition	Slightly pocked, porous and oxidized	Slightly pocked, porous and oxidized
Bulk Specific Gravity	2.71	2.71
Aggregate Absorption	0.31 percent No adjustment needed	0.31 percent No adjustment needed
Residual Asphalt Content of the Binder	0.67	0.67

Cover Aggregate Application Rate

U.S. Customary Units:

$$C = 46.8\,(1-(0.4)(V))(H)(G)(E) = 46.8(1-(0.4)(0.46))(0.146\text{ in.})(2.71)(1.05) = 15.8\text{ lbs/yd}^2 \qquad (15)$$

Where:

C = Cover Aggregate Application Rate, lbs./yd^2
V = Voids in the Loose Aggregate, in percent expressed as a decimal
H = Average Least Dimension, inches
G = Bulk Specific Gravity of the Aggregate
E = Wastage Factor for Traffic Whip-Off (Table 4.5)

S.I. Metric Units:

$$C = (1-(0.4)(V))(H)(G)(E) = (1-(0.4)(0.46))(3.75\text{ mm})(2.71)(1.05) = 8.7\text{ kg/m}^2 \qquad (16)$$

Where:

C = Cover Aggregate Application Rate, kg/m^2
V = Voids in the Loose Aggregate, in percent expressed as a decimal
H = Average Least Dimension, mm
G = Bulk Specific Gravity of the Aggregate
E = Wastage Factor for Traffic Whip-Off (Table 4.5)

The recommended results should be rounded up to the nearest pound or kilogram. Once the aggregate application rate has been determined it is a good idea to test it. This is done by spreading the recommended amount of aggregate in a one square yard (or one square meter) plywood box. The aggregate should provide a one-stone thick layer. This will provide a good representation of how the chip seal should look in the field.

Binder Design Equation

The binder application rate is determined from the following equations:

U.S. Customary Units:

$$B = \frac{(2.244)(H)(T)(V) + S + A}{R} \tag{17}$$

Where:

B = Binder Application Rate, gallons/yd^2
H = Average Least Dimension, inches
T = Traffic Factor (based on expected vehicles per day, Table 4.4) V
= Voids in Loose Aggregate, in decimal percent (Equation 2)
S = Surface Condition Factor, gallons/yd^2 (based on existing surface, Table 4.6)
A = Aggregate Absorption Factor, gallons/yd^2
R = Residual Asphalt Content of Binder, in decimal percent

Binder Application Rate for Wheel paths:

$$B = \frac{(2.244)(0.146\text{ in.})(0.70)(0.46) + 0.06 + 0.00}{0.67} = 0.25\text{ gal/yd}^2 \tag{18}$$

This application rate should provide proper embedment of the chips once they have laid on their flattest side. In Minnesota, it is recommended that the binder application rate for non-traffic areas also be calculated and the average of the two be used as the starting point in the field. This is done by substituting the Median Particle Size for the Average Least Dimension.

Binder Application Rate for non-wheel paths areas:

$$B = \frac{(2.244)(0.215\text{ in.})(0.70)(0.46) + 0.06 + 0.00}{0.67} = 0.32\text{ gal/yd}^2 \tag{19}$$

Take the average of the two as the starting point in the field:

$$\textit{Starting Application Rate in the Field} = \frac{0.25 + 0.32}{2} = 0.29\text{ gal/yd}^2 \tag{20}$$

S.I. metric Units:

$$B = \frac{(0.40)(H)(T)(V) + S + A}{R} \quad (21)$$

Where:
B = Binder Application Rate, liters/m^2
H = Average Least Dimension, mm
T = Traffic Factor (based on expected vehicles per day, Table 3.4)
V = Voids in Loose Aggregate, in decimal percent (Equation 3)
S = Surface Condition Factor, liters/m^2 (based on existing surface, Table 3.6)
A = Aggregate Absorption Factor, liters/m^2
R = Residual Asphalt Content of Binder, in decimal percent

Application rate for wheel paths:

$$B = \frac{(0.40)(3.75\ mm)(0.70)(0.46) + 0.27\ L/m^2 + 0.00}{0.67} = 1.12\ L/m^2 \quad (22)$$

The binder application rate in the non-traffic areas is:

$$B = \frac{(0.40)(5.50\ mm)(0.70)(0.46) + 0.27\ L/m^2 + 0.00}{0.67} = 1.46\ L/m^2 \quad (23)$$

Once again, take the average as a starting point in the field:

$$\textit{Starting Application Rate in the Field} = \frac{1.12 + 1.46}{2} = 1.29\ L/m^2 \quad (24)$$

SUMMARY

In summary, a good chip seal design incorporates many characteristic factors of the binder and aggregate. The results should yield a good starting point for field test sections. Since the binder application rate makes assumptions concerning the amount of texture and porosity of the existing pavement, the binder application rate will almost always need to be adjusted in the field. Most of the time it will need to be adjusted upward (apply more binder). The more single-sized aggregate used, the higher the tendency of a chip seal design to overestimate the amount of aggregate needed. In this case, the cover application rate may need to be adjusted in the field.

A good tool to use in the field is a binder adjustment chart. This type of chart calculates the design application rate for all combinations of traffic (Table 3.4.4) and surface condition (Table 3.4.6). It can be used by the inspector to make adjustments in the field. Figure 3.4.12 shows the binder adjustment chart for the above example.

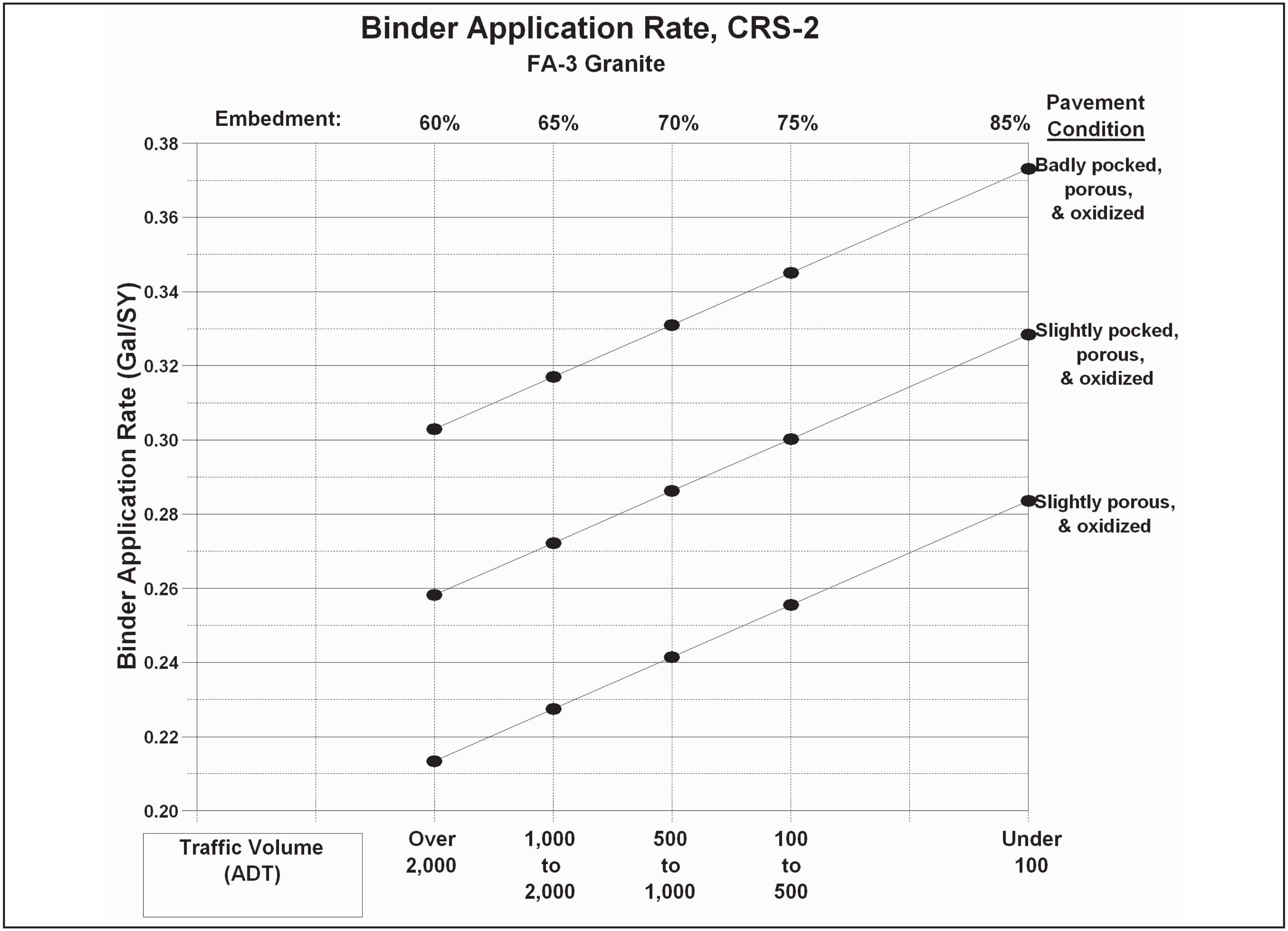

Figure 3.4.12. Example of a Binder Adjustment Chart

3.5 FOG SEALING A CHIP SEAL

Fog sealing is a method that is used to lock in chips by placing a light application of a diluted asphalt emulsion over a chip seal. It is commonly done to ensure reduction of stone loss and to add life to the pavement by increasing a pavement's impermeability to water and air.

Fog seals may be applied to an existing pavement as a means of rejuvenation or to a new chip seal application to reduce stone loss and increase pavement life. In any application, the fog seal material (emulsion) must be of sufficiently low viscosity to penetrate the voids. The most common type of fog seal emulsions used in Minnesota is CSS-1hd. However, other fast setting emulsions such as CQS-1hD50 are also being used.

SURFACE PREPARATION AND SITE CONDITIONS

Fog sealing should only be done on a clean, dry pavement surface. As part of a new chip seal application, it is applied immediately after sweeping. To be effective, fog seals need to break quickly (revert to solid asphalt) and cure completely (lose water to form a cohesive film). Asphalt films do not form well at low temperatures. Therefore, warm conditions with little to no chance of rain are necessary to ensure successful applications.

FOG SEAL APPLICATION

When applying a fog seal, properly calibrated distribution trucks are critical. Spray nozzles should be adjusted based on the manufacturer's recommendation to ensure proper application. MnDOT specification 2355 Bituminous Fog Seal requires fog sealing to be performed only during daylight hours and not during foggy conditions. It further requires the pavement and air temperature to be 60° F and rising. The fog seal may be applied to a damp pavement surface, but not if standing water is present.


Figure 3.5.1. Fog sealing after chip sealing

If unexpected rain occurs, prior to the emulsion breaking, the emulsion may wash out of the pores of the pavement and break on the surface of the pavement resulting in a slippery surface causing a traffic safety concern.

MnDOT specification 2356 Bituminous Seal Coat and Bituminous Underseal calls for fog sealing all chip seal applications as a matter of course, with the exception of residential streets. The standard application method is to lap the centerline in both directions. For example, if the travel lanes are 12-feet wide, then the fog seal should be applied to a 13-foot swath of roadway in both directions, lapping over the centerline. What this accomplishes is the maximum placement of embedment on the area of the roadway receiving the least amount of traffic. In Minnesota, this is especially critical as it ensures protection of the chip seal during the winter months from the impact of snow removal equipment. In one test of fog sealing applied under these specifications, it was found that the fog-sealed roadway suffered no snowplow damage while the non-fog-sealed segment suffered close to a 15-percent loss of chips along the centerline.

APPLICATION RATE

The normal application rate is from 0.06 to 0.12 gallons per square yard of diluted CSS-1h emulsion (depending on the size 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 to one part water (1:1) be done at the place of the emulsion manufacture. **Field dilution is not allowed.**

THE BENEFITS OF FOG SEALING

There are numerous benefits resulting from a fog seal application.

1. The traveling public believes they are driving on a new HMA surface rather than a chip seal.
2. The emulsion is diluted, which yields a very low viscosity that allows most, if not all, of the additional asphalt binder to fill the chip voids increasing embedment by up to 15-percent with no bleeding.
3. The fog seal re-coats and adheres any chips that may have partially broken loose during sweeping operations.
4. Darkening the pavement surface with a light application of asphalt emulsion allows the pavement surface temperature to rise. The subsequent softening of the binder allows the chips to orient to their least dimension more quickly. This factor is very important in Minnesota where late season chip seal projects are more susceptible to failure due to colder weather conditions.
5. Fog sealing can provide a designer with a chance for a “re-do” of a chip seal application. If, after traffic has driven on the surface, it appears that embedment is low, an engineer can add additional binder to the chip seal by increasing the fog seal application rate. In some cases, the amount of fog seal emulsion applied increased to over 0.20 gallon per square yard.
6. When a fog seal is applied, a reduced amount of paint is necessary to make pavement markings visible on the surface.

3.6. CHIP SEALING FOR RECREATIONAL TRAILS

Because of the unique ways in which recreational trails are used and maintained, designing, and applying a chip seal requires a slight modification of practices over sealing a road or street. Ensuring a smooth and even pavement surface is critical on a recreational trail. For this reason, a material with an FA-1 aggregate gradation is recommended. A fine-graded aggregate material will distribute more evenly throughout the binder, resulting in a longer-lasting and smoother wear course.

CHIP SEAL APPLICATION FOR RECREATIONAL TRAILS

Practice when chip sealing recreational trails is to apply slightly higher applications of binder and aggregate than is typical for roadway pavements. Historically, when chip sealing recreational trails, 0.23 to 0.26 gallons per square yard of asphalt binder followed by 18 – 20 pounds of FA-1 graded aggregate per square yard has been applied. The combination of a thicker asphalt binder with a heavier application of fine-graded aggregate results in a chip seal with more evenly distributed aggregate throughout the binder material. What this means is that, as the chip seal wears down over time, the surface will remain relatively smooth with an even distribution of aggregate throughout.

Figure 3.6.1. Chip sealing of recreational trail

SURFACE TREATMENT

The best possible scenario when smoothing out a freshly applied chip seal on a recreational trail is to use a rubber-tire roller in addition to a double-drum steel roller. The steel roller will ensure that the aggregate is well-compacted and firmly set in the asphalt binder. By following this with a rubber-tire roller, a smoother surface will be ensured.

BEST PRACTICES FOR RECREATIONAL TRAIL CHIP SEALING

Recreational trail pavements are not designed and built to handle heavily loaded construction equipment. For this reason, chip seals should only be applied to these pavements during that time of the year when the trail is most structurally sound. In Minnesota, this would be during the high summer months of July and August. Since this also corresponds to the times when the trail will be most heavily used, good communication with advance notice of the planned application is critical. This would include signage along the trail alerting users to dates and times of application as well as other means of notification, such as information distributed through the agency that manages the trail.

As with roads and streets sweeping of chip seals applied on recreational trails should occur as soon as possible but no more than 24 hours after application. A kicker broom may be used to sweep excess aggregate to the side of the trail in relatively rural areas where acceptable. In parks and urban areas, a pick-up broom should be used to pick up the excess rock.

If a fine-graded, FA-1 aggregate has been used, a fog seal application should not be necessary on recreational trails. The use of the heavier binder and fine-graded aggregate will accomplish what a fog seal is intended to do; namely, to ensure good aggregate embedment and a smooth surface wear course.

BENEFITS OF RECREATIONAL TRAIL CHIP SEALING

By managing recreational trails with a regular program of chip seal applications, the life of the trail will be extended while providing for a better recreational experience for trail users. Just as roads and streets need to receive regular maintenance to extend their pavement life, so do recreational trails. Unfortunately, some trails have degraded to the extent that they are no longer good candidates for a chip seal application. If a trail is severely block cracked and/or suffers from severe pavement deformation, then it is not a good candidate for a chip seal and will likely need to be reconstructed. However, if an asphalt-paved recreational trail has a reasonably smooth and uniform surface but needs some surface rehabilitation, then a chip seal can help to extend its life at a very reasonable cost. Recreational trails can be re-sealed every six to seven years, like best practices for road and street sealing. By thinking proactively about maintaining recreational trails, road designers and engineers can more effectively manage the trail infrastructure in their community. Chip seal applications are a relatively low-cost and cost- effective method for recreational trail pavement preservation.

3.7 FIELD INSPECTOR RESPONSIBILITIES

Inspecting chip seal projects is an area unfamiliar to many individuals. As with any other type of construction, the inspector must be familiar with the process and know what to look for to achieve quality results. A knowledgeable field inspector is key to a successful chip seal project. The field inspector needs to observe calibration of the equipment, determine if enough material (emulsion and cover aggregate) is being applied to the roadway, and recognize and correct any problems that arise. The field inspector sets the quality standards for the project. In recognition of this, the Federal Highway Administration developed the Chip Seal Checklist (13) to assist field inspectors.

PRECONSTRUCTION MEETING

Once the project has been bid and awarded or the public works department has completed required field preparations, a preconstruction meeting is scheduled, normally, a week prior to construction. The purpose of the meeting is to review the project parameters, timeline, and establish quality expectations. Attendees should include:

- Engineer/Public Works Director representing the owner.
- Field inspector, representing the owner.
- The designated person representing the contractor.
- Field supervisor (who should not double as a member of the crew doing the work and have authority to make field decisions).

- A recording secretary to take minutes of the meeting.

What occurs at the preconstruction meeting?

The Owner's Engineer/Public Works Director

- Verifies the contract documents are in order and approval to proceed is given.
- Discusses the method of payment, contract approval process, and a general overview of the project.
- Reviews/approves subcontractor(s) if any, and materials to be used on the project.
- Determine responsibility for public notification of chip sealing activities. Which may include no parking signage within the project limits during construction.

The Field Inspector

- Distributes maps of the area(s) to be chip sealed.
- Points out roads not to be chip sealed as a part of the project (county roads, state roads, new city roads, roads under construction, etc.).
- Describes the work and reviews the contractor's responsibilities.
- Discusses bituminous material and application rates (ranges).
- Discusses aggregate materials and application rates (ranges).
- Approves equipment scheduled for the project and indicates areas where overnight parking is allowed.
- Discusses pre-sweeping and pick-up sweeping requirements, including a schedule.
- Reviews protection of existing structures and preferred method to cover manholes, gate valves, etc.
- Discusses daily commencement of work parameters.

The field inspector also inspects and approves the material to be used, determines sites to stockpile the aggregate, and location(s) for the binder transports to park during the operation prior to commencement of the project.

Operation Field Supervisor

- Reviews anticipated starting date and normal hours.
- Discusses completion date of the chip seal portion of the project and pick-up sweeping process.
- Reviews material delivery schedules.

A TYPICAL CHIP SEAL PROJECT

While not every chip seal project is the same, there are many things that will be repeated from project to project. The field inspector must be familiar with these items and pay close attention to them for the project to proceed smoothly. The following section will give the field inspector a good overview of what typically occurs during a chip seal project and the role they play.

Day One Activities

Review the Project

Prior to beginning the work, the inspector should drive the first few roads to be chip sealed to ensure they are clean, dry, and free of obstructions, verify that appropriate traffic control is in place and that structures in the road are properly covered or protected. The inspector should also inspect and calibrate all equipment for proper operation, check for leaks, proper tire pressure on rollers, binder temperature in distributors, and ensure that all needed equipment is on the site.

Once this has been done, the equipment has been calibrated and the binder application rate adjusted for the actual field conditions, the project can proceed full speed ahead. The first day of the operation requires the field inspector's full attention and time to set the expected quality standards with the field supervisor.

Pretreat Pavement Markings

To improve chip seal performance, existing pavement markings are pretreated just ahead of the chip seal operations (Fig. 3.7.1).

Fig. 3.7.1. Pretreatment of pavement markings prior to chip seal (MnDOT - Paul Nolan)

Equipment Calibrations for Proper Application Rates

Calibrate the distributor(s) and the chip spreader, notifying the field supervisor of any adjustments to application rates. Verification of these rates is performed shall occur frequently throughout the first day of operation.

The field inspector checks yields on binder and aggregate and discusses procedures with the field supervisor to establish the desired quality standards. The first day will set the expectations of both the field inspector and field supervisor for the balance of the project.

Calibrate the Chip Spreader

When the chip seal crew is assembled, the first task performed by the inspector is to calibrate the chip spreader. Calibrating the spreader will ensure that all the gates across the front of the spreader are applying the same amount of the aggregate, ensuring uniform coverage. Also, the calibration procedure will determine the number of pounds required to apply a single layer (one stone thick) of aggregate. Refer to Chapter 8 of this handbook for more details on calibration.

Another important reason to calibrate the spreader is to ensure the amount of aggregate being placed remains within specified payment and design standards.

Lastly, the spreader needs to be calibrated before the binder application rate can be evaluated. If the cover aggregate is applied heavily (i.e. more than one layer), it will be difficult to determine if the correct amount of binder is being applied. The inspector must sweep off all the excess aggregate before he/she can determine how much embedment is being achieved.

Figure 3.7.2. Too much aggregate (no binder is visible)

Determine the Proper Binder Application Rate

Because certain assumptions are made in the chip seal design process, the actual binder application rate must be verified in the field. Once the chip spreader is calibrated so that it is applying a single uniform layer of aggregate, the binder application rate is determined.

If the existing pavement surface is oxidized, porous and/or has lots of texture caused by raveling or pop outs it will require more asphalt binder. This is because some of the binder will be absorbed into the pavement and not be available for bonding to the cover aggregate. In some cases, this can be quite extreme. Increases in the binder application rate due to the existing surface conditions can add as much as 60 percent. Failure to recognize this fact can lead to the loss of aggregate in as little as one year. In order for the chip seal to be successful, the inspector must be able to determine if the proper embedment has been achieved.

This is done by the following:

- Spray approximately 200 feet of one lane of pavement at the design application rate.
- Check each distributor application rate by measuring the amount at 1000 feet and comparing the gallons applied by the distributor float gauge with the read out on the computer.
- Apply a single layer of cover aggregate from the calibrated chip spreader.
- Inspect the height of the binder in relation to the height of the chips in the wheel paths of the chip spreader. The binder should rise almost to the top of the chips to ensure proper embedment after the binder cures.
- Adjust the binder application rate as necessary, generally in 0.02 gal/yd^2 (0.09 L/m^2) increments up or down.
- Repeat until the application rate being applied is yielding the proper embedment. See Figure 3.7.4.
- Record the setting on the distributor's computer for comparison with the actual application rate later that day.

Figure 3.7.3. Not enough binder (binder is too low)

Figure 3.7.4. Correct amount of binder (binder has risen to top of chips)

Figure 3.7.5. Darker wheel paths indicate binder has risen near the top of the aggregate

Day Two through Completion

The days following should allow the inspector to monitor, inspect, and observe the operation with minimal procedural adjustments needed. The field inspector spends the majority of his/her time walking behind and ahead of the operation checking for the following:

- Making decisions on application rate adjustments.
- Ensuring full width application of chip seal.
- Requiring touch up of uncovered binder before rolling.
- Ensuring structures in the road are being protected and promptly cleaned after final rolling.
- Making sure the distributor is not applying binder too far ahead of the chip spreader (if binder starts to turn black, before the chips are applied, the distributor is too far ahead).
- Ensuring the roller operation occurs immediately behind the chip spreader.
- Making sure the traffic control devices are keeping up with the project.

Generally, the inspector will be observing and inspecting the operation from the binder application to the final rolling to ensure the product meets the desired results. At the end of each day the inspector tours the areas sealed and looks for bleeding problems, excess aggregate or float, and how well the curing process is working. Any concerns or problems noticed should be brought to the attention of the field supervisor and corrections made as needed.

The field inspector should keep a daily dairy of the project's progress, quantities of aggregate and binder placed, weather conditions, any problems that occurred, and the performance of the equipment and operators. The inspector and field supervisor should agree on pay item quantities and calculate yields daily to minimize overruns and avoid disagreements at closing of the project.

The Last Day

On the last day of the chip seal project, the owner's field inspector and the field supervisor should do the following:

- Agree on total pay quantities for the project in writing.
- Remove excess binder or aggregate for the site or agree on the schedule to do so.
- Review the daily diary of the project and discuss methods or ways to improve the operation for future projects.
- Clean up the sites used to store the equipment or stockpile materials.

Helpful Guidelines for the Field Inspector

Appearance Checks by Field Inspector

- To determine if your application rates are appropriate to the road surface condition, try a wave test.

  1. Allow sealed area to cure for at least an hour or until aggregate is totally dry and dusty.

  2. Place your hand on the road with fingers spread and in a rapid waving motion lightly brush any loose chips until you see the remaining aggregate that stuck into the binder.

  3. Visibly check to see if the aggregate is uniformly covering the binder, compacted into

the binder consistently, and there is adequate aggregate coverage.

4. You will be able to judge if you need to adjust application rates up or down using this procedure.

- Excessive aggregate or float after an hour of curing takes place indicates the application rates should be reduced to the point where you are getting single layer coverage and minimal excess float remaining.

- Binder bleeding out the aggregate consistently after rolling indicates you should *reduce the application rate of binder rather than increase the application rate of the aggregate.*

- If after doing a wave test, you see that rock chips are not staying in place, you should increase the binder application rate.

- Bluish colored smoke from the binder as it is applied means binder is too hot - check temperature gauge on distributor and allow to cool to specified temperature before proceeding.

- Streaking or binder lines appearing prior to initial rolling of the aggregate means that the height of the distributor bar is too high or too low and operator should adjust accordingly. See Chapter 8 for details.

- The binder will be brown in color at application and will turn black as it breaks or cures.

- The cover aggregate must be applied prior to the binder breaking to ensure proper bond occurs between the aggregate and the road surface.

- On a hot, low-humidity day the binder will break in 3 to 5 minutes. The chips should be rolled with the rubber-tire roller before this happens.

- A strong indication of the success of a chip seal application can be observed by touring the project in the spring after a winter of snow plowing and freeze-thaw cycles.

Weather Problems

The field inspector and the supervisor should agree daily if weather conditions are conductive for chip sealing. Threatening weather conditions often result in a wait and see posture. If rainfall occurs, no chip sealing should take place until there is no standing water (a damp surface is ok) and the road surface is clean (re-sweeping with a pick-up sweeper may be required prior to resuming project).

- If an unexpected rainfall occurs, discontinue chip sealing immediately - inspect areas sealed that have not yet cured for puddles of brownish colored water bleeding out of chips. Blotting with 1/8-inch minus (3.2 mm -) rock of the same type as the chip seal usually will save the chip seal and heal it satisfactorily. Another option for blotting up the diluted asphalt emulsion would be clean washed sand or natural pit run gravel. However, either of these options could result in an aesthetically unacceptable appearance because of contrasting colors in the aggregate.

- If the rain is severe enough that blotting does not heal it, you may have to re-seal over the top of the failed areas with a small aggregate (1/8-inch minus, 3.2 mm -) aggregate of the same type as the chip seal once it is totally dry. Binder application rates vary from 0.10 - 0.20 gallons per yard, depending of severity.

Miscellaneous

- Placing traffic cones over lawn sprinkler heads helps prevent roads from getting wet if sprinklers cannot be turned off.

- Attention to dirt and debris on the road is required throughout the project. It is not uncommon to re-sweep ahead of the operation daily. A clean and dry road is critical to the success of the chip seal.
- Maintaining close proximity of the asphalt distributor, the chip spreader and the rollers are vital to the lasting adherence of the chip seal to the road surface.

Sweeping

Pick-up sweeping should occur as soon as possible after application of the chip seal and no later than the next morning. The field inspector should inspect the equipment for leaks. Fuel or hydraulic leaks will destroy the bond between the chip seal and the pavement surface. Leaky sweepers or trucks should not be allowed on the project until they are repaired or replaced.

The sweeping operation includes the following:

- A location to stockpile sweepings.
- Full width sweeping attaining at least 85% pick-up of loose chips.
- Minimizing turning movements of sweepers and trucks at low speeds to avoid damage to chip seal.

The field inspector should do a windshield inspection behind the sweeping operation to ensure the following:

- That all roads sealed are swept.
- To note defects in the chip seal surface requiring attention by the contractor.
- To check to see that all utility structures are uncovered.
- To monitor the progress and quality of the sweeping operation.

SUMMARY

The field inspector is key to the success of a chip seal project. The inspector's role as an overseer ensures specifications are being adhered to and quality standards are met. The inspector's work aids the contractor or public workforce in the production and coordination of the project to produce an acceptable final product as economically as possible while minimizing inconvenience to the public. Chip seal field inspection requires full-time attention and hands-on involvement to accomplish the desired quality of the finished product and provide continued reliable service of the road system.

FIELD INSPECTOR'S CHECKLIST

1. Preconstruction Meeting

Date________________ Location______________________________________

Contractor/Public Workforce ______________________________________

Project Supervisor ______________________________________

Phone ______________________________________

Subcontractors/Material Supplies

Aggregate______________________________________

Binder______________________________________

Subcontractors ______________________________________

Project Schedule

Material Delivery ______________________________________

Starting Date ______________________________________

Estimated Completion Date ______________________________________

Review provisions of contract specifications such as:

- ☐ Distribute maps of roads to be sealed.
- ☐ Indicate locations to stockpile aggregate, park equipment and locate delivery transports.
- ☐ Discuss traffic control requirements.
- ☐ Review preferred method of covering structures in the roadway.
- ☐ Discuss specific procedures for sealing radii, cul-de-sacs, sweeping operations, etc.

1. DAY ONE ACTIVITIES

- ☐ Check Road conditions .... Yes____ No_____

  Comment: ____

- ☐ Traffic control in place: .... Yes____ No_____

- ☐ Structures protected: .... Yes____ No_____

- ☐ Appropriate equipment/operators on site: .... Yes____ No_____

  Comment: ____

- ☐ Calibrate distributor: .... Yes____ No_____

  Comment: ____

- ☐ Calibrate chip separator: .... Yes____ No_____

  Comment: ____

- ☐ Record settings of distributor and spreader after calibration:

  Spreader____

  Distributor ____

- ☐ Monitor and check yields of aggregate and binder throughout the day and adjust rates accordingly.

3. PROJECT DIARY

Field Inspector should record the following information on a daily basis:

- ☐ Weather conditions: Temperature ____________________
  Humidity ____________________

- ☐ Update map showing roads that have been chip sealed.

- ☐ Binder quantity placed____________________gallons.

- ☐ Note binder left in distributors (if any) for next day's operation.

- ☐ Estimated aggregate placed____________________tons.

- ☐ Note performance of equipment, operators, and overall quality of the operation.

  ____
  ____
  ____
  ____

- ☐ Note application rates and any adjustments made.

  Binder ____________________
  ____
  ____

  Rock ____________________
  ____
  ____

- ☐ Pick-up sweeping should occur 24 to 72 hours after application of chip seal.
- ☐ Verify schedule and inspect operation as it proceeds in addition to the chip seal operation.

4. THE LAST DAY OF THE PROJECT

- ▫ Verify that all roads scheduled to be sealed have been and that the pick-up sweeping operation is completed prior to contractor or workforce leaving the project area.
- ▫ Field inspector and field supervisor agree on total pay quantities for the project in writing.
- ▫ Remove excess binder and/or aggregate from the site or agree on a schedule to do so.
- ▫ Clean up sites used to store equipment or stockpile materials.

This page intentionally left blank.

3.8 EQUIPMENT CALIBRATION

Calibrating and maintaining the equipment used in chip sealing is an important step in achieving good results. Poorly calibrated or mis-calibrated equipment can negate what would otherwise be a quality chip seal project. Calibrating the chip spreader and asphalt distributor ensures that:

- All of the chip spreader gates are applying the same amount of aggregate across its entire width.
- The chip spreader is applying the desired amount of aggregate per unit area.
- The distributor spray bar nozzles are all adjusted to the same angle, resulting in uniform coverage of the binder across the entire lane.
- None of the spray bar nozzles are plugged with debris.
- The spray bar height is correct. If it is too high, the fans will overlap too much. If it is too low, there will be areas with insufficient binder. Both conditions will cause streaking.

The following pages describe the calibration procedures and adjustments that routinely must be made to both the aggregate chip spreader and asphalt distributor before the project starts.

CHIP SPREADER CALIBRATION

The recommended procedure for calibrating an aggregate chip spreader is ASTM D5624-95.

Calibrating a chip spreader requires the following:

- A 12- to 16-foot length of a grooved rubber mat (depending on the width of the spreader), typically used as stair runners. They can be purchased from building supply stores and come in either 27- or 36-inch widths. The mat is then cut into one-foot wide strips. The result will be mats that are either one-fourth or one-third of a square yard, depending on how wide they are (27 or 36 inches). The grooves run across the short dimension of the mats.
- A scale of some type to weigh the chips. A spring-loaded dairy scale has been used successfully.
- Twelve to sixteen one-gallon size plastic food bags to be used for holding the contents of each rubber mat during weighing.
- Wide masking or duct tape to prevent the rubber mats from slipping on the pavement surface.
- A notepad and pen or pencil for recording the results.
- A 5-gallon bucket for storing and carrying the above items.

Chip Spreader Calibration Steps:

Step 1

The rubber mats are laid side by side on the roadway until they extend the entire width of the chip spreader. To prevent the mats from slipping, wide masking tape can be used on the upstream end of the mats as shown in Figure 3.8.1.

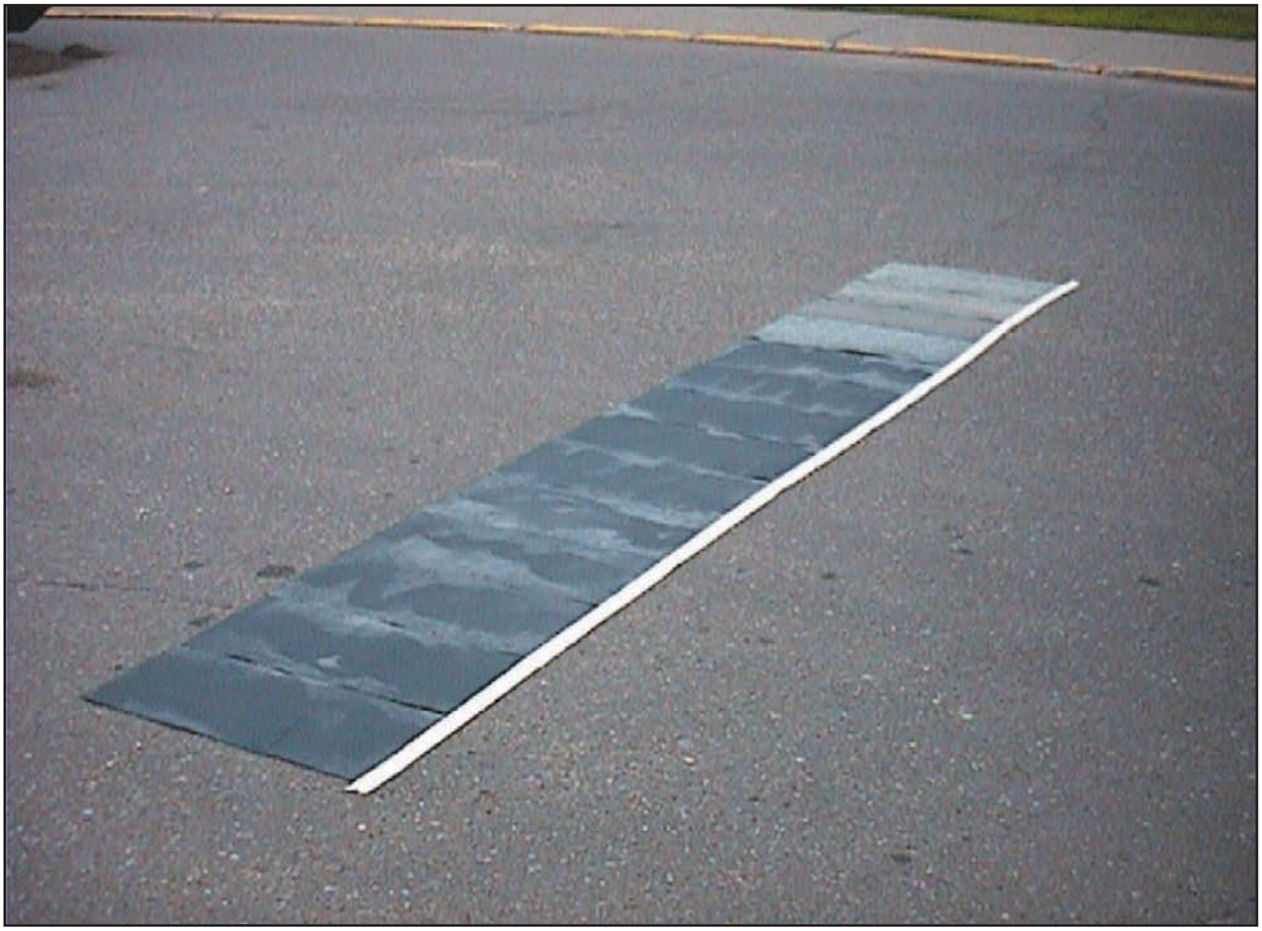

Figure 3.8.1. One-foot wide rubber mats are placed into position

Step 2

The chip spreader is driven over the mats. The spreader should begin dropping chips about 6 to 8 feet before the mats to ensure the gates are open and functioning properly. ***It is critical that the spreader travel speed and tachometer be monitored to ensure they are the same as those used during construction.*** The inspector should record these values to make sure this is done. If the spreader is traveling too fast or slow during calibration, it will not provide correct information as to the actual yield obtained during production.

Figure 3.8.2. The rubber mats are covered with aggregate from the chip spreader

Step 3

The aggregate dropped on each mat is then carefully emptied into the one-gallon plastic bags. The order of the bags must be kept straight so the gate openings can be matched to the proper mat.

Figure 3.8.3. The aggregate on each mat emptied into plastic bags

Step 4

The content of each bag is weighed and converted to pounds per square yard or kilograms per square meter. This amount is recorded on the notepad along with the position of the gate relative to the outer edge.

Figure 3.8.4. The contents of each bag are weighed and recorded

Step 5

The first adjustment made is to get each gate to drop the same amount of aggregate, even if it is not the desired amount. This will involve adjusting individual gate openings on the front of the spreader.

Figure 3.8.5. A spreader gate is adjusted

The test is repeated until the gates are all placing the same amount of aggregate, plus or minus one pound per square yard. Once the gates are all dropping the same amount of aggregate, the main feed is adjusted until the correct amount of aggregate is being placed. Normally the spreader must be adjusted two or three times before all the gates are dropping uniformly at the target amount.

The calibration can be done the day before construction to reduce any delays. It is recommended to perform the calibration off-site for safety and efficiency. It eliminates the equipment and personnel from waiting on the roadway while the calibration is done. This procedure typically requires 30 and 60 minutes to complete. The calibration procedure can be sped up by first adjusting the spreader gates before loading the hopper with aggregate. This can best be accomplished by fully opening the gates and adjusting the gates such that the distance between the roller and the bottom edge of each gate is the same before filling the hopper with aggregate.

ASPHALT DISTRIBUTOR CALIBRATION

Several calibration procedures or adjustments should be done to the asphalt distributor before it is used. While these adjustments are very simple and quick, failure to perform them can lead to non-uniform application of binder that not only affects the appearance of the chip seal, but also its performance.

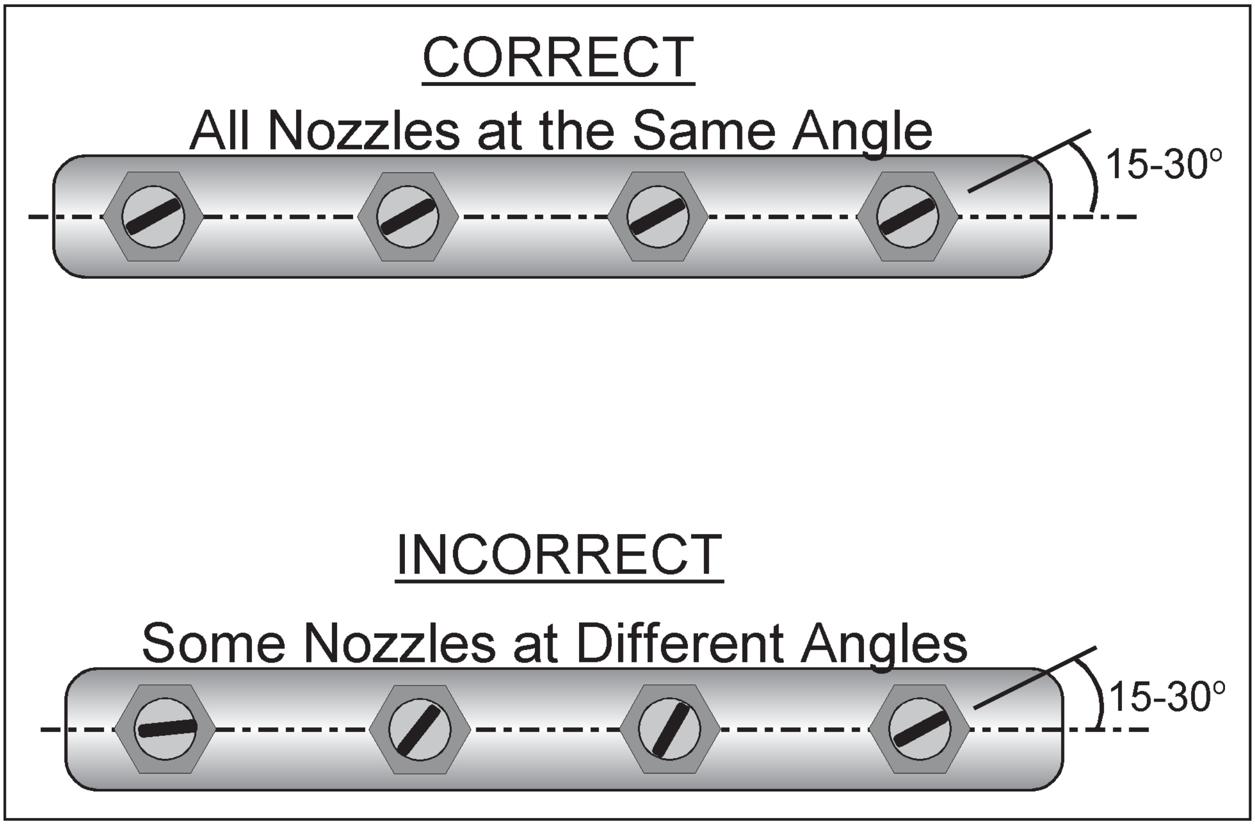

Figure 3.8.6. Spray bar nozzle alignment

SPRAY BAR NOZZLE ALIGNMENT

The first thing that should be done is to check the spray nozzle alignment on the distributor spray bar. To enable the distributor to spray a uniform layer of binder, the angle of each nozzle must be the same. The exceptions to this are the two nozzles on the very end of the spray bar. These nozzles are typically angled almost perpendicular to the spray bar to create a straight, uniform edge. Nozzle adjustment is very easy to do, typically only involving a slight turn with a wrench or other tool provided by the distributor manufacturer. When performing the nozzle alignment check, inspect each nozzle for any debris that may be obstructing the opening and impact the spray pattern.

Figure 3.8.7. Spray bar nozzle showing poor alignment

Figure 3.8.8. Spray bar nozzle showing proper alignment

SPRAY BAR HEIGHT ADJUSTMENT

The next step in adjusting the distributor is to determine if the spray bar is at the correct height. This is done by shutting off certain nozzles and examining the point at which the fans hit the pavement surface. For a triple lap application, two nozzles should be shut off for every one that is open. For a double lap application every other nozzle should be shut off. The distributor operator then sprays for a very quick moment. If the fans do not hit the pavement surface at the same point, the spray bar is either too high or too low and should be adjusted accordingly. As the distributor becomes less full, the spray bar will rise slightly due to the decreased weight on the vehicle. However, this is normally a minimal height and can be ignored.

If the spray bar is not adjusted to the proper height above the pavement, one of two situations will result. Either the spray bar will be too high, in which case the fans will overlap too much in certain areas resulting in ridges or it will be too low, in which case there will be gaps between the fans. In either case, streaking will be the result and is not desired.

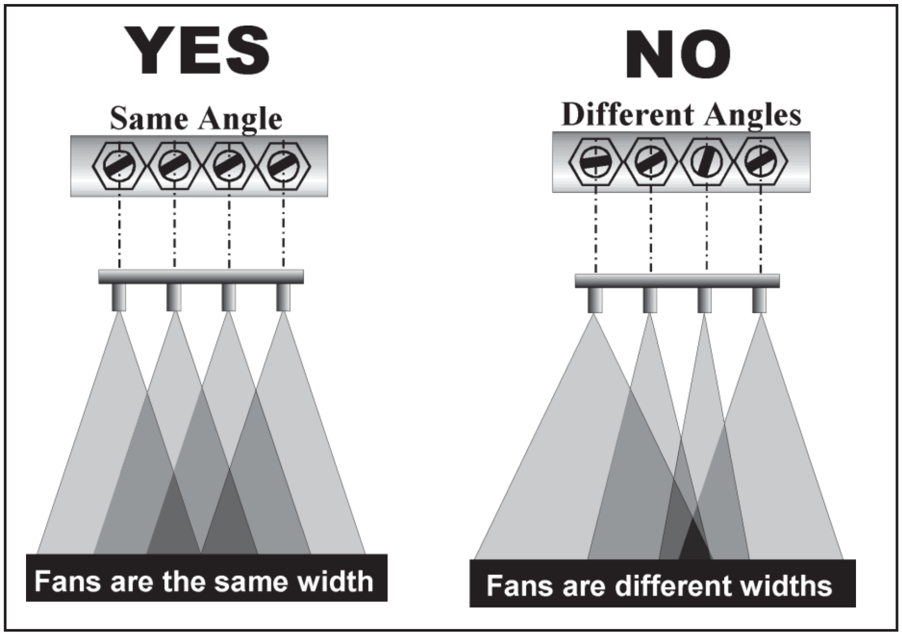

Figure 3.8.9. Spray bar nozzle alignment

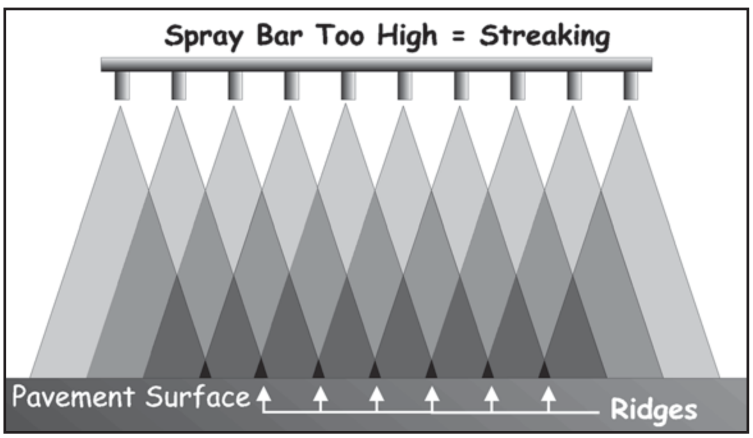

Figure 3.8.10. Spray bar is too high (ridges)

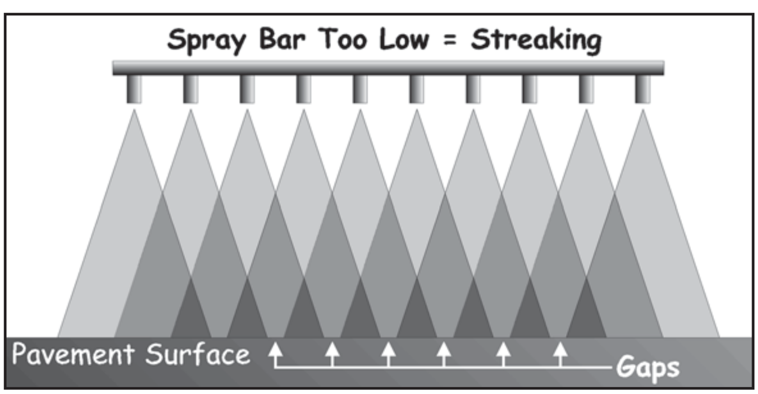

Figure 3.8.11. Spray bar is too low (gaps)

To determine if the spray bar is at the correct height, the following test should be done before any work begins.

For a Triple Lap Application:

To determine if the spray bar height is correct for a triple lap application, conduct the following test:

1) Align all spray nozzles to the same angle.

2) Shut off two consecutive nozzles for each that is left open (Figure 3.8.12).

3) Have the distributor apply a spot binder application and examine the point where the fans hit the pavement surface. If they do not meet at the same point, the spray bar is not at the correct height.

4) If the fans overlap, the spray bar is too high. If they are too far apart, the spray bar is too low. Adjust the bar height as needed and repeat until the fans meet the pavement at the same point.

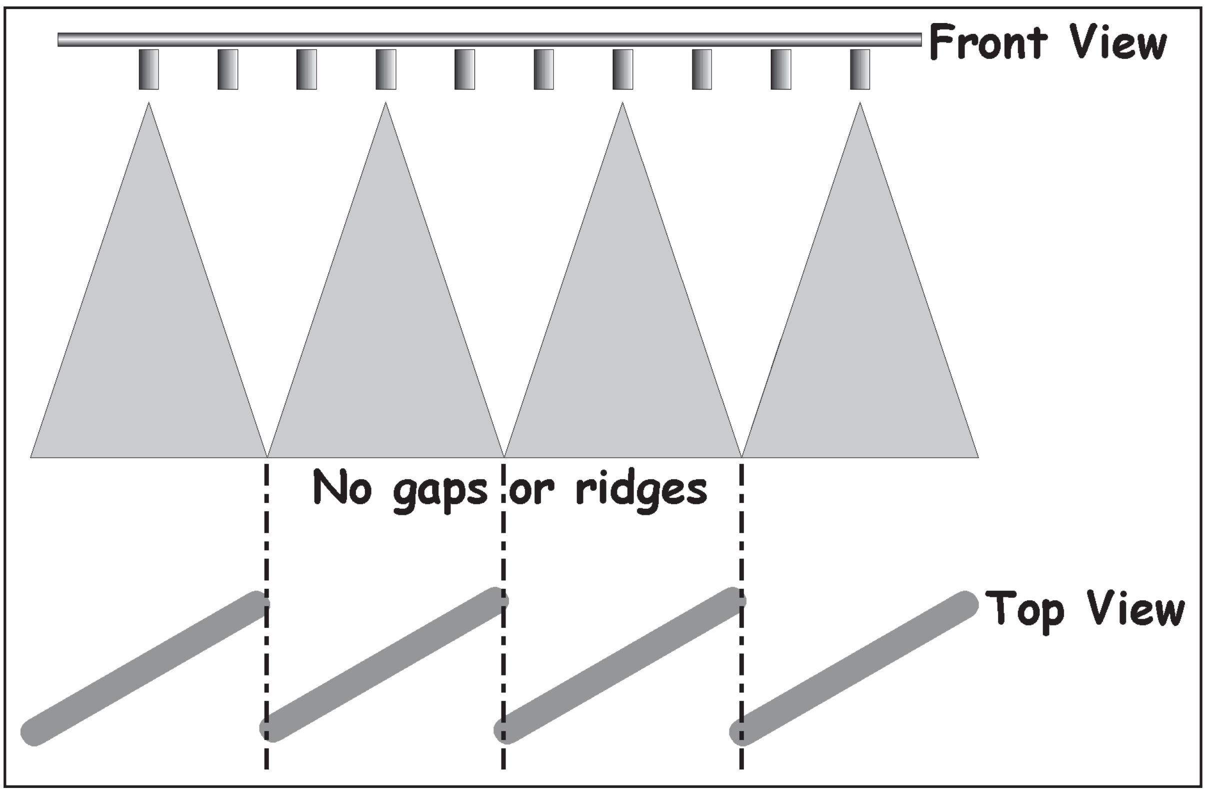

Figure 3.8.12. Spray bar height test for a triple lap seal

For a Double Lap Application:

To determine if the spray bar height is correct for a double lap application, conduct the following test:

1) Align all spray nozzles to the same angle.

2) Shut off every other nozzle (Figure 3.8.13).

3) Have the distributor apply a spot binder application and examine the point where the fans hit the pavement surface. If they do not meet at the same point, the spray bar is not at the correct height.

4) If the fans overlap, the spray bar is too high. If they are too far apart, the spray bar is too low. Adjust the bar height as needed and repeat until the fans meet the pavement at the same point.

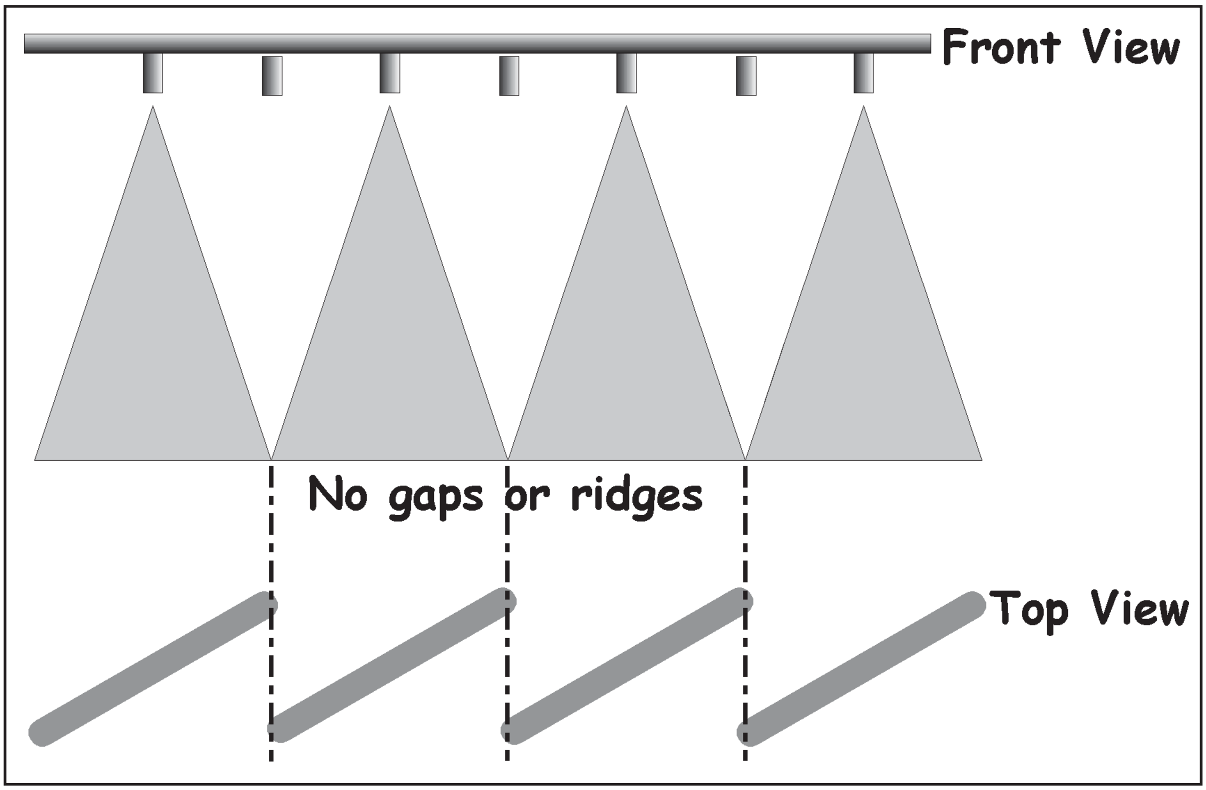

Figure 3.8.13. Spray bar height test for a double lap seal

This page intentionally left blank.

3.9 COMMON PROBLEMS and SOLUTIONS

Construction of a good chip seal depends on several factors, including the following:

- Aggregate gradation, hardness, size, and shape.
- Asphalt binder grade, viscosity, and electrical charge.
- Existing pavement condition.
- Construction methods.
- Equipment used and skill of operator.
- Traffic volume and movement.

Insufficient detail to any of these factors can result in defects in the sealed surface. The degree of the defect can range from a minor cosmetic one to complete failure and loss of the chip seal cover aggregate. The three most common problems that occur in the construction of a chip seal are:

- Loss of Cover Aggregate.
- Bleeding or Flushing.
- Streaked Appearance.

PROBLEM: *LOSS OF COVER AGGREGATE*

Perhaps the most common problem, and the least desirable, is the loss of cover aggregate. Possible causes are:

- Insufficient asphalt binder.
- Poor rolling of longitudinal seam at the centerline.
- Allowing the binder to break before chips are placed and rolled.
- Dusty aggregate.
- Poor gradation.
- Excessive snowplow down pressure.

Solution #1: *Apply more asphalt binder*

Without a doubt, the most common reason for loss of chip seal aggregate, especially in large amounts, is the lack of asphalt binder. Because most asphalt emulsions have only 65 to 70 percent residual asphalt, it is necessary to apply binder so that it will rise almost to the very top of the aggregate layer. This is because of the extensive loss in volume that occurs as the water and emulsifier evaporate during curing (Figure 3.9.1).

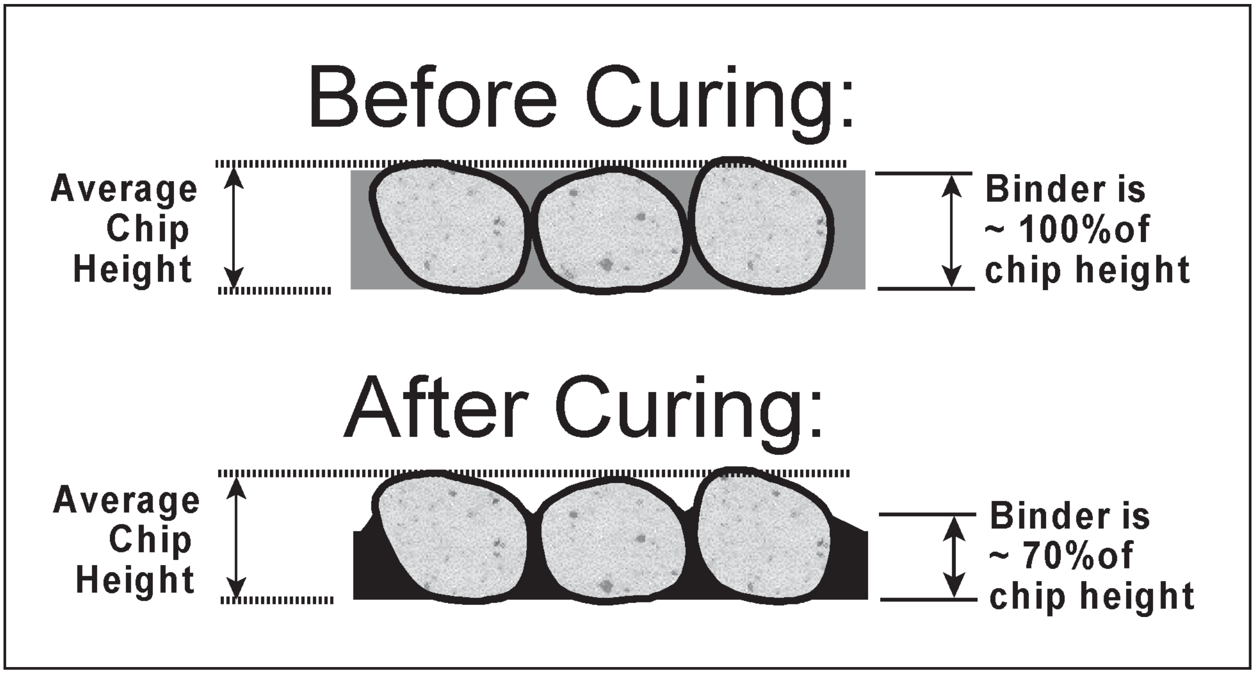

Figure 3.9.1. Change in volume after emulsion has cured

In addition, old and/or porous pavements, as well as the cover aggregate itself, can absorb some of the binder intended for holding onto chips. If extra binder is not applied to account for this, chip loss will result. Remember, the goal is to have as many stones as possible be about 70 percent embedded into the residual asphalt. The residual asphalt is the asphalt cement remaining on the pavement after water and emulsifier have evaporated.

Performing a chip seal design and constructing field test strips will determine the correct binder application rate. In some cases, the field application rate may have to be increased by as much as 50 percent to account for absorption onto existing pavement surface and cover aggregate.

Solution #2: ***Use a clean, dust-free aggregate***

Aggregates containing dust should not be used for chip sealing unless precautions are taken. To avoid dusty aggregate, the specified aggregate gradation should have 1 percent or less passing the #200 sieve (75µm).

Dust coats the outside of the aggregate particles and prevents them from bonding with the bituminous binder. Consequently, extensive chip loss will result.

If clean dust-free aggregate is not available, one of the following **must** be done before the aggregate is used:

- Wash the aggregate to remove dust.
- Use a high-float emulsion, such as HFMS-2.
- Pre-coat the chips with asphalt cement.

More detail on chip seal aggregates can be found in Chapter 2 of this handbook.

PROBLEM: *BLEEDING OR FLUSHING*

Bleeding, also referred to as flushing, is defined as "excess asphalt in the wheel path, or traffic areas." It is caused by too much asphalt binder. If the binder is applied too thick, it may rise above the top of the aggregate and stick to the construction equipment. More often, the binder is just below the surface of the pavement after curing and is sucked to the top by traffic, particularly on hot days. Localized areas of bleeding or flushing can be helped by applying either aggregate lime or cement to harden the asphalt binder.

Solution #1: *Use a cubicle aggregate*

Using flat aggregate can greatly increase the risk of bleeding. This is because traffic forces flat chips in the wheel path to lay down on their flattest side. If there are enough flat chips, they will be driven down below the surface of the binder in the traffic areas.

Solution #2: *Reduce the asphalt binder application rate*

Bleeding can also occur when using cubical aggregate if too much binder is applied to the pavement. The items presented above point out the need for performing a chip seal design and building test sections prior to construction.

For more details on chip seal design, refer to section 3.4 Design of this handbook.

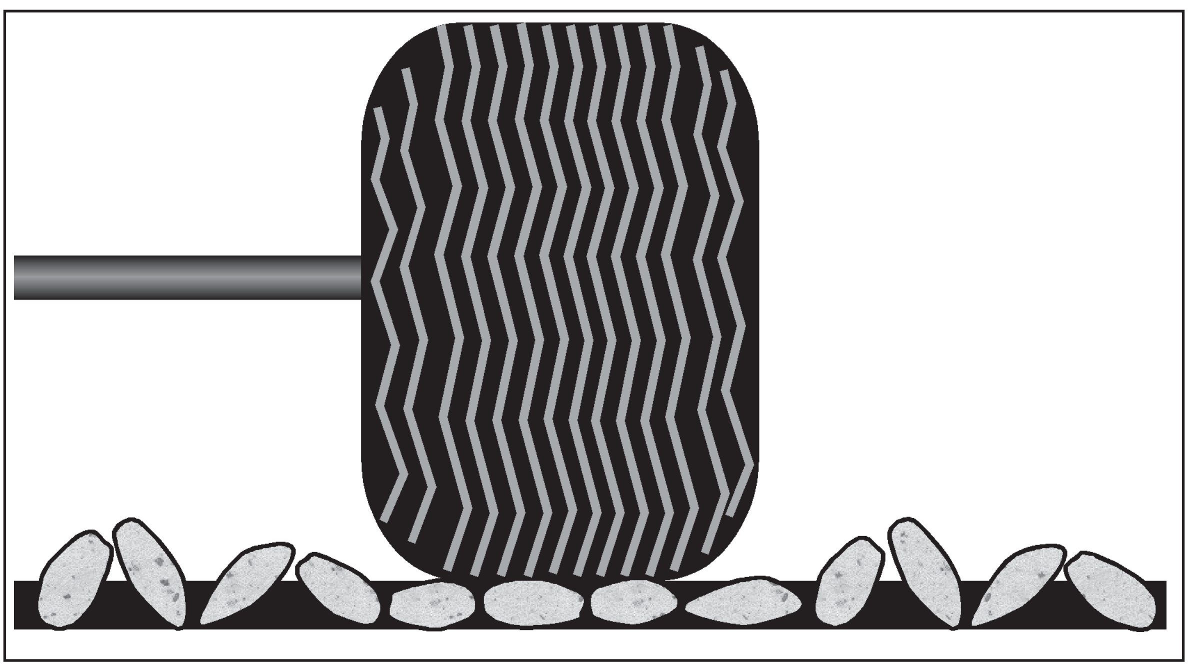

Figure 3.9.2. Traffic cause flat chips in the wheel path to lay down on their flattest side

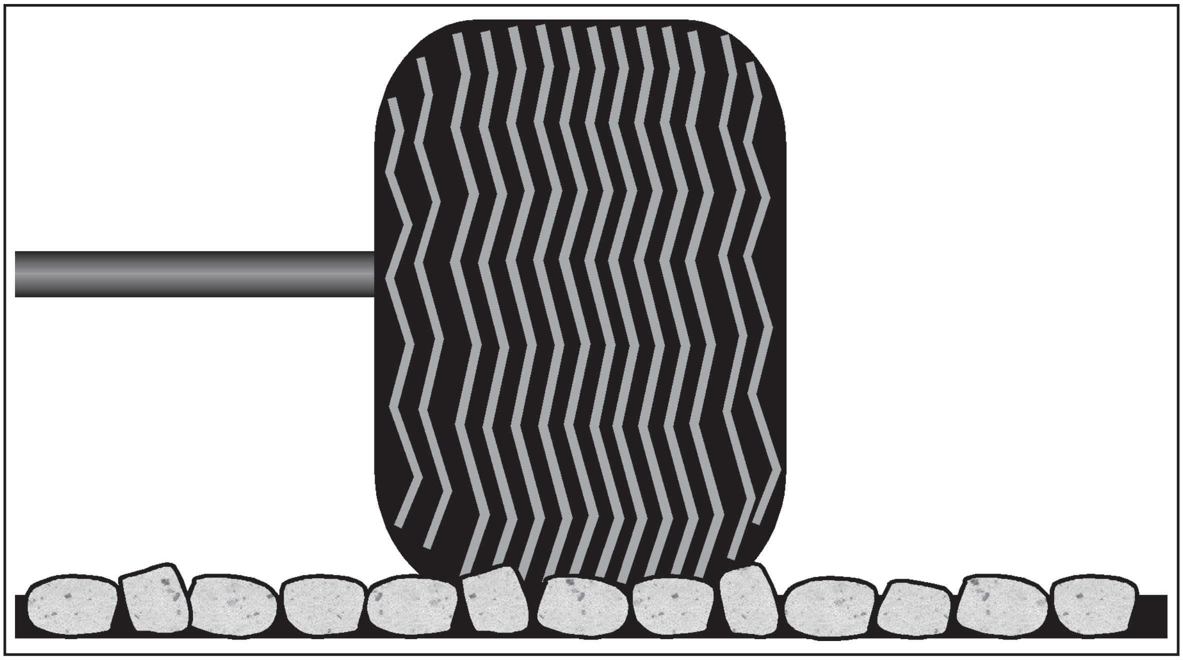

Figure 3.9.3. Traffic has little effect on cubical aggregate

PROBLEM: *STREAKED APPEARANCE*

Streaking is identified by longitudinal grooves or ridges in the chip seal surface. Though streaking is primarily a cosmetic problem it is an undesirable one. If the distributor is calibrated properly, streaking can virtually be eliminated. Figure 3.9.4 shows an example of streaking.

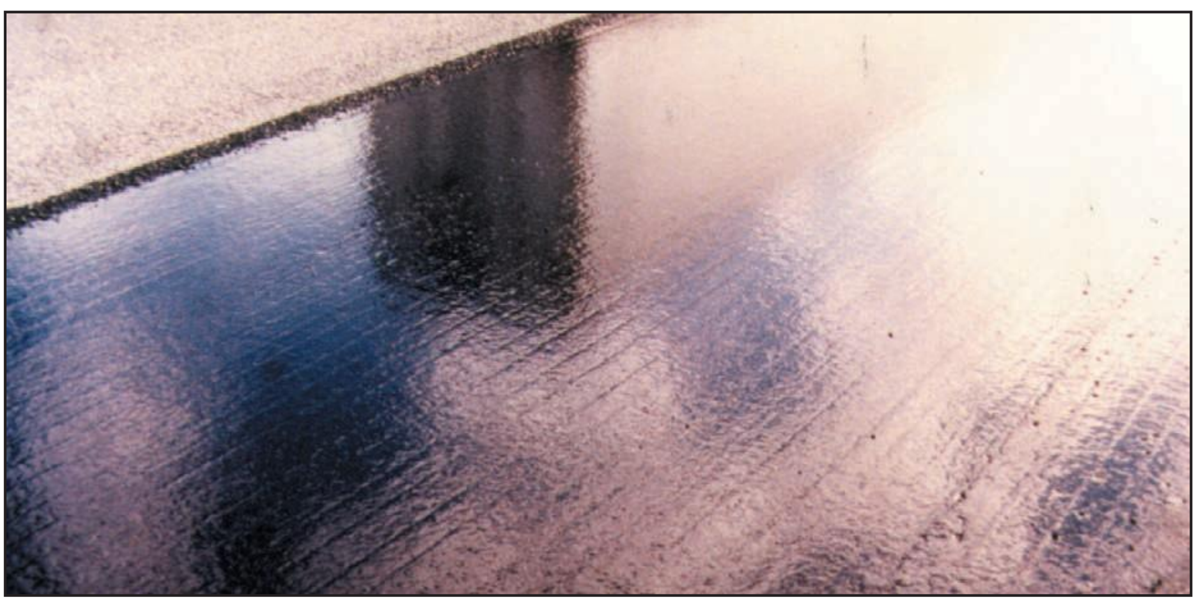

Figure 3.9.4. Example of streaking caused by incorrect spray bar height (notice streaks)

The three most common causes of streaking, in order of occurrence, are:

- Incorrect Spray Bar Height.
- Misalignment of the Nozzles.
- Clogged Nozzles.

Solution #1: ***Check the spray bar height***

If the distributor's spray bar is the wrong height, the fans of asphalt from the nozzles will not meet the pavement surface at the same point. As a result, there will be gaps, if the bar is too low and ridges if the bar is too high. Both result in a non-uniform layer of asphalt binder.

When using smaller aggregate, such as FA-2, the problem is much more noticeable because the chips can become securely embedded in the areas where ridges of binder exist. In Figure 3.9.5, notice that for a triple lap application, every fourth nozzle should hit the pavement at the same point. For double lap application, every other nozzle should meet the pavement at the same point.

Refer to the calibration section of this handbook for more details.

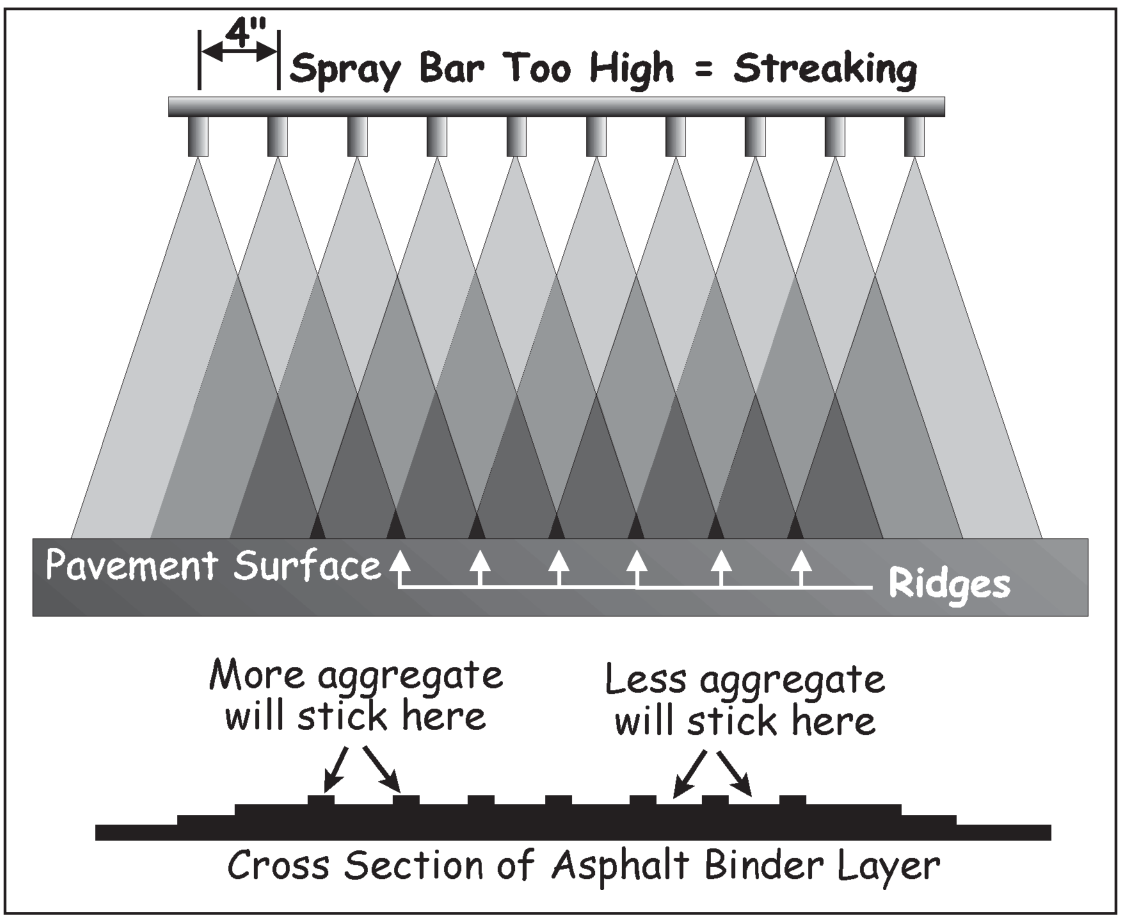

Figure 3.9.5. Schematic of incorrect spray bar height

Solution #2: ***Align the nozzles properly***

To apply asphalt binder at a uniform thickness across the pavement surface, the spray bar nozzles must all be set at the same angle. If the nozzles are at different angles, the width of the fans will also be different. This results in a non-uniform application across the spray bar width. Normally the angle of the nozzles can be easily adjusted with a simple turn of a wrench.

Solution #3: ***Make sure the nozzles are not clogged***

Because asphalt is sticky, and its viscosity increases when it cools, the nozzles of the spray bar are susceptible to clogging from stiff asphalt as well as grass and weeds which may be picked up during construction. Prior to beginning a chip seal project, the nozzles of the spray bar should be inspected and cleared of any debris. The emulsion must be heated to approximately 150° F (66°C) so that viscosity of the old binder in the nozzles can be reduced enough to prevent clogging. During construction, the spray pattern should be regularly checked, and any noticeable blockage should be cleared immediately.

Figure 3.9.6. Evidence of a dusty aggregate

PROBLEM: ***BAD CENTERLINE JOINT***

If the existing roadway has a deteriorated centerline joint, it should be repaired prior to chip sealing. A poorly compacted paving seam will absorb much more of the binder than the surrounding pavement. The result is insufficient binder in this area and loss of cover aggregate. Since snowplows tend to ride on this high spot of the pavement, having a good longitudinal seam is important to the longevity of the chip seal project.

Solution: ***Apply a fog seal***

Placing a fog seal in this area will help to prevent too much of the binder from being absorbed into the pavement. A two to three-foot wide application of CRS-2 emulsion applied about 0.01 - 0.2 gallons/sq. yd. has worked well as shown in Figure 3.9.7. The emulsion should be allowed to cure prior to placing the chip seal.

Figure 3.9.7. Fog seal on centerline prior to chip seal to prevent excess absorption

PROBLEM: ***INADEQUATE COVERAGE OF PAVEMENT MARKINGS WITH POSSIBLE COVER AGGREGATE LOSS***

It is possible existing pavement markings can interfere with constructing a quality chip seal treatment.

Solution: ***Remove and/or pretreat existing pavement markings***

Some recommendations for pavement markings are as follows:

1. Remove pavement messages such as turn arrows, stop bars, crosswalks, and railroad crossing messages.

2. For long lines, skip stripes can be pre-treated by applying the same asphalt emulsion used for the chip seal. The normal application rate is 0.10 gallons per square yard applied one (1) foot wide.
    a. For skip stripes it is recommend applying the pre-treat continuously.

3. Cost comparison

    a. MnDOT's average cost for pavement marking per linear foot was about $0.80 (2019).
    b. CRS-2P at 0.10 gallons per square yard cost is $0.03 linear foot (2019).

Figure 3.8.21. Pretreatment of pavement markings *Paul Nolan, MnDOT*

Advantages of pre-treating pavement markings include extra asphalt binder applied over the markings and increased total binder in the pavement areas that receive the least traffic and typically see most snowplow damage. These areas are also commonly found near longitudinal construction joints which are known to have lower mat density and higher air voids.

PROBLEM: ***LOSS OF AGGREGATE AND/OR BLEEDING IN CUL-DE-SACS***

One of the most common problems encountered when chip sealing in urban areas is the loss of cover aggregate, and subsequent bleeding in cul-de-sacs. For this reason, it is recommended to NOT chip seal cul-de-sacs, but only fog seal them.

Figure 3.8.22. Wrong way to sealcoat a cul-de-sac (emulsion will break before chips are placed and rolled)

Solution: ***Use proper technique materials***

The main cause of aggregate loss in cul-de-sacs is poor construction technique. In most cases, the binder is not placed properly. As a result, it breaks before the chips are applied and/or rolled. This is because of the increased viscosity of the binder. Once the binder breaks, it is nearly impossible to properly embed and coat the aggregate particles.

Another common error when chip sealing cul-de-sacs is too much overlap of adjacent passes of the distributor. If the distributor operator is not careful, two or even three times the desired thickness of binder can be applied in certain areas. This will result in bleeding and cause the chip seal to be very tender which will cause scuffing as vehicles stop and turn.

Refer to Section **3.10 Special Situations** for recommended guidance on chip sealing a cul-de-sac.

PROBLEM: ***UTILITIES IN THE PAVEMENT***

When chip sealing in urban areas where manholes and gate valves in the street are common, the asphalt binder will stick to these structures unless precautions are taken.

Solution: ***Cover the utilities***

To prevent the binder from adhering to the utilities, they are normally covered. Appropriate covers range from roofing paper, kraft paper or sand. Since the material must be disposed of properly, using sand is the preferred method. The manholes and gate valves are normally covered just prior to the chip seal being placed.

Figure 3.8.23. Sand cover on manholes

PROBLEM: ***BITUMINOUS PAVEMENT IS STRIPPING IMMEDIATELY BELOW THE CHIP SEAL***

Chip seals are not a structural surfacing. Therefore, the pavement to receive a chip seal should be structurally sound. A low-density bituminous pavement typically has an associated high void content allowing moisture to move through the pavement. A chip seal can seal this moisture in the pavement structure resulting in stripping of the pavement immediately below the chip seal. The use of CRS-2P binder may increase this potential because of it's characteristic of the polymer additive reducing permeability. This phenomenon has been researched by the Minnesota Local Road Research Board (LRRB). The reports can be found at www.lrrb.org

Solution: ***Project Selection is Key!***

The best methods to determine if a pavement has low density or high air voids is to obtain cores for lab testing or run in-place permeability tests. If pavements are found to have low density/high air voids or your agency has history of this occurring, an alternate preventive maintenance treatment should be considered. A good option is placement of a thinlay or mill the pavement surface and place a thin overlay.

PROBLEM: ***GRINDING HEAD IS GUMMING UP WHEN ATTEMPTING TO PLACE GROUND-IN PAVEMENT MARKINGS***

It is common practice to place ground-in pavement markings after application of a chip seal. The grinding head on the pavement marking grinding machine is gumming up in a short distance rendering it useless. It is not efficient or cost effective to continue grinding in of the pavement strips.

Solution: *Asphalt Emulsion has not Sufficiently Cured!*

Let the asphalt emulsion fully cure before attempting to grind-in pavement markings. Under typical conditions, the asphalt emulsion should sufficiently cure in one to two weeks. It has been experienced that after this allowed curing time, pavement markings can be ground-in with no problem of the grinding head gumming up. If pavement markings are to be ground-in, it may be necessary to place tab type lane markers prior to constructing the chip seal or place temporary lane marking after construction.

This page intentionally left blank

3.10 FREQUENTLY ASKED QUESTIONS ABOUT CHIP SEALING

1. **Q)** I have a locally produced chip that does not meet any of MnDOT's gradation specification for the different sizes (FA-2, FA-2 1/2, or FA-3). Can I still successfully use these chips?
   A) Yes, if there is less than 1 percent passing the # 200 sieve, you should be able to successfully use the chips. If you have more than 1 percent passing, check with your binder supplier to see what it recommends. The MnDOT chip seal design program will give you application rates for the chip and asphalt binder (see MnDOT website).

2. **Q)** Is there a good way to determine if I have placed enough asphalt binder on my chip seal project?
   A) Determining if enough binder has been placed to achieve proper embedment is a little bit like playing poker; if you look closely, there are always signs for you to follow. One sign in chip sealing is to look closely at crack seals that exist in your pavement. These areas have almost no absorption when compared to a normal HMA surface. If you do not see signs of the crack seal shadowing through the chip seal, then you are probably low on embedment.

3. **Q)** A surprise rain shower caught us when we were laying down our chip seal. What can we do to limit the amount of damage done by the rain?
   A) Getting caught in a surprise shower is one of the joys of chip sealing in the Midwest. One of the first things to do is increase the aggregate cover rate by 100 percent as you finish covering the asphalt binder. If you have a truck with a sander on the job to repair damaged areas, have it sand the fresh chip seal. Any extra covering you can place on the chip seal helps to protect it from the rain. If you are lucky and have aggregate lime available, use it to blot the chip seal. This will cause the Cationic emulsion to break faster. Of course, the best-case scenario is for you to watch the weather closely and suspend operations if you believe there is a chance of rain.

4. **Q)** My starts and stops to change trucks on the chip spreader result in spots that are rough and very dark. What can I do to improve them?
   A) One successful method of dealing with starts and stops is to use roofing felt as a launching pad. Place one or two pieces of felt across the lane. The distributor can start spraying on the felt and then the felt can be removed after the application is complete, leaving a clean and straight edge.

5. **Q)** Does fog sealing on a chip seal reduce the friction number to an un-safe level?
   A) The answer is "no", assuming you've properly designed your fog seal. The macro texture available on chip seals yields such high friction numbers (> 50) that a slight reduction from a newly placed fog seal still results in the friction numbers that achieve a safe level (<30).

6. **Q)** What is a good way to adjust chip and binder application rates in the field for changing conditions (ie: more porous pavement conditions), after calibrating the equipment and setting the rates?
   A) See response to question # 2 above.

7. **Q)** How do pavement and air temperatures affect chip seal operations?
   A) If the air and pavement temperature are low during construction, the chip seal will take much longer to develop enough strength to withstand traffic. One other point to consider

is the time of day. For example, it may be forecast to be 60ºF at 6:00 AM on July 1 which is a very different indication than if you had a 60ºF at 4:00 PM. Now if it is 60ºF at 4:00 PM, applying a chip seal is not recommended because the temperature will fall after sunset.

8. **Q)** How does ADT affect chip seal design and is there a maximum ADT on a roadway to be considered for chip sealing?
   A) ADT affects chip seal design in the following way: as the ADT goes up, the chip seal needs less asphalt binder. The reason for this is that increased traffic causes a higher percentage of the chips to be orientated on their least-dimension side. The inverse is that as ADT decreases, the asphalt binder must be increased. This is because there is less chance for the chips to be orientated on their least-dimension side with lower traffic volumes.

   Roadways with ADT of 20,000 have been successfully chip sealed in Minnesota; however, most agencies use 10,000 ADT as their cut-off point when considering a chip seal application.

9. **Q)** Will ADT or anticipated truck traffic volumes affect the type of oil or aggregate used in a chip seal?
   A) The answer is "yes." Increased ADT or truck traffic requires using a stronger binder. MnDOT recommends using CRS-2p (Cationic Rapid Set polymer modified) because it builds strength in a matter of hours while it can take weeks for non-modified asphalt to develop strength. The aggregate will also be affected on a high-volume or high truck traffic roadway, with a more durable aggregate required.

10. **Q)** How many times can you chip seal the same pavement?
    A) You can chip seal a structurally sound pavement an unlimited number of times if you want. There are some counties that have placed as many as four chip seals on a roadway and they are planning on continuing to chip seal the roadway every seven to ten years given the roadway stays structurally sound.

11. **Q)** What is the maximum rut depth a chip seal can fix?
    A) If the average rutting is over 1/4-inch, the roadway is marginally sound as a candidate to receive a chip seal.

12. **Q)** What do I need to know about protecting pavement markings during operations and/or re-applying markings after operations?
    A) If you have pavement markings that need to be saved, there is cover-up tape available that can be placed over the marking to preserve it during the chip seal application. As for re-applying pavement markings, if you are using latex paint, you can apply as soon as the sweeping is completed. Epoxy paint requires a minimum of 14-days of curing before it can be used.

13. **Q)** Can I successfully re-use the sweepings from a chip seal application on another chip seal project?
    A) Yes, sweepings may be re-used. It is recommended the chips be rescreened and if possible rewashed, which would be the best option. When using sweepings that have not been washed, a high-float emulsion such as HFMS-2 is recommended. If you are re-using sweepings, you should retest them and prepare a new chip seal design, making sure you select the appropriate binder.

3.11 SPECIAL SITUATIONS

There are certain situations that can occur that will present special challenges on chip seal projects. Among these are:

- Cul-de-sacs.
- Intersections & Turn Lanes.
- Parking Lots.
- High Volume Roadways.

Each of these will be discussed below.

SEALING CUL-DE-SACS

Chip sealing cul-de-sacs presents unique challenges for the chip seal crew. The most common problems associated with sealing cul-de sacs is excessive loss of the cover aggregate. Primarily this is caused from either insufficient aggregate embedment (i.e. not enough binder) or placing the aggregate after the asphalt binder has already broken resulting in a poor bond between the binder and the aggregate. The following items contribute to the difficulty sealing a cul-de-sac.

1) Its large area and round shape requires extra care by the distributor operator in order to prevent overlapping of successive passes which can lead to bleeding.

2) Since the traffic flow is not as channelized as other roadways, the chips never end up on their flattest side. As discussed previously in this manual, this will require more binder to achieve proper embedment.

3) If the application of the binder is not planned carefully, the binder will break before the chips are placed and rolled. Once the binder breaks, it will be nearly impossible to achieve a good bond between the binder and the aggregate.

4) The turning movements in the cul-de-sac cause the chips to want to roll over. Using an aggregate with a poor gradation or shape can lead to problems with exposed binder as the particles roll over.

The following figures show the proper way to seal a cul-de-sac to ensure that the chips are placed and rolled before the binder breaks. This process has been observed in the field and has proven to result in good embedment.

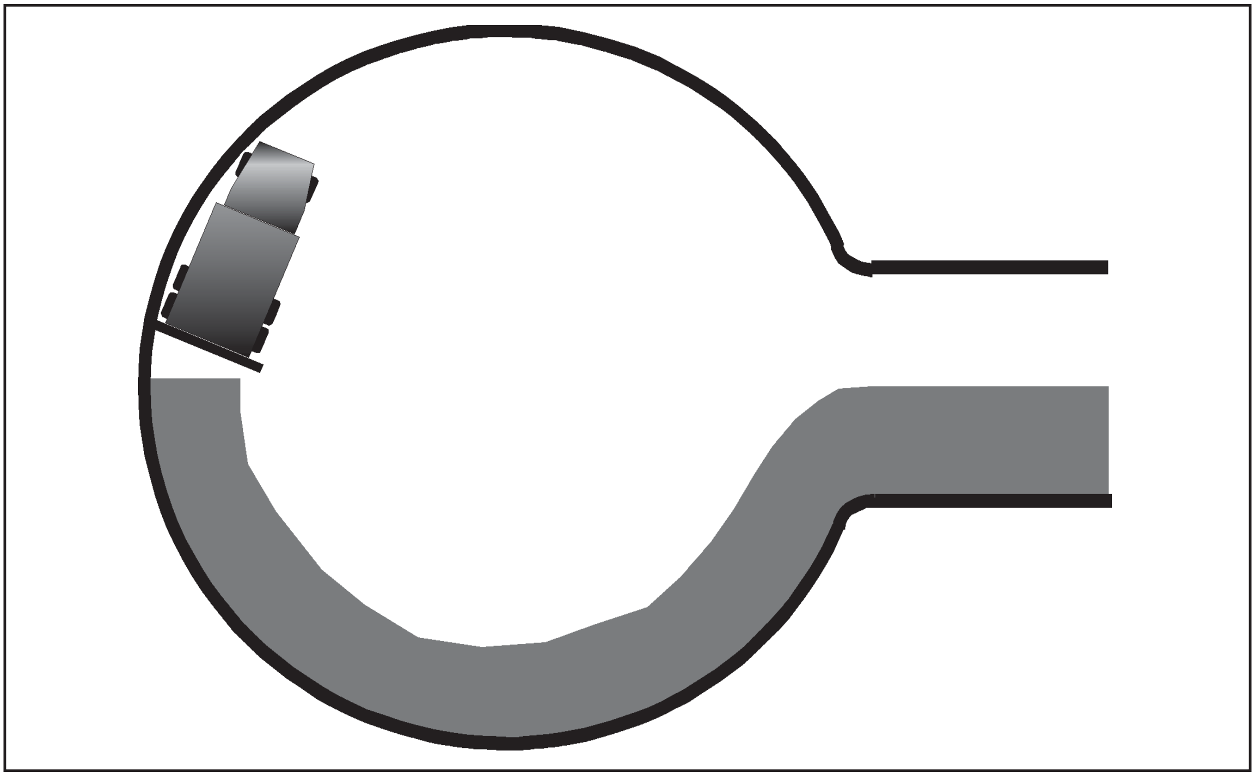

Figure 3.11.1. Distributor sprays halfway around the perimeter of the cul-de-sac.

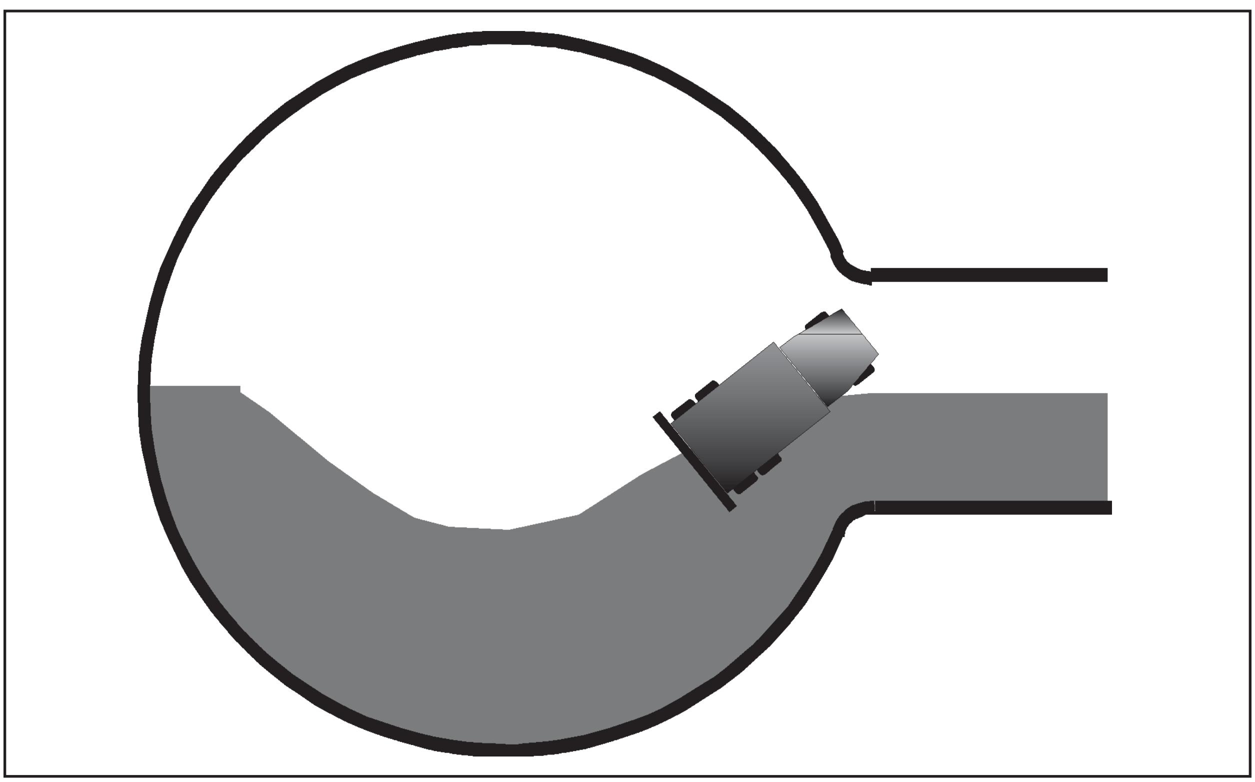

Figure 3.11.2. After backing into position, the distributor sprays adjacent to the previous pass.

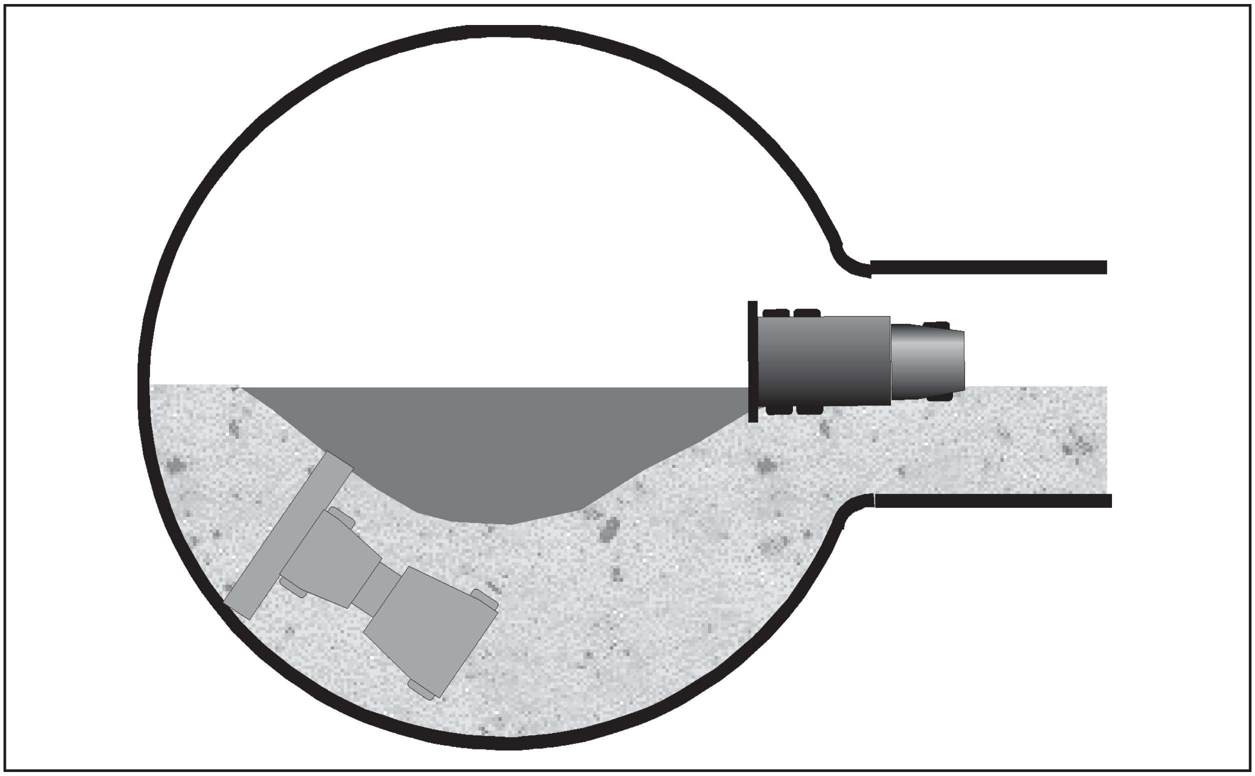

Figure 3.11.3. After backing into place, the distributor completes half of the cul-de-sac. The chip spreader and rollers begin working.

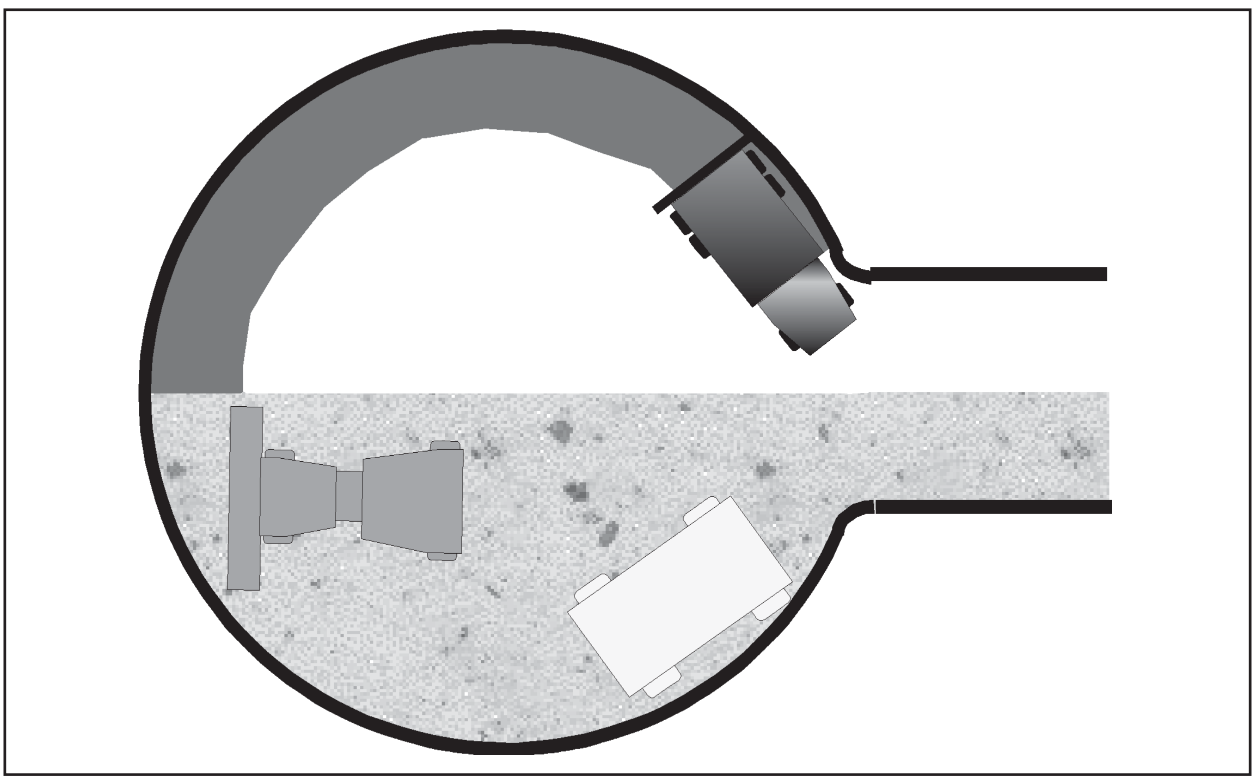

Figure 3.11.4. Distributor backs up to previous perimeter pass and completes spraying around the outside of the cul-de-sac. The spreader and rollers continue to work.

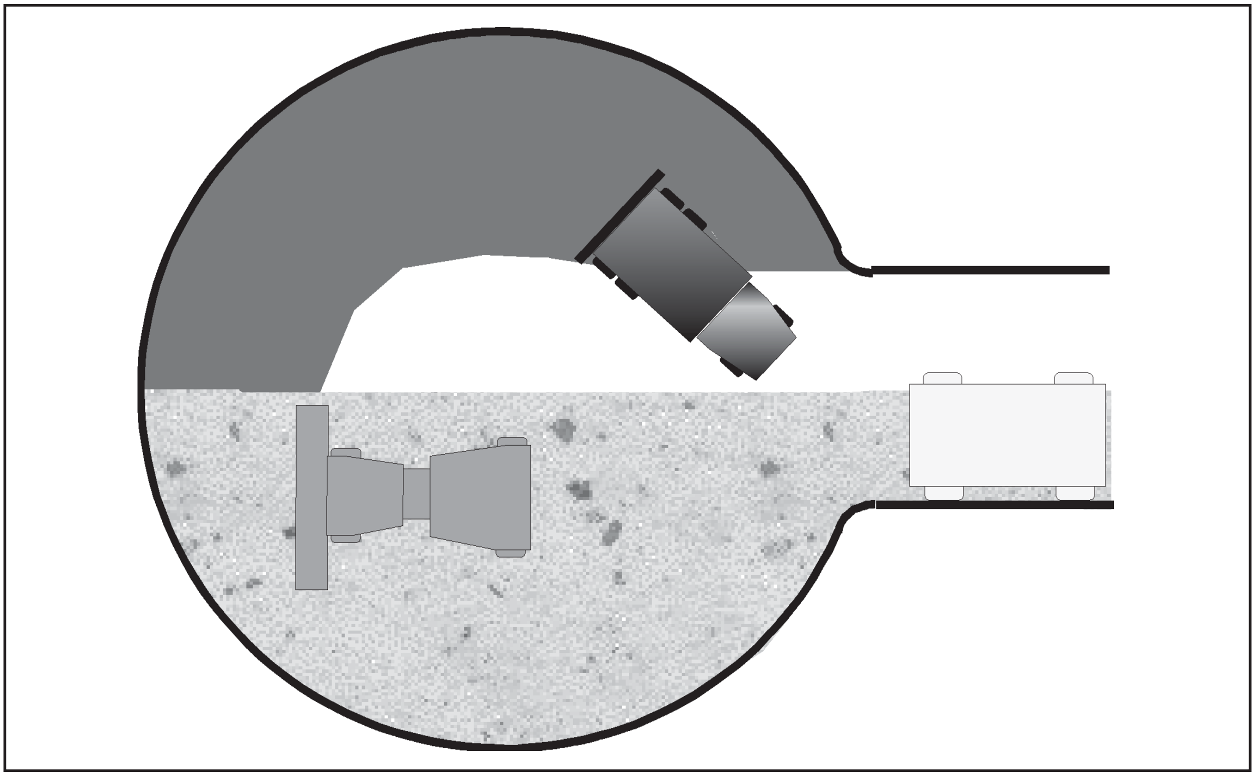

Figure 3.11.5. Distributor continues matching up with previous pass around the perimeter. Spreader and rollers finish the first half of the cul-de-sac.

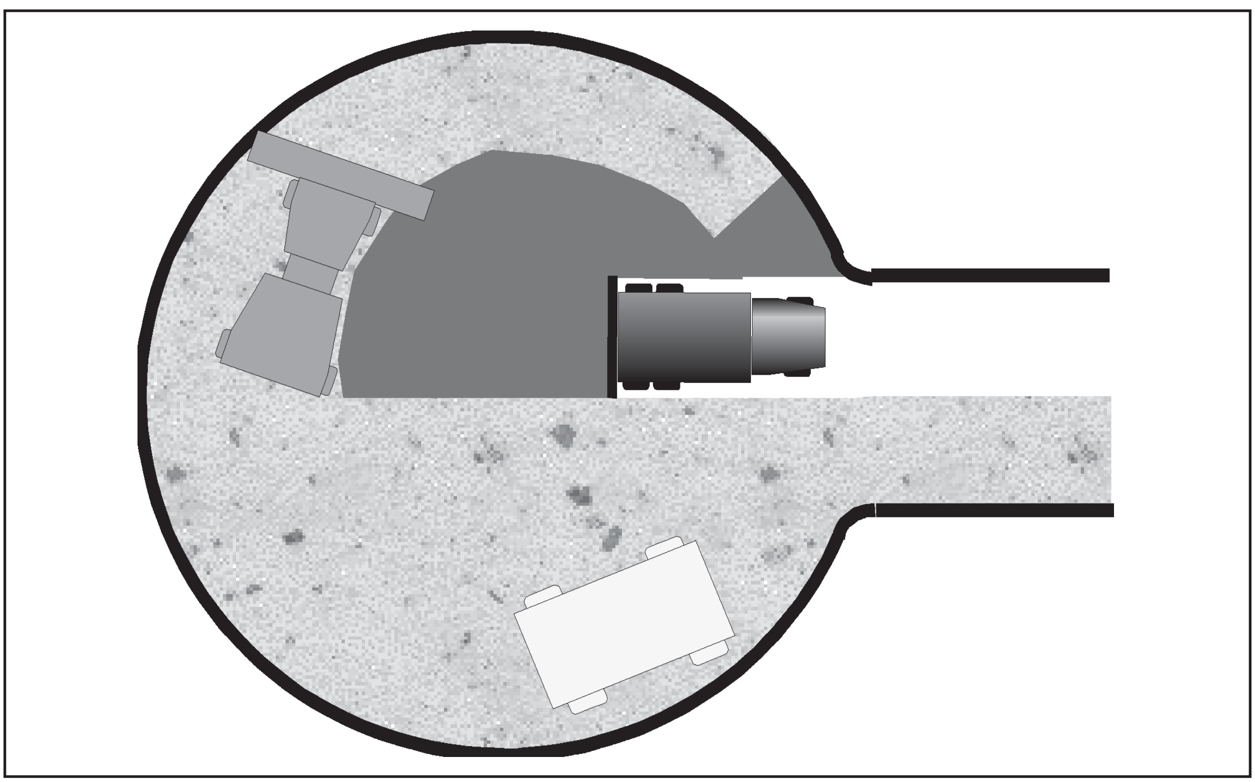

Figure 3.11.6. Distributor is ready to make its final pass out of the cul-de-sac. The spreader begins covering the other half of the cul-de-sac while the roller continues to work.

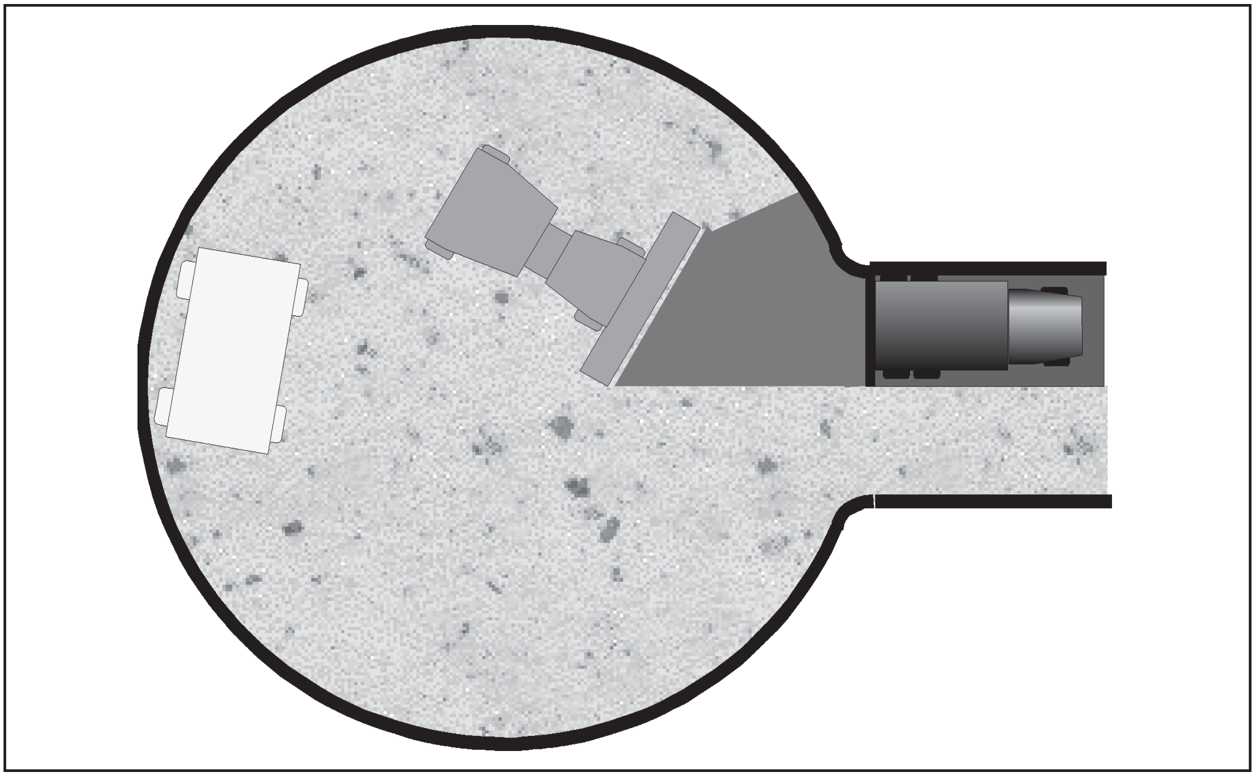

Figure 3.11.7. Distributor makes its final pass out of the cul-de-sac and completes the other entrance lane into the cul-de-sac. The spreader and rollers are nearly finished.

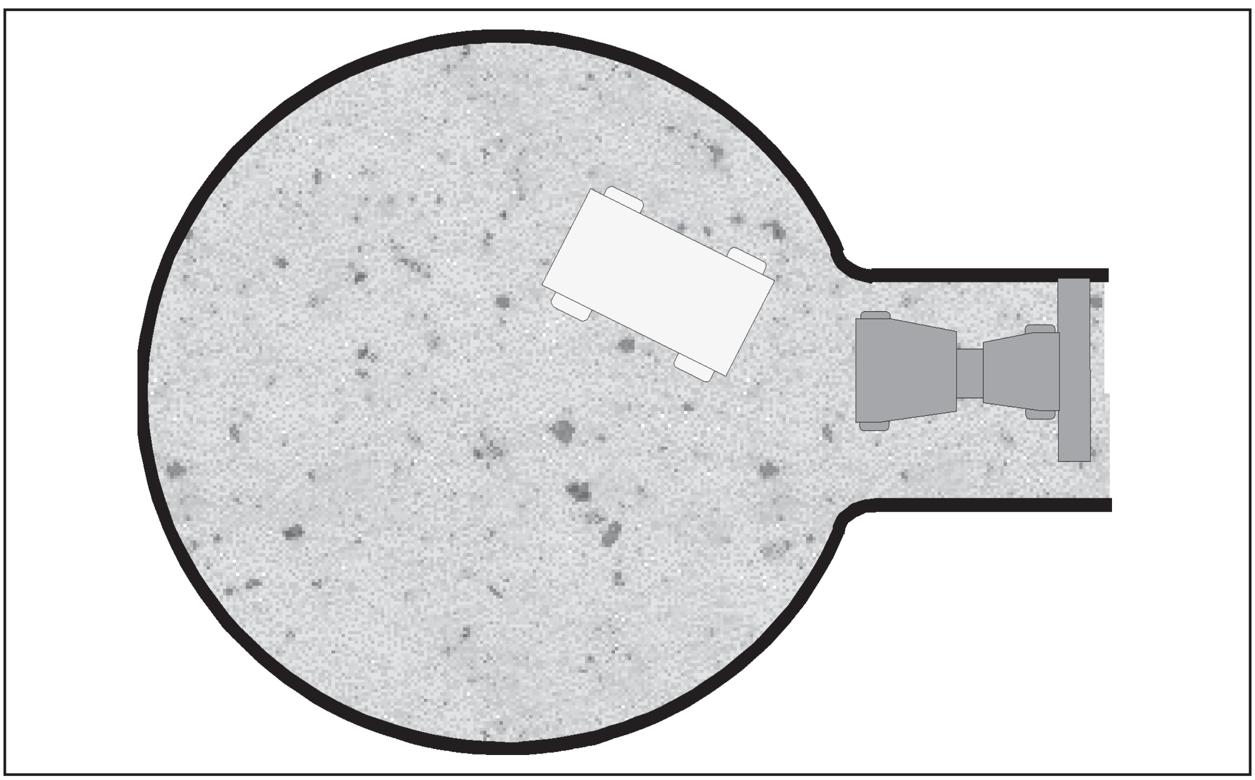

Figure 3.11.8. Chips spreader and rollers finish the cul-de-sac and head out to finish the rest of the street.

INTERSECTIONS AND TURN LANES

Intersections and turn lanes also can present special challenges. Among the reasons are increased turning, which can cause scuffing, chip rollover and channelized traffic which causes the chips to lay very flat and can lead to bleeding if not accounted for. In addition, stopping action at intersections can suck the binder to the surface of the pavement, especially on hot summer days.

PARKING LOTS

Parking lots, like cul-de-sacs, involve large expanses of pavement which must be sealed in many passes of the distributor and chip spreader. Careful planning and proper operation of the distributor and spreader will help to ensure good results. The goal is to achieve proper embedment and roll the chips before the binder breaks.

HIGH VOLUME ROADWAYS

One of the main reasons chip sealing is primarily used on low to moderate trafficked pavements is the fear of cracked or broken windshields caused by flying, loose aggregate during and shortly after construction. Long term, there is also the potential for bleeding problems if flat aggregate is used. Because traffic will cause aggregate to lay on its flattest side, high traffic roadways will have a more chips laying on their flat side than low volume roadways due to the increase in the number of vehicles. If the aggregate used has a high Flakiness Index, the difference in height between the traffic and non-traffic areas will be very pronounced. The result will either be bleeding in the wheel paths or loss of aggregate between them, both of which are undesirable. Some of the precautions that can be taken to minimize the potential for problems on higher volume roadways are:

1) **Use a Choke Seal.** This involves applying second layer of aggregate on top of a conventional chip seal. The aggregate in this top layer is much smaller than the aggregate in the bottom layer. When they are rolled, they will be become lodged into the voids in the bottom layer which locks the bottom aggregate together. With this type of surface, the chance of any of the bottom stones becoming dislodged is greatly reduced.

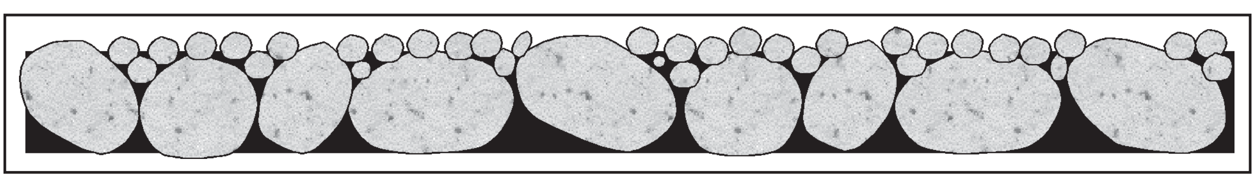

Figure 3.11.9. Schematic of a Choke Seal (One layer of binder two layers of aggregate)

2) **Use a Double Seal.** This involves applying a second layer of binder and aggregate. The second layer of binder will totally encase the bottom layer in asphalt. The aggregate in the top layer is normally half the size of the aggregate beneath it. As a result, the surface locks together, similar to a choke seal, greatly reducing the possibility of loose rocks. If there are any loose rocks, they will be the small ones in the top layer which will also greatly reduce any chance of damage to vehicles.

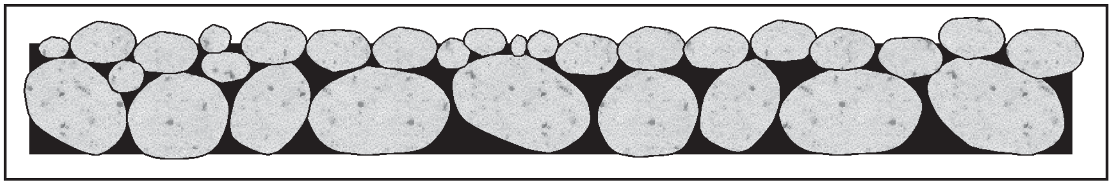

Figure 3.11.10. Schematic of a Double Seal (two layers of binder and aggregate)

3) **Use a smaller aggregate such as MnDOT FA-2.** One sure way to avoid cracking windshields is to use aggregate small enough that this won't happen. The downside to this is the protective layer of asphalt cannot be very thick when using small aggregate.

This page intentionally left blank

APPENDIX

This page intentionally left blank

Appendix A.

- **MnDOT Specification 2355 BITUMINOUS FOG SEAL**
- **MnDOT Specification 2356 BITUMINOUS SEAL COAT AND BITUMINOUS UNDERSEAL**

2355 BITUMINOUS FOG SEAL

2355.1 DESCRIPTION

This work consists of constructing a fog seal on a prepared surface as shown on the plans.

2355.2 MATERIALS

Bituminous Material

Provide bituminous emulsion as shown in the plans meeting the following requirements:

(1) CSS-1h (3151.2.D.1), or
(2) CRS-2Pd (3151.E.2).

Dilute during manufacture. Do not dilute in the field.

2355.3 CONSTRUCTION REQUIREMENTS

A Weather Limitations

Perform fog seal operations only during daylight hours and not during foggy weather. Begin fog seal operations when the pavement and air temperatures are 60° F and rising. The Contractor may perform fog sealing on a damp road surface, but not on a road surface with standing water.

B Road Surface Preparation

Clean pavements, including depressions, before fog sealing.

Cover metal surfaces to prevent adherence of the bituminous material. Remove the protective coverings before opening the road to traffic.

C Application of Bituminous Material

Begin using the rate of application for bituminous fog seal as shown in Table 2355-1, Fog Seal Application Rates, and within the temperatures specified in Table 2355-2, Fog Seal Application Temperatures.

Demonstrate a uniform application of asphalt emulsion producing 100 percent coverage of the surface after curing, as approved by the Engineer. Stop operations if the application demonstration does not meet the coverage requirements. Minimize the amount of overspray during the fog seal operation.

Using a distance of 1,000-feet, perform a yield check at the beginning of each project to verify the application rate is correct. The Engineer may require additional yield checks be performed if the application rate is questioned. The Engineer may also require the Contractor to verify application is within 10% of the intended application rate by ASTM D 2995 test method A.

Table 2355-1
Fog Seal Application Rates

Application Rates – gallons/square yard	
CSS-1h	CRS-2Pd
0.05 to 0.20	0.05 to 0.20

Table 2355-2
Fog Seal Application Temperatures

Bituminous Material	Minimum Temperature	Ideal Temperature
CRS-2Pd	140 °F	170 °F – 180 °F
CSS-1h	100 °F	100 °F – 140 °F

D Protection of the Surface

Do not all w traffic on the fog sealed surface until after the bituminous material has set and will not pick up on vehicle tires.

E Equipment

E.1 Distributor

Use a distributor in accordance with 2360.3.B.2.d, "Distributor."

E.2 Brooms

Provide motorized brooms with a positive means of controlling vertical pressure and with the capability to clean the road surface prior to spraying bituminous material.

2355.4 METHOD OF MEASUREMENT

The Engineer will measure the diluted bituminous material for fog seal by volume, at 60° F.

2355.5 BASIS OF PAYMENT

The Department will pay for fog seal on the basis of the following schedule:

Item No.:	Item:	Unit:
2355.506	Bituminous Material for Fog Seal	gallon

2356 BITUMINOUS SEAL COAT AND BITUMINOUS UNDERSEAL

2356.1 DESCRIPTION

This work applies to both a Bituminous Seal Coat, which goes on top of a bituminous surface and a Bituminous Underseal, which is placed beneath a new bituminous surface. This specification applies to both processes, unless it is specified only for the Bituminous Seal Coat or the Bituminous Underseal. The work consists of applying bituminous material, a single layer of aggregate, and a fog seal on a prepared surface.

2356.2 MATERIALS

A Bituminous Material

Provide CRS-2P bituminous material for seal coat meeting the requirements of 3151 E.1,

Provide Cationic Emulsified Asphalt for fog seal meeting 3151.2.D.1 or 3151.2.D.2.

B Seal Coat Aggregate

Provide aggregate meeting the gradation, job mix formula tolerance, and quality requirements of Tables 3127-1 and 3127-2, for the gradation specified in the Contract. If no requirements are specified in the Contract, provide aggregate meeting the requirements of Tables 3127-1 and 3127-2 for FA-3.

C Blank

D Water

Use potable water compatible with the seal coat and meeting the requirements of 3906, "Water for Concrete and Mortar".

E Seal Coat Design

Use the Minnesota Seal Coat Handbook, available on the MnDOT website, to design the seal coat and determine the starting application rate for the bituminous material and seal coat aggregate. Base the mix design on the traffic volume and pavement conditions.

Provide the following to the Engineer at least 2 weeks before beginning construction:

(1) Gradation and quality test results as specified in 3127.3,
(2) Seal coat aggregate design application rate,
(3) Bituminous material design application rate, and
(4) 150 lb sample of aggregate from each proposed aggregate source.

The Contractor cannot start work until submittal of the design and approval by the Engineer in accordance with the requirements of this section.

The Department considers the seal coat's design aggregate application rate as a target amount.

2356.3 CONSTRUCTION REQUIREMENTS

Any failure of QC or QA in the mix design submittal, pre-production and production gradation or quality tests constitute a Hold Point per 2356.3N. This includes test results, which are outside the job Mix formula tolerance of Tables 3127-1 and 3127-2.

Provide a remediation plan for all failures originating by any cause including a failing stockpile or poor handling procedures. Bucket blending of a stockpile to remediate for failing material is not acceptable. The remediation plan must be accepted by the Engineer.

A Weather, Time and Date Limitations

A.1 Bituminous Seal Coat

Apply the bituminous seal coat in accordance with the following:

(1) From May 15 to August 10, if located in the North or North-Central Road Spring Restriction Zone (Zones are defined on the MnDOT Pavement Design Website),
(2) From May 15 to August 31, if located south of the North and North-Central Spring Road Restriction Zone,
(3) Work only during daylight hours,
(4) Begin work when the pavement and air temperatures are 60º F and rising.
(5) The road surface may be damp, but ensure that the road is free of standing water, and
(6) Do not perform work during foggy weather.

A.2 Bituminous Underseal

Construct bituminous underseal operations (including traffic restrictions on the freshly constructed bituminous underseal) according to the following:

(1) The road surface may be damp, but there shall be no standing water.
(2) No construction is allowed in foggy weather.

(3) Follow restrictions for weather and date per 2360.3.A.4

B Equipment

B.1 Distributor

Use a distributor in accordance with 2360.3.B.2.d, "Distributor."

B.2 Aggregate Spreader

Use a self-propelled mechanical type aggregate spreader, mounted on pneumatic-tired wheels, capable of distributing the aggregate uniformly to the width required by the contract and at the design application rate.

B.3 Pneumatic-Tired Rollers

Provide at least three self-propelled pneumatic-tired rollers in accordance with 2360.3.B.2.e(2), "Pneumatic Tired Rollers."

B.4 Brooms

Provide motorized brooms with the following characteristics:

(1) Positive means of controlling vertical pressure,
(2) Capable of cleaning the road surface before applying bituminous material, and
(3) Capable of removing loose aggregate after seal coating.

C Road Surface Preparation

Clean pavements, including depressions, before seal coating.

Cover iron fixtures in or near the pavement to prevent adherence of the bituminous material.

Remove the protective coverings before opening the road to traffic.

D Application of Bituminous Material

D.1 Pre-Treat Longitudinal Pavement Markings

Apply bituminous material one (1) foot wide over all longitudinal pavement markings. Cover center line skip stripe with continuous coverage. Apply in a rate range of 0.10 to 0.15 gallons per square yard. Apply bituminous material for seal coat immediately after pre-treating pavement markings.

D.2 Application of Bituminous Material for Seal Coat

Begin the rate of application for the bituminous material as determined by the mix design. Construct a test strip 200 ft long to ensure the bituminous material application rate is adequate given the field conditions. After applying the bituminous material to this test strip, place the seal coat aggregate at the design application rate. Inspect the aggregate in the wheel paths for proper embedment. Make adjustments to the rate of application, if necessary. Construct one full lane width at a time.

Apply the bituminous material in accordance with Table 2356-2:

Table 2356-2
Recommended Application Temperatures

Bituminous Material	Minimum Temperature
CRS-2P	140 F*
CSS-1h	100 F

* Intended for uniform lay down of emulsion

E Application of Aggregate

Before construction, calibrate the aggregate spreader to meet the requirements of ASTM D 5624, in the presence of the Engineer. Maintain the aggregate application rate within ±1 lb per square yard of the design.

Provide uniformly moistened aggregates at the time of placement. Place aggregate within 1 min after applying the bituminous material. Do not use previously applied aggregates.

F Rolling Operations

Complete the initial rolling within 2 min after applying the aggregate at a speed no greater than 5 mph to prevent turning over aggregate. Make at least three complete passes over the aggregate. Roll the aggregate so the entire width of the treatment area is covered in one pass by all the rollers.

G Sweeping

Remove surplus aggregate on the same day as the seal coat construction. Re-sweep areas the day after the initial sweeping. Dispose of the surplus seal coat aggregate as approved by the Engineer.

H Protection of the Surface

Do not allow traffic on the seal coated road surface until after rolling is completed and the bituminous material has set.

I Protection of Motor Vehicles

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

J Application of Bituminous Material for Fog Sealing

The application of a fog seal is required for a Bituminous Seal Coat. A fog seal is not required for a Bituminous Underseal, unless the underseal is not paved within seven calendar days of the application of the underseal.

Apply fog seal to seal coated areas, after sweeping and before placement of permanent pavement markings.

Apply the fog seal in accordance with 2355, "Bituminous Fog Seal," and as modified as follows:

(1) Construct a 200 ft test strip,
(2) Review the application of diluted bituminous material and adjust the application rate as necessary to yield a uniform and full coverage of the underlying seal coat,
(3) Apply from 0.07 gal to 0.18 gal per sq. yd diluted,
(4) Apply the fog seal to minimize the amount of overspray, and
(5) Do not allow traffic on the fog seal until it has cured.

K Progress of Work

Allow the seal coat to cure for at least one day before fogging. Place interim pavement markings after the fog seal cures and before removal of traffic control. Do not place permanent pavement markings using latex paint before three days after placing the fog seal. Place all other types of permanent pavement markings at least 14 days after placement of the fog seal.

L Contractor Quality Control Testing

Sample and test according to the rates in the Schedule of Materials Control.

Submit test results to the Engineer within 24 hours of test completion.

Verify and report the average daily bituminous material application rate by dividing the volume used by the area covered.

If gradations fall outside of the Job Mix Formula Tolerance of Table 3127-1, but within specifications, stop placement and submit a new mix design.

M Agency Quality Assurance (QA) Sampling and Testing

Sample and test according to the rates in the Schedule of Materials Control.

N Hold Point

Any failure to meet a requirement creates a Hold Point, whereby no additional material may be placed until Corrective action and passing retest(s) have occurred, or accepted by the Engineer. All additional material placed before corrective action and passing retest(s) occur constitutes Unauthorized Work per 1512.2.

2356.4 METHOD OF MEASUREMENT

The Engineer will measure the bituminous material for fog seal per 2355.4. Conversion factors are located in the MnDOT Bituminous Manual.

The Engineer will measure the bituminous material for seal coat by volume at 60º F.

The Engineer will measure the seal coat by area of pavement surfaced.

2356.5 BASIS OF PAYMENT

For Bituminous Seal Coat, the Department will pay for bituminous material for fog seal in accordance with 2355.5, "Basis of Payment." For Bituminous Underseal, **payment for bituminous material for fog seal is incidental**.

The contract gallon price for accepted quantities of *Bituminous Material for Seal Coat,* including necessary additives, includes the costs of providing and applying the material as required by the contract.

The contract square yard unit price for *Bituminous Seal Coat* includes the cost of providing and applying the material as required by the contract. The contract square yard price for *Bituminous Seal Coat* includes the cost of all applied aggregate and all testing.

A Monetary Price Adjustments

The Engineer may allow the Contractor to accept a monetary price adjustment instead of removing and replacing failing materials in accordance with the following:

1) The Department will reduce the Contract price by 10 percent for each failing quality test per Table 3127-2.
2) The Department will reduce the contract price for bituminous seal coat by 0.5 percent for each 1 percent passing outside

of the requirements for any sieve as specified in 3127, "Fine Aggregate for Bituminous Seal Coat", except for the #200 sieve, as determined by QA testing.

3) The Department will reduce the contract price for bituminous seal coat by 2 percent for each 0.1 percent passing outside of the requirements for the #200 sieve as specified in 3127, "Fine Aggregate for Bituminous Seal Coat", as determined by QA testing.
4) The maximum monetary price adjustment is 50%. Material placed that has a cumulative monetary price adjustment greater than 50% is subject to remove and replace per 1512.1 "Unacceptable Work."

The monetary price adjustment for 2356.5.A.2 and 2356.5.A.3 are based upon the contract bid price for bituminous seal coat, however if the contract bid price is less than 75% of the Department's average bid price for Bituminous Seal Coat, the Engineer may use the average bid price to assess the monetary price adjustment.

The Department will add the monetary price adjustments for all failing test results together.

The Department will pay for Bituminous Seal Coat and Bituminous Underseal on the basis of the following schedule:

Item No.:	**Item:**	**Unit:**
2356.504	Bituminous Seal Coat	square yard
2355.506	Bituminous Material for Fog Seal	gallon
2356.506	Bituminous Material for Seal Coat	gallon

This page intentionally left blank

Appendix B. REFERENCES

1. Pavement Preservation & Recycling Alliance, www.roadresource.org

2. Report FHWA/TX-06/0-4391-1 - Guidelines for the use of underseals as a pavement moisture barrier published in November 2006

3. D.W. Janisch, *Reevaluation of Chip sealing Practices in Minnesota*, Transportation Research Record 1507, TRB, National Research Council, Washington, D.C. 1995.

4. J.R. Reed and G. Holleran, *Asphalt Emulsions: Definition, Manufacture and Usage.* Valley Slurry Seal Company. Congresso Eljectivo de Carreteras, Monterrey Mexico, October, 1996.

5. *Standard Specifications for Construction*. Minnesota Department of Transportation, St. Paul, MN, 1995, pp 697-700.

6. *Standard Specifications for Construction*. Minnesota Department of Transportation, St. Paul, MN, 2018, pp 171-175.

7. S. Shuler, *Chip seals for High Traffic Pavements.* Transportation Research Record 1259, TRB, National Research Council, Washington, D.C. 1990.

8. N.W. McLeod, *A General Method of Design for Chip seals and Surface Treatments,* Proceedings of the Association of Asphalt Paving Technologists, Volume 38. St. Paul, MN, 1969.

9. *A Basic Asphalt Emulsion Manual.* Manual Series No. 19 (MS-19). The Asphalt Institute. Lexington, KY, 1979.

10. *A Recommended Guideline for Single and Multiple Chip seals Using Asphalt Emulsion.* Asphalt Emulsion Manufacturers Association. Annapolis, MD, 1985.

11. D.J. Bullard, R.E. Smith, T.J. Freeman, *Development of a Procedure to Rate the Application of Pavement Maintenance Treatment,* Strategic Highway Research Program Report No. SHRP-M/FR-92-102. TRB, National Research Council, Washington D.C., 1992, pp 357-410.

12. *Standard Method of Determining the Flakiness Index and Average Least Dimension of Aggregates.* FLH Designation T 508. Central Federal Lands Highway Office. U.S. Department of Transportation.

13. *Chip Seal Checklist (2019).* Pavement Preservation Checklist Series, Federal Highway Administration.

This page intentionally left blank

Office of Materials and Road Research
Mailstop 645
1400 Gervais Avenue
Maplewood, MN 55109

General questions: 651-366-5592

Email: materialslab.dot@state.mn.us