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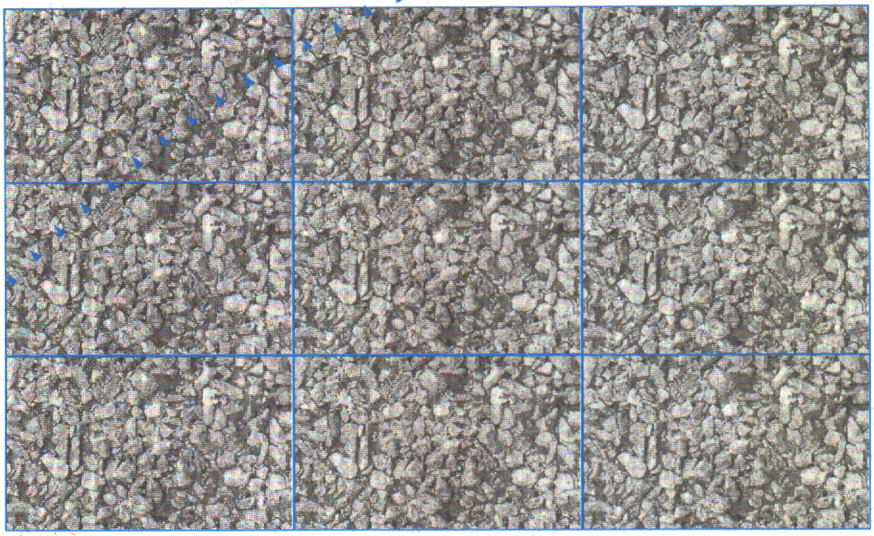

Minnesota Seal Coat Handbook

Minnesota Department of Transportation

Handbook

Minnesota Seal Coat Handbook

DRAFT

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The Minnesota Department of Transportation (Mn/DOT) has concluded a research study on the proper techniques involved in seal coating. A key part of the research project involved performing seal coat designs using the procedure developed by Norman McLeod. In addition, research personnel were present on many seal coat construction projects assisting the inspector and contractor. Based on the many phone calls from local agencies and requests for presentations on this material, it was felt that a handbook would be of extreme value. It should serve as a good reference for everyone involved in the process.

The primary purpose of this handbook is to provide a solid background in seal coat materials, equipment, design and construction for the field inspector. The field inspector chapter was written by an accomplished field inspector with many years of experience constructing high quality seal coat projects in the Minnesota.

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CHAPTER 1. SEAL COAT INTRODUCTION

Seal coating is a common preventive maintenance activity in Minnesota performed by most cities, counties and rural Mn/DOT districts (1). 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).

BENEFITS OF SEAL COATING

The primary reason to seal coat 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 seal coat 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 base material.

A secondary benefit of seal coating 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 an asphalt pavement surface. 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 course aggregate. As these aggregate particles begin to become smooth and polished, the roadway may become slippery, making it difficult to stop quickly. A seal coat increases the pavement texture and increases the surface friction properties.

CONDITIONS CONDUCIVE TO LONG LASTING SEAL COATS

In most cases, seal coating is done on roadways with low to moderate traffic volumes (up to several thousand vehicles per day). This is due to 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 seal coat high speed, high traffic roads such as interstate highways, special precautions must be taken when seal coats are placed on these types of roadways to minimize the chance of problems occurring. Refer to Chapter 7 of this handbook for more details.

Seal coats are affected greatly by weather conditions, especially during construction. The ideal conditions are a warm, sunny day with low humidity. Humidity and cool weather will delay the curing time and cause the seal coat to be tender for a longer period of time making it more susceptible to damage by traffic. Rain can cause major problems when seal coating. 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. Seal coating should **never** be done when showers are threatening. For information on what to do if it begins to rain during construction, refer to Chapter 5 of this handbook.

Roadways to be seal coated should also be in relatively good condition. This means that there should be little, if any, load related distress such as alligator cracking, rutting and potholes. If these conditions exist, the road should not be sealed unless it is repaired first.

In summary, seal coating is a good maintenance technique for pavements with the following:

- 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 SEAL COAT CONSTRUCTION

The two main materials used in seal coat 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 commonly used type of asphalt binder for seal coats in Minnesota is an asphalt emulsion. The other type of binder used for seal coating is cutback asphalt. However, their use has declined rapidly due to the costly and harmful solvents used.

Cutback Asphalt

A cutback asphalt consists of asphalt cement dissolved in a solvent, typically kerosene or naptha (gasoline). The solvent softens the asphalt cement and allows it to be pumped and sprayed at fairly low temperatures. As the solvent evaporates into the atmosphere, only the asphalt cement remains. Once the solvent has evaporated, the cutback has fully cured.

Asphalt Emulsion

An asphalt emulsion consists of the following three components:

- Asphalt Cement
- Water
- Emulsifying Agent (surfactant)

The asphalt cement makes up about two thirds of the volume of the emulsion. In Minnesota, most emulsions are made with a base asphalt in the 120-150 penetration range. This is the same range that most asphalt cements used in hot mix production are in. In some cases, latex or polymer modified asphalt is used to make emulsion. These modified emulsions are used to improve early chip retention and seal coat durability.

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 able to be 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 (2), Cationic (+) emulsions, such as CRS-2, 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 snow plows and vehicles. In Minnesota, the gradation of seal coat aggregate is referred to as either FA-1, 2, 3, 4 or 5 (3). The larger the number, the larger the aggregate. The FA stands for Fine Aggregate. By far, the most commonly used sizes are FA-2 and FA-3. An FA-2 (Figure 1.1) consists mainly of particles smaller than 1/4 inch. An FA-3 (Figure 1.2) consists mainly of the chips smaller than 3/8 inch.

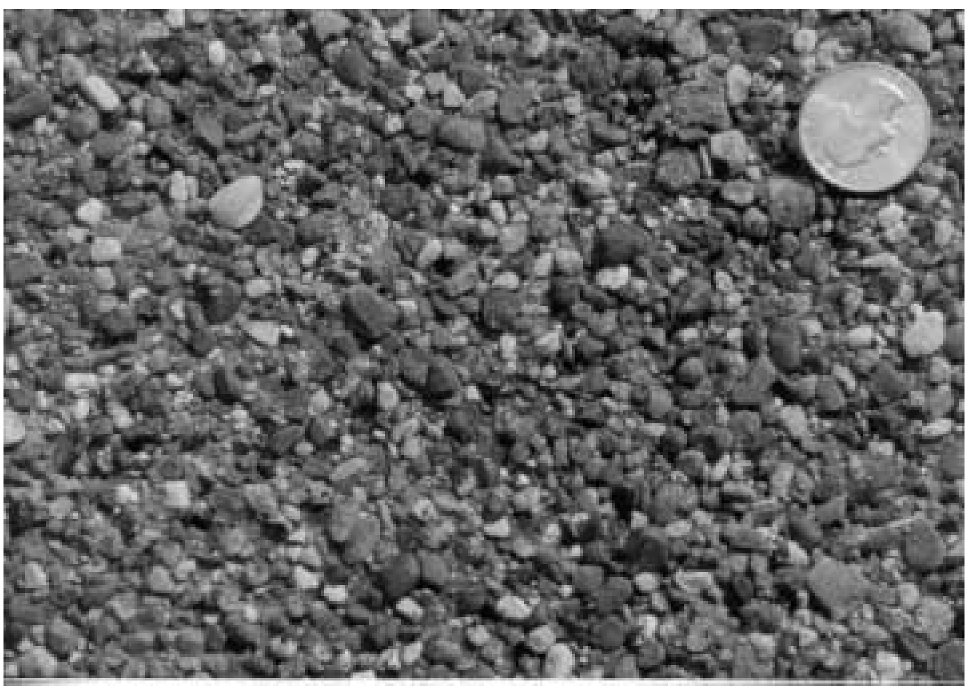

Figure 1.1. Example of an FA-2 Pea Rock (buckshot)

Figure 1.2. Example of an FA-3 Trap Rock

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 SEAL COAT CONSTRUCTION

There are several different types of equipment normally used to construct a seal coat. 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 Tired Rollers
- Haul Trucks
- Front End Loader
- Asphalt Tanker
- Miscellaneous Hand Tools

Power Brooms

There are two different types of power brooms used in seal coating. Seal coats constructed in rural settings typically use front mounted rotary sweepers (Figure 1.3) whereas those constructed in urban settings use pick-up sweepers (Figure 1.4). The brooms are used before the seal coat 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 seal coat has been constructed, the brooms are used to remove any excess aggregate not embedded into the binder.

Figure 1.3. Rotary sweeper typically used in rural areas

Figure 1.4. Pick-up sweeper typically used in urban areas

Asphalt Distributor

One of the key pieces of equipment on a seal coat 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 to 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 seal coat project. This allows one to continue to work while the other is being refilled by the tanker.

Figure 1.5. Computer controlled asphalt distributor

Figure 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 chips 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 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, drive side-by-side rolling the 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 1.8. Pneumatic tired rollers

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 seal coat 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 seal coat 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, seal coating is a common, cost effective, preventive maintenance activity involving a number of 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 seal coat project without experienced and qualified operators.

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CHAPTER 2. SEAL COAT AGGREGATE

Due 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 seal coat project.

Aggregate Types

The Mn/DOT specification 3127, "Fine Aggregate for Bituminous Seal Coat" (4) identifies the following four classes of aggregate:

> ***Class A*** aggregate consists of crushed quarry or mine trap rock (basalt, diabase, gabbro or other related igneous rock types), quartzite or granite. These are primarily 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. Primarily, 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.
>
> ***Class D*** aggregate consists of a mixture of any two or more of the above classes.

As with most any type of construction material, seal coat 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 Snow Plow 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. This will generally result in better protection against snow plow blades.
>
> ***Effect on Asphalt Binder Quantity:*** Class B and C aggregates will generally require more asphalt binder because they are much more absorptive than Class A aggregates.
>
> ***Cost***: Class C aggregates are less expensive than Class A or B aggregates due to the lack of crushing.
>
> ***Resistance to Turning & Scuffing:*** Because of crushing, Class A and B aggregates are much more angular than Class C aggregates and thus better able to withstand vehicle stopping and turning actions.

Aggregate Application Rate

When constructing a seal coat, the cover aggregate should be applied so it is only one-layer thick, unless a double or choke seal is being constructed (see Chapter 8). 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 slight excess of aggregate, about 5 or 10 percent, can help reduce the scuffing caused by vehicle tires turning on the fresh, uncured, seal coat.

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 seal coats constructed with flat and elongated aggregate. The flatter the aggregate, the more susceptible the seal coat will be to either bleeding in the wheelpaths or excessive chip loss in the non-wheelpath areas. This is because traffic causes any flat chips in the wheelpath to lie on their flattest side. This results in a thinner seal coat in the wheelpath than in the non-traffic areas as shown in Figure 2.1. If the binder is applied too thick in the wheelpaths, 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 snow plows blades.

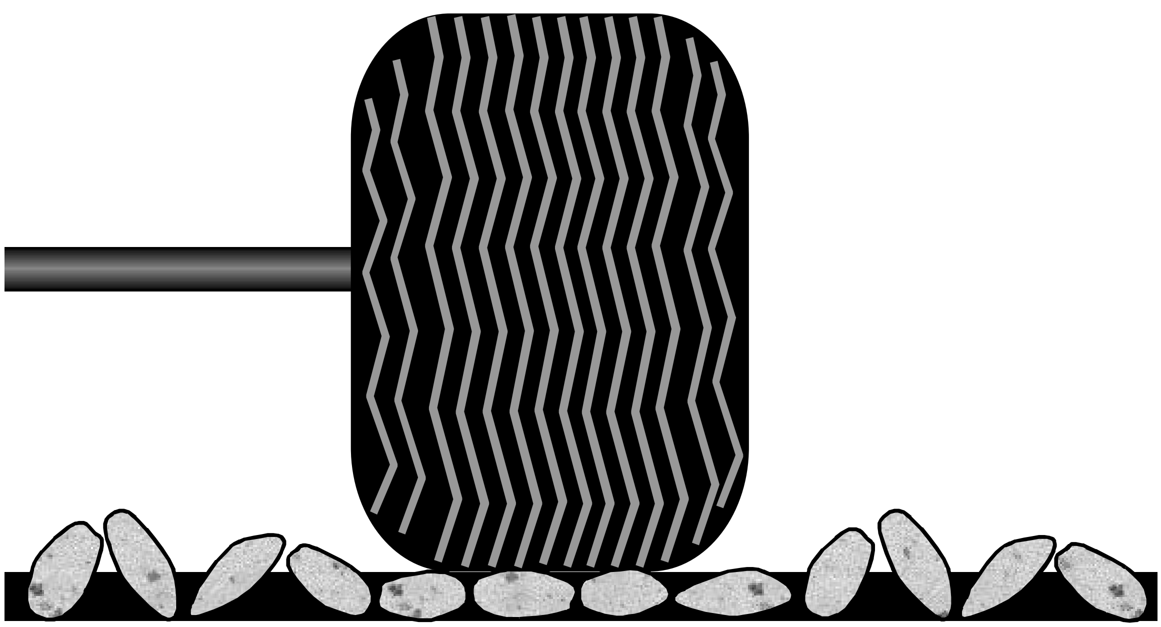

Figure 2.1. Traffic causes flat chips in the wheelpath to lay down on their flattest side.

On low volume roadways and parking lots, this difference in seal coat thickness may not become 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 wheelpath, 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 seal coat height will be essentially the same and chip embedment will be uniform.

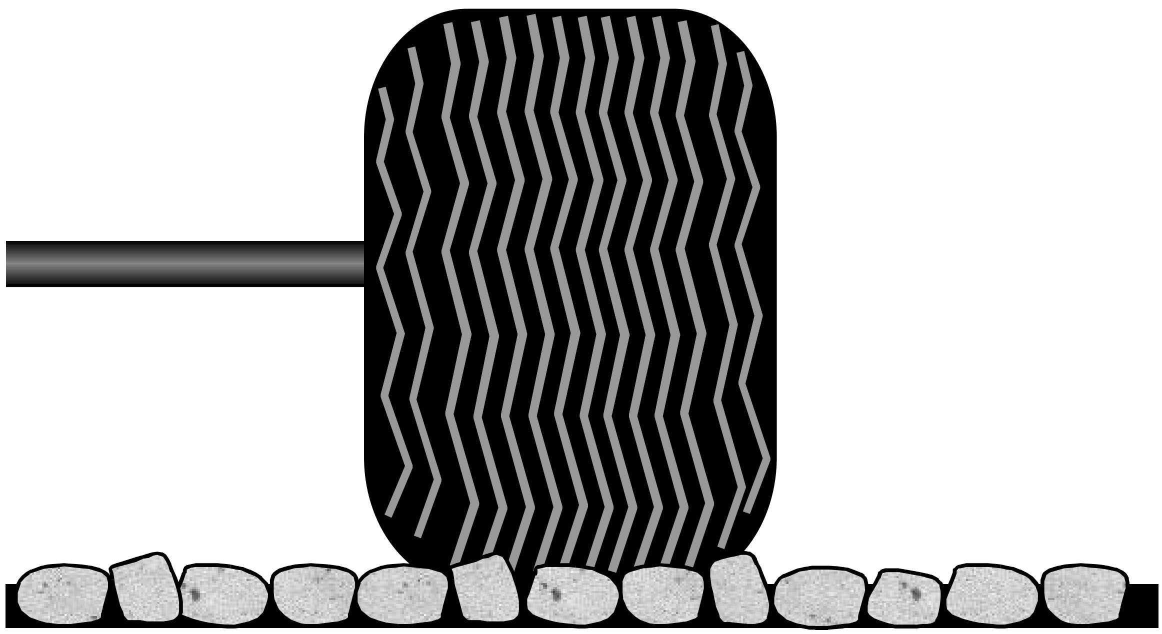

Figure 2.2. Traffic has little effect on cubical aggregate

The way to measure the flatness of an aggregate is the Flakiness Index (see Chapter 4). 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 30 percent should not be used for seal coating. On high volume roadways, the Flakiness Index should not exceed 20 percent.

Tips for using Flat Aggregate:

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

- Flat aggregate should not be used on high volume roadways, period. There will either be too much binder in the wheelpaths or not enough between them. For high volume roadways, a cubical aggregate with a Flakiness Index of 20 percent or less should be used.
- Use a little extra aggregate (5-10%) in the wheelpaths 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 wheelpath will likely be covered with the binder. The excess aggregate will help to prevent them from sticking to vehicles.

- Modify the spray bar on the asphalt distributor so that is has smaller nozzles in the wheelpaths than it does in the areas between them. This results in more binder in the non-traffic areas than in the traffic areas. This technique has been used successfully in Texas to chip seal high volume roadways (5).

Impact of Aggregate Roundness

The roundness of the aggregate will determine how resistant the seal coat will be to turning and stopping movements. Round aggregates are much more susceptible to rolling and displacement by traffic than angular aggregates, which tend to lock together better. Because of their shape, it is very difficult to achieve this same result with round aggregate unless the aggregate is extremely graded. The graded aggregate will allow the smaller stones to fill in the areas between the larger ones. However, as explained later in this handbook, graded aggregate has many problems of its own.

Tips for using round aggregate:

- When using a round aggregate, use a one-size gradation. Since round aggregates are more easily dislodged by snow plows, due to their lack of locking together, using a one-size aggregate will help prevent the plow blade from shaving off the tall stones.

- Extra care must be taken when constructing seal coats with round aggregate to ensure the proper embedment will be achieved. Due to their shape, seal coats constructed with round aggregate tend to be more susceptible to snow plow damage unless the chips are deeply embedded into the binder.

- 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 seal coats, one on top of the other. The aggregate used for the top layer is roughly half the size of the aggregate on the bottom layer. When the second layer of binder is applied, the bottom stones are 100 percent embedded. The smaller stones in the top layer are too small to cause windshield damage. In addition, the surface is generally smoother than a single seal, which minimizes snow plow damage.

Aggregate Gradation

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

One-Size Aggregate

The best seal coat gradations are those that are essentially one-size. An aggregate is considered one-size if nearly all of 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 2.3.

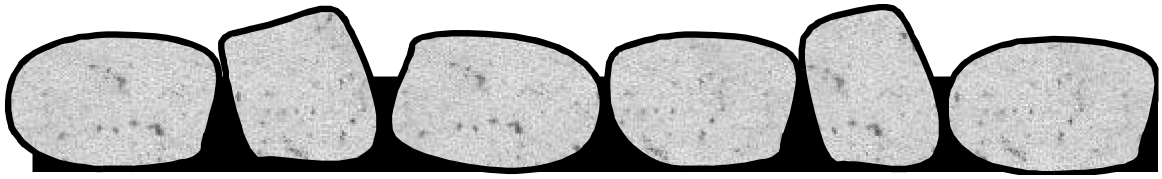

Figure 2.3. Cross section of a one-size seal coat aggregate

Notice that all of the chips are fairly close to the same size. Also, notice 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 because if one particle is embedded properly, nearly all of the others are also.

- Better drainage due to clear 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 dense graded to gap graded. The more graded an aggregate is, the less desirable it will be for seal coat construction. Because graded aggregates have lower air voids, there is less room to fit the binder in between the chips. 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 will increase the chance of bleeding as the binder is squeezed out of the matrix by traffic.

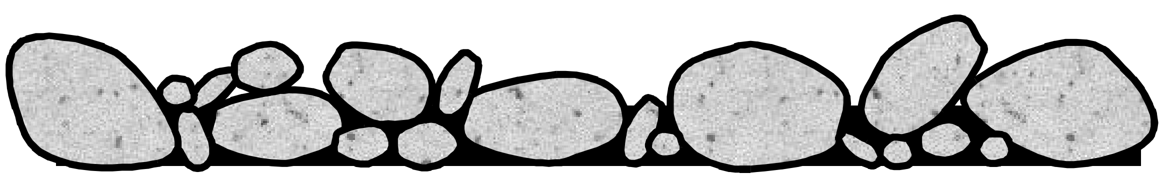

Figure 2.4. Cross section of a graded seal coat aggregate

Some problems with using graded aggregate are:

- Some of the larger particles project so far above the average thickness of the seal coat they are torn out of the surface by vehicle tires and snow plow blades.

- Some of the smaller particles are so small that they are completely submerged into the asphalt binder which causes 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 the larger particles and yet not submerge too many of the smaller particles.

The two most often used seal coat gradations in Minnesota are the Mn/DOT FA-2 and FA-3 gradations. Both are considered to be graded aggregates. However, within both of these gradation bands there is the possibility of a fairly one-size gradation as well as a very graded one.

Figure 2.5. Example of a one-size FA-4 seal coat aggregate

Figure 2.6. Example of a graded seal coat aggregate.

Dusty Aggregate

Aggregates containing dust should not be used for seal coating unless certain precautions are taken. To avoid dusty aggregate, the specified aggregate gradation should have 1 percent or less passing the #200 sieve (75 μm). Dust will coat the outside of the aggregate particles and prevent 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 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 is allowed to dry.

- Use a high-float emulsion, such as HFMS-2. 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 with the aggregate particles.

- Pre-coat the chips with asphalt cement. This technique involves putting the aggregate through an asphalt plant and coating it lightly with asphalt. This will bond the dust to the aggregate.

Figure 2.7. Evidence of a dusty aggregate

Figure 2.8. Dusty aggregate before sweeping

Figure 2.9. Dusty aggregate after sweeping (notice most of the large aggregate is missing)

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CHAPTER 3. ASPHALT BINDERS

The main reason asphalt is used in road applications is 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
- Making a cutback asphalt
- Making an asphalt emulsion

The two methods most often used for constructing seal coats are using cutback asphalts and asphalt emulsions.

CUTBACK ASPHALTS

Cutback asphalts (liquid asphalts) are asphalts that are dissolved in a petroleum solvent (cutter). Typical solvents include naptha (gasoline) and kerosene. The type of solvent controls the curing time of the cutback and thus when it will obtain its ultimate strength. Rapid curing cutbacks use naptha (gasoline) while medium curing cutbacks use kerosene. The amount of cutter affects the viscosity of the cutback asphalt. The higher the cutter content, the lower the viscosity and the more fluid it will be. The use of cutbacks has declined rapidly over the years due to concerns over pollution and health risks as the solvents evaporate into the atmosphere.

One advantage cutbacks have over emulsions is a much higher residual asphalt percent, typically over 80 percent. This compares with just over 65 percent for asphalt emulsions. The result is more asphalt cement left on the roadway after curing, for the same volume of binder applied.

Cutback Classification

Cutbacks are divided into two classifications, Rapid-Curing (RC) and Medium-Curing (MC) depending on the solvent used. They are further defined by a number which indicates the minimum kinematic viscosity (fluidity) of the cutback. The lower the number, the more fluid the cutback is. The shaded grades in Table 3.1 are the ones typically used for seal coating.

Table 3.1. Cutback Asphalt Grades and Properties (Mn/DOT 3151.2B & 3151.2C)

Cutback Grade	Curing Speed	Viscosity of Cutback[A]	Penetration of Residue[B]
MC-30	Medium	30 - 60	120 - 150
MC-70	Medium	70 - 140	120 - 150
MC-250	Medium	250 - 500	120 - 150
MC-800	Medium	800 - 1,600	120 - 150
MC-3000	Medium	3,000 - 6,000	120 - 150
RC-70	Rapid	70 - 140	80 - 120
RC-250	Rapid	250 - 500	80 - 120
RC-800	Rapid	800 - 1,600	80 - 120
RC-3000	Rapid	3,000 - 6,000	80 - 120

[A]Kinematic viscosity of the cutback at 140 deg.F (60 deg.C), centistokes
[B]Penetration of the residue at 77 deg.F (25 deg.C), 100g, 5 sec.

ASPHALT EMULSIONS

An emulsion is one phenomena that occurs when you mix two incompatible components together. Common examples of emulsions are milk, margarine, butter, beer and paint. Emulsions are made up of two components with one dispersed in the other. Maintaining the dispersion requires some way of overcoming the lack of compatibility. The methods that have been found to work over many years are high shear blending and chemical treatment. An asphalt emulsion consists of asphalt particles dispersed in water and chemically stabilized as shown in Figure 3.1.

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 soluble in water, keeping it dispersed in fine particles is a significant feat.

Emulsion Classification

Emulsions are divided into three grades for classification: cationic , anionic and non-ionic. In practice, only the first two types 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.

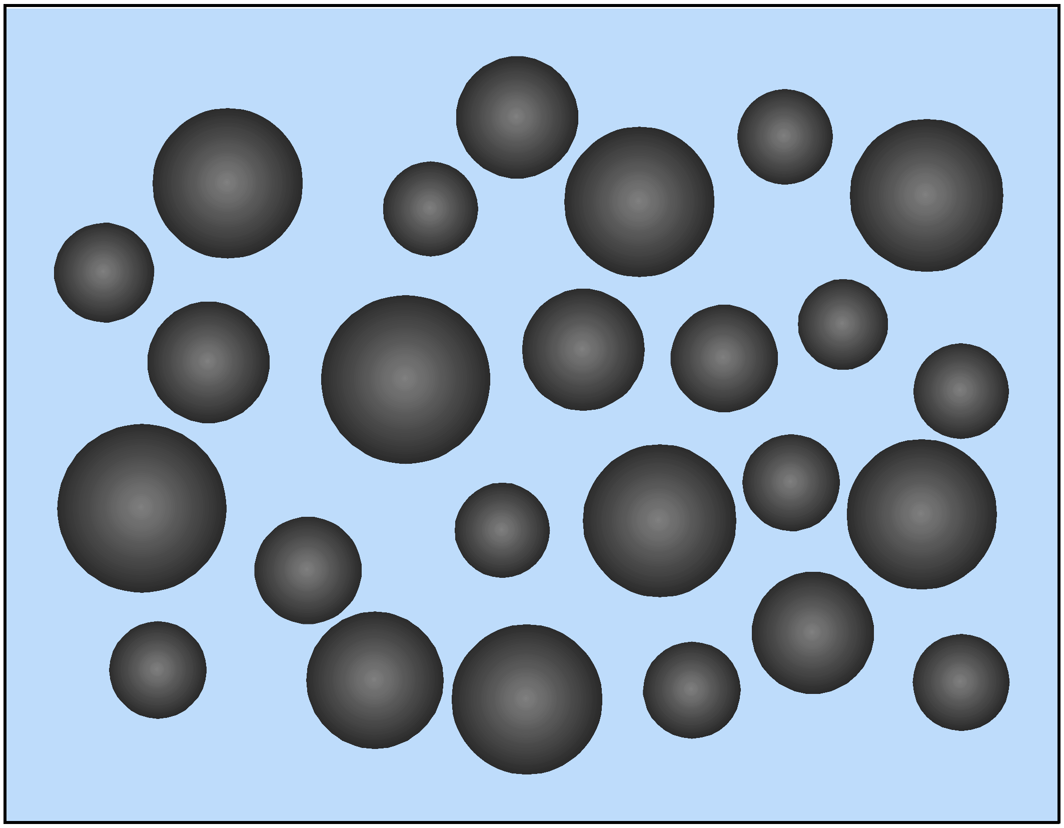

Figure 3.1. Asphalt emulsion

In addition to being classified by their electrical charge, emulsions are further classified according to how quickly they will 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 grades in the following tables which are shaded are suitable for seal coat projects.

Table 3.2. Anionic (-) Emulsified Asphalt Grades (Mn/DOT 3151.2E)

Grade	Setting Speed	Viscosity of Emulsion[A1]	Penetration of Residue[B]
RS-1	Rapid	20 - 100	100 - 200
RS-2	Rapid	75 - 400[A2]	100 - 200
HFRS-2	Rapid	75 - 400[A2]	100 - 200
MS-1	Medium	20 - 100	100 - 200
MS-2	Medium	≥100	100 - 200
MS-2h	Medium	≥100	60 - 100
HFMS-1	Medium	20 - 100	100 - 200
HFMS-2	Medium	≥50[A2]	100 - 200
HFMS-2h	Medium	≥50[A2]	60 - 100
HFMS-2s	Slow	≥50[A2]	≥200
SS-1	Slow	20 - 100	100 - 200
SS-1h	Slow	20 - 100	60 - 100

[A1]Emulsion Viscosity, Saybolt Furol at 77 deg.F (25 deg.C), sec.
[A2]Emulsion Viscosity, Saybolt Furol at 122 deg.F (50 deg.C), sec.
[B]Penetration of Residue at 77 deg.F (25 deg.C), 100 g, 5 sec.

Table 3.3. Cationic (+) Emulsified Asphalt Grades (Mn/DOT 3151.2E)

Grade	Setting Speed	Viscosity of Emulsion[A1]	Penetration of Residue[B]
CRS-1	Rapid	20 - 100	100 - 250
CRS-2	Rapid	100 - 400	100 - 250
CMS-2	Medium	50 - 450	100 - 250
CMS-2h	Medium	50 - 450	60 - 100
CSS-1	Slow	20 - 100[A2]	100 - 250
CSS-1h	Slow	20 - 100[A2]	60 - 100

[A1]Emulsion Viscosity, Saybolt Furol at 122 deg.F (50 deg.C), sec.
[A2]Emulsion Viscosity, Saybolt Furol at 77 deg.F (25 deg.C), sec.
[B]Penetration of Residue at 77 deg.F (25 deg.C), 100 g, 5 sec.

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 3.2 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 shows a cationic emulsified asphalt particle.

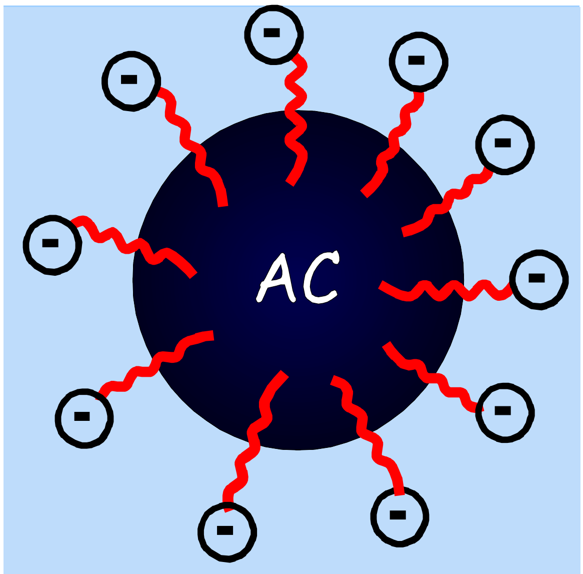

Figure 3.2. Anionic (-) Emulsion

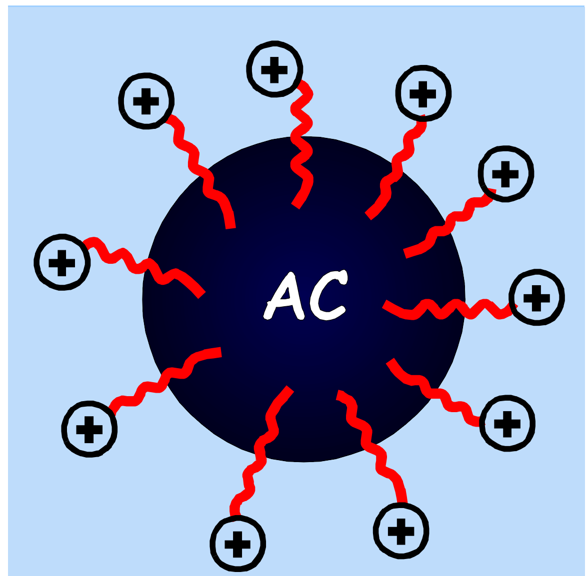

Figure 3.3. Cationic (+) emulsion

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 due to it's attraction to the surface of the aggregate. Since asphalt is heavier than water, the asphalt particles will settle to the bottom of the solution.

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 seal coating, this occurs as the water evaporates out of the emulsion. In Minnesota, the most commonly used anionic emulsion for seal coating 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 3.4 and 3.5. The size of the charge, affects stability, ie. 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 commonly used cationic emulsion is CRS-2.

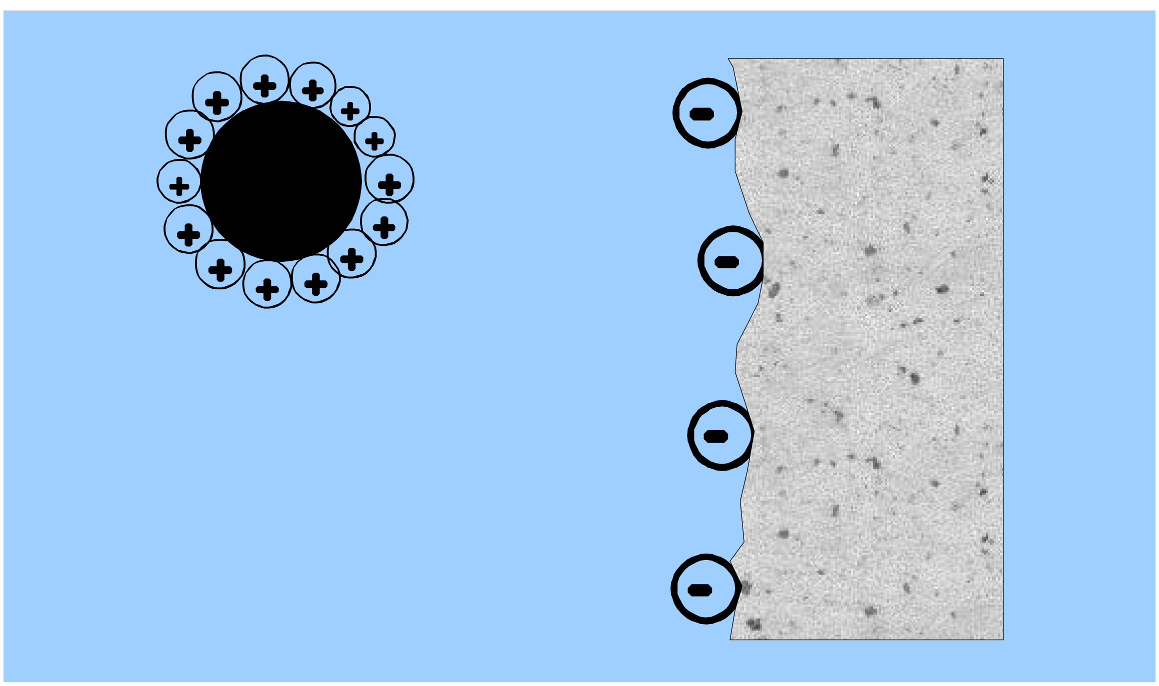

Figure 3.4. Cationic Emulsion before "breaking".

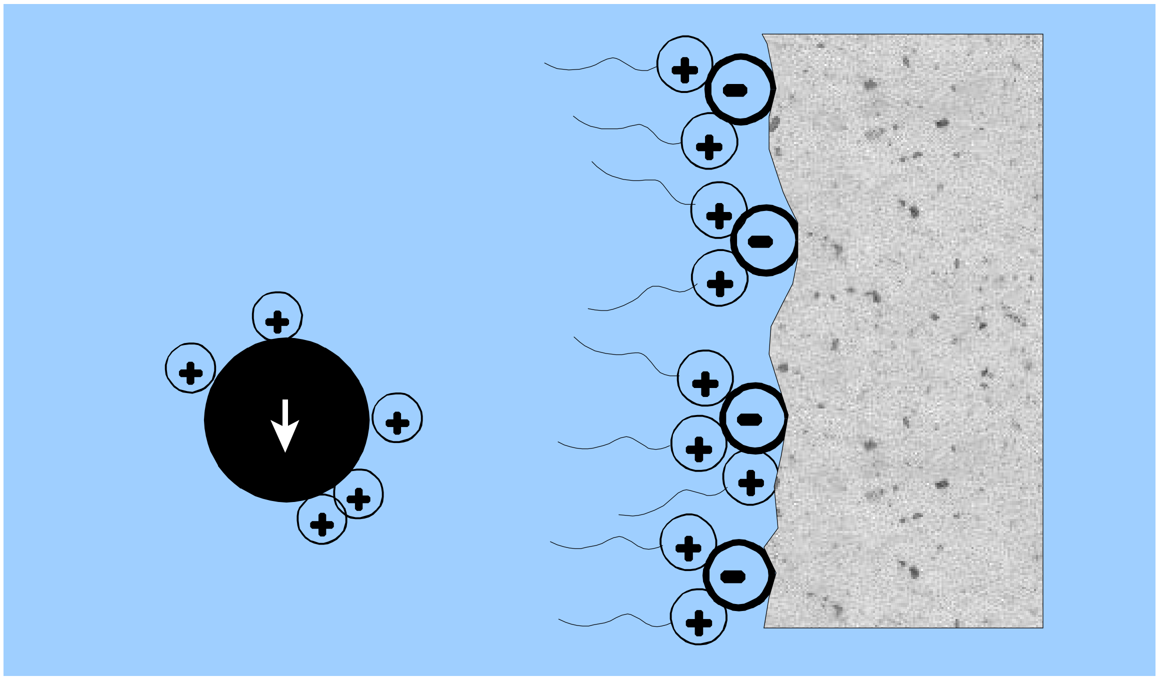

Figure 3.5. Cationic emulsion beginning to “break”

Polymer Modified Emulsions

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. Typically, about 2.5 to 3 percent polymer, by weight, is added to the emulsion.

Advantages of using polymers are:

- Increased viscosity of the residual asphalt which helps to minimize bleeding
- Better early chip retention due to increased early stiffness
- Enhanced flexibility over time

The main disadvantage of using polymer modified emulsions is the additional cost. Modified emulsions typically cost 30 percent more than conventional emulsions. However, in high traffic areas where windshield damage is a concern, the added cost is often warranted.

ADVANTAGES OF ASPHALT EMULSIONS

The main advantages of using emulsions rather than cutbacks can be summarized in terms of pollution control and safety.

Pollution Control

Kerosene and gas fumes are green house gases. In a cutback, they evaporate into the air and become pollutants. The cutbacks are designed this way. In an emulsion, there are no such pollutants.

Safety

Since 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).

STORAGE AND HANDLING OF ASPHALT EMULSIONS

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.

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 coarser 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 shrink. In an emulsion, this means that the asphalt droplets get closer together. Thus, if the emulsion gets too cold, the asphalt particles can become too close together causing the emulsion to revert back to asphalt cement.

When materials get hot they expand. Thus for an emulsion, heating is a useful thing. However, when water gets hot its evaporation rate increases enormously. If the water leaves the emulsion, the asphalt droplets get closer together and can go back to asphalt cement. If any part of the emulsion gets hotter than 200°F (95°C), localized boiling may occur causing the droplets back to asphalt cement.

This has a number of important results:

- When heating emulsion, do it gently and only 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 a fire or blow torch.

Cleaning

For emulsions, cleanliness is very important. A sloppy operation will produce problems. When an emulsion comes in contact with air it can begin to break. When a cationic emulsion comes into contact with metal it can also begin to break. Thus, if a pump is left without flushing it will clog. If lines are left part full of emulsion they will clog. The higher the performance of the emulsion the more critical cleaning is. Cleaning should be done before storage of equipment and it should be done thoroughly.

Cleaning Procedure:

1. Flush thoroughly with WATER.

2. Flush with kerosene, not diesel, distillate or other solvent. While these materials may cut asphalt cement but they are also incompatible with the emulsion and may break it rather than allow it to be flushed away.

3. Finish with a water flush. DO NOT FLUSH INTO THE EMULSION TANK.

4. If the pump or line is already clogged with asphalt cement, gentle heat may be applied at the blockage. Do not apply up the line as this will break the emulsion there.

5. Soak pumps with kerosene for an hour or more.

6. Reflush with water after blockage is removed.

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CHAPTER 4. SEAL COAT DESIGN

Seal coats should be designed to ensure that the proposed materials are of sufficient quality and have the desired properties required for a successful seal coat project. In addition, the design will determine the proper amount of cover aggregate and bituminous binder to apply. The design procedure recommended by the author is based on the one first presented in the late 1960's by Norman McLeod (5). This procedure was later adapted by the Asphalt Institute (6) and the Asphalt Emulsion Manufacturers Association (7). 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 (8).

ASPHALT BINDER CONSIDERATIONS

In both cutback asphalts and asphalt emulsions, a portion of the binder is comprised of either cutter (cutbacks) or water (emulsions) which will evaporate as the binder cures. This will result in a collapse of the asphalt film; effectively reducing the height of the binder. In designing a seal coat, 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 cutter or water has evaporated out of the binder.

As shown in Figure 4.1 cutback asphalts generally consist of about 85 percent asphalt cement and 15 percent cutter, by weight. Since the specific gravity of asphalt is very close to 1.0, this works out to about 85 percent asphalt cement and 15 percent cutter by volume. Asphalt emulsions generally consist of about two-thirds asphalt cement, with the remainder being water and emulsifier.

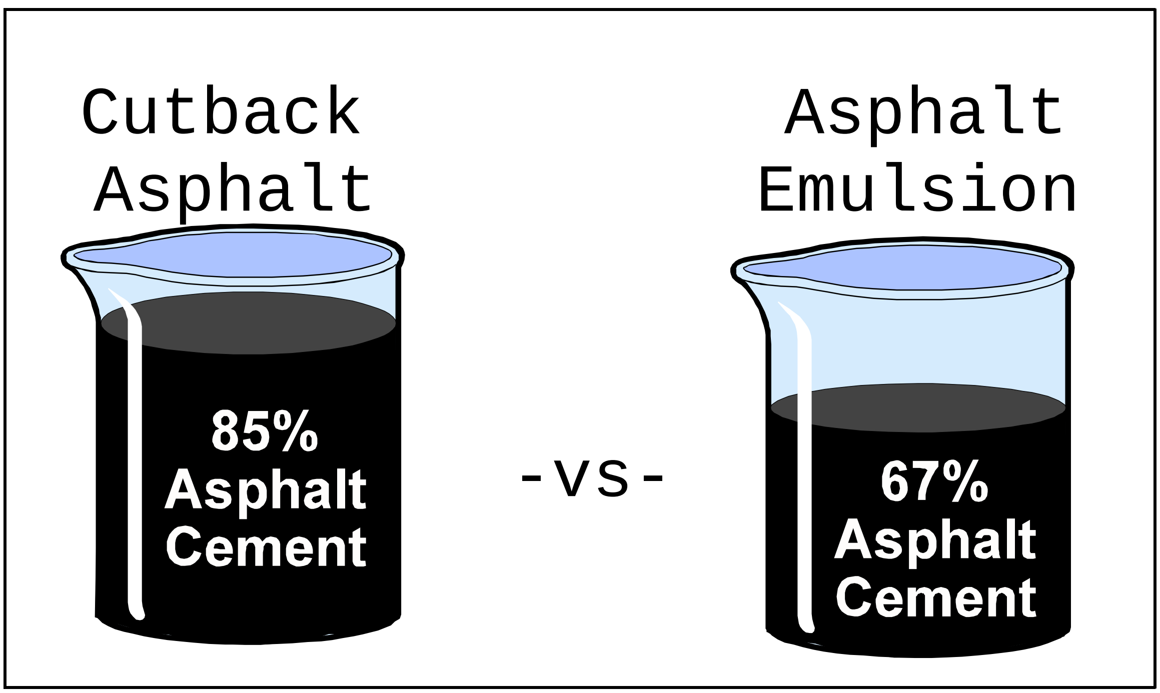

Figure 4.1. Comparison of the residual asphalt content of different binders.

In Minnesota, many agencies reported problems when first switching from cutbacks to emulsions. Most of the problems occurred because they were applying the same amount of emulsion as they had been with cutbacks. This results in approximately 20 percent less asphalt cement on the pavement *after* curing. This lack of binder led to excessive chip loss and lack of confidence in asphalt emulsions. This problem can be avoided if the concept of residual asphalt is understood.

In order for aggregate particles to remain on the roadway, they need to have approximately 70 percent of their height embedded into the *residual asphalt*. For this to occur with an asphalt emulsion, the binder must rise near the top of the aggregate particles. This is demonstrated in the Figure 4.2. 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 seal coat is exposed to snow plows and traffic.

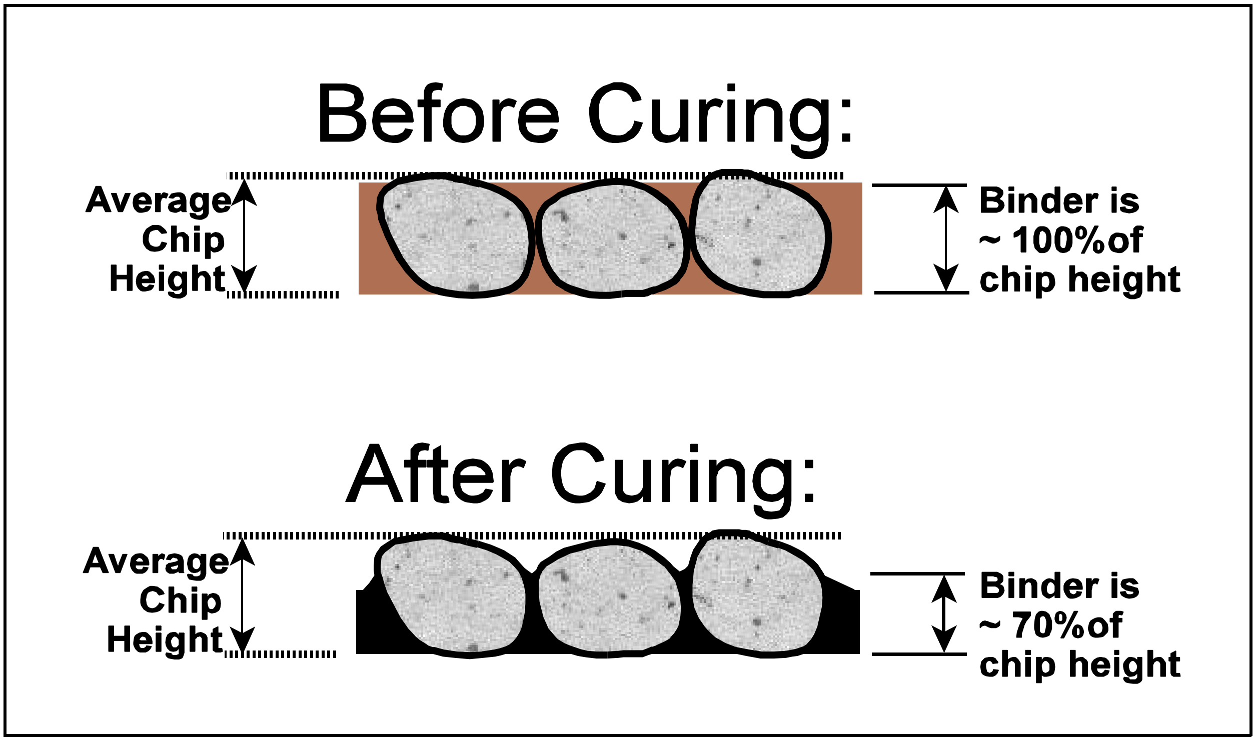

Figure 4.2. Change in volume after emulsion has cured.

Refer to Chapter 3 of this handbook for more details on asphalt binders used in seal coat construction.

COVER AGGREGATE CONSIDERATIONS

When designing a seal coat, 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 the aggregate 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 seal coat aggregate is one-size. This means that most every chip is the same size. A one-size aggregate 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 better the seal coat is able to withstand turning and stopping of vehicles as well as damage from snow plows.

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 seal coat 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 or meter of pavement than it will of 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 due to lack of embedment.

THE McLEOD DESIGN PROCEDURE

In the McLeod 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.

In Minnesota, the McLeod design procedure has been modified to apply slightly more binder in order to minimize snow plow damage in the non-wheelpath 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 seal coat 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 to be **70 percent filled with asphalt cement** for good performance on pavements with moderate levels of traffic.

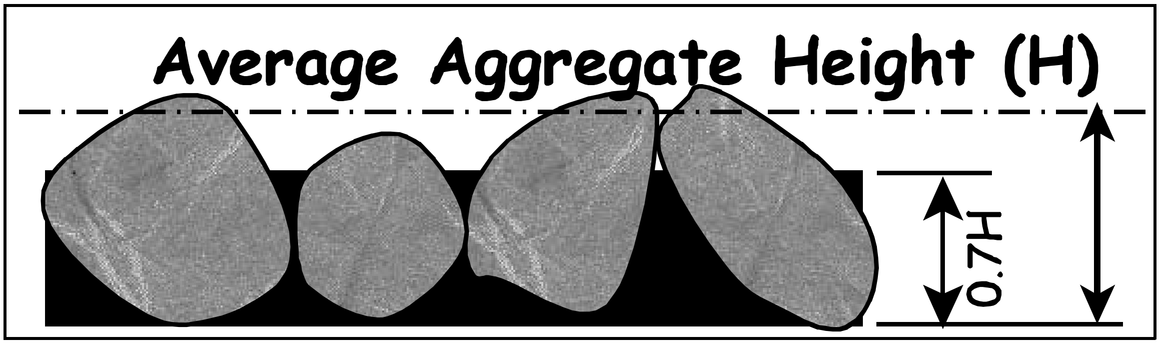

Figure 4.3. McLeod design: One-stone thick & Proper embedment

Figure 4.4 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 4.4. Proper embedment (~70%) into the residual asphalt.

The 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 4.1 Sieve nest for seal coat 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 4.5. Seal Coat Sieve Nest

Flakiness Index

The Flakiness Index (FI) is a measure of the percent, by weight, of flat particles. It is determined by testing a small sample of aggregate particles for their ability to fit through a slotted plate (Figure 4.6).

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 to be flat. If not, they are considered to be 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 (9).

The five slots in the plate 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 (9.5 mm).
- Slot 3: Material passing the 1/2 in. sieve (9.5 mm) but retained on the 3/8 in. sieve (6.3 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 4.6. Flakiness Index Testing Plate

For most seal coat aggregate in Minnesota only the smallest three slots are used. This is because most seal coat projects do not use 1, 3/4 or 1/2 inch (25, 19 or 12.5 mm) stone. The weight of material passing all of 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 seal coat 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:

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

Where:

H	=	Average Least Dimension, inches or mm
M	=	Median Particle Size, inches or mm
FI	=	Flakiness Index, in percent

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 takes. 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 4.7. 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 near 50 percent for one-size aggregate, less for graded aggregate. After initial rolling, the voids are assumed to be reduced to 30 percent and will reach a low of about 20 percent after sufficient traffic has oriented the stones on their flattest side. However, if there is very little traffic, the voids will remain near 30 percent and the seal coat will require more binder to ensure good chip retention. One of the following equations is used to calculate the voids in the loose aggregate:

U.S. Customary Units:

$$V = 1 - \frac{W}{62.4G} \tag{2}$$

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:

$$V = 1 - \frac{W}{1000G} \tag{3}$$

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 taken into account 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 4.2 can be used as a guideline for determining the specific gravity of typical seal coat aggregates in Minnesota.

Table 4.2. Typical Bulk Specific Gravity of Common Seal Coat 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 4.3 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 2 percent. The author recommends using this correction if the absorption is 1.5 percent or higher.

Table 4.3. Typical Absorption of Common Seal Coat 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. Generally speaking, 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 seal coat to be as thin as possible. If this is not taken into account, the wheelpaths will likely bleed. The McLeod design procedure uses Table 4.4 to estimate the required embedment, based on the number of vehicles per day on the roadway.

Table 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 thrown to the side of the roadway be passing vehicles as the fresh seal coat is curing. The amount of aggregate that will do this is related to the speed and number of vehicles on the new seal coat. 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 for low volume, residential type traffic and 10 percent for higher speed roadways such as county roads . The traffic whip-off factor is shown in Table 4.5.

Table 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 4.6 to add or reduce the amount of binder to apply in the field.

Table 4.6. Surface Correction Factor, S

Existing Pavement Texture	***Correction, S***	
	S.I. Metric (L/m^2)	*U.S. Customary (gal/yd^2)*
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 of these conditions should they change at some point throughout the project.

Most agencies 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 sealed in a given project will need the same amount of asphalt binder.***

Examples of some of these pavement conditions are shown in Figures 4.8 to 4.11.

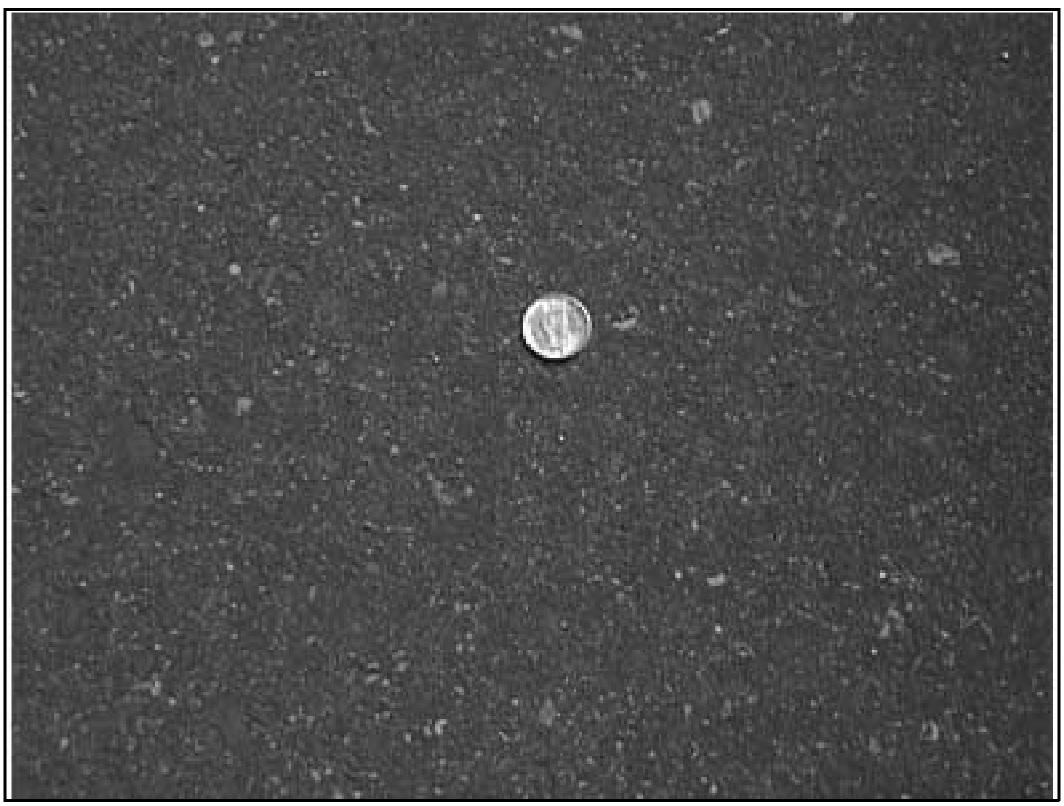

Figure 4.8. Example of a smooth, non-porous surface

Figure 4.9. Example of a slightly porous and oxidized surface.

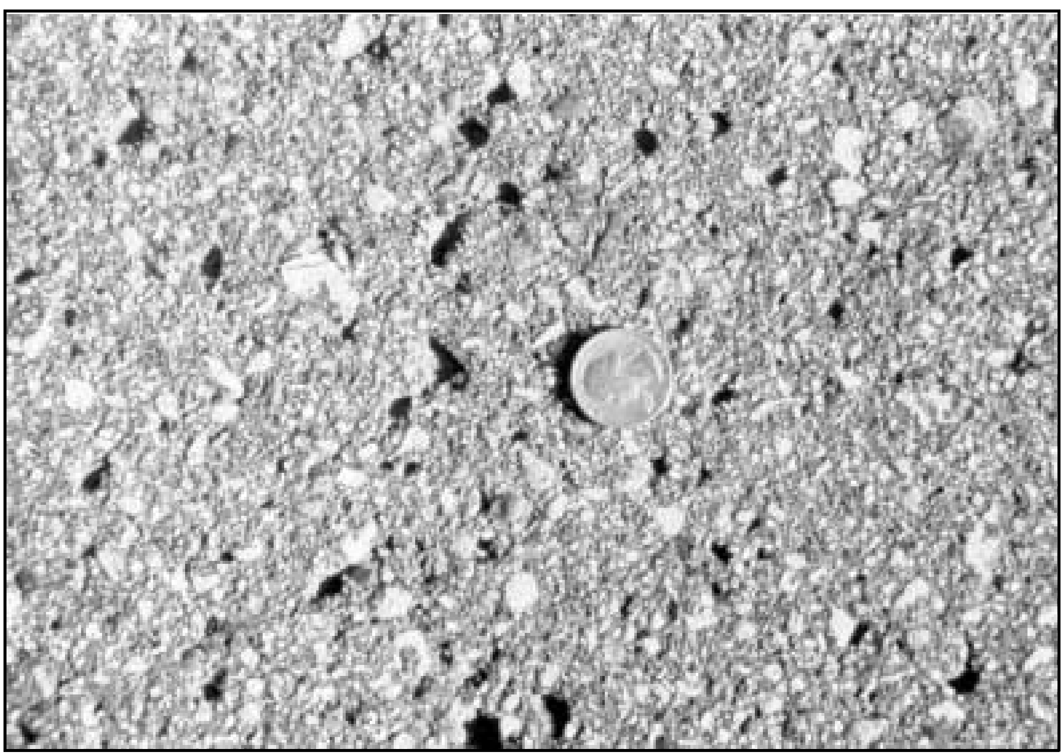

Figure 4.10. Example of a slight pocked, porous and oxidized surface.

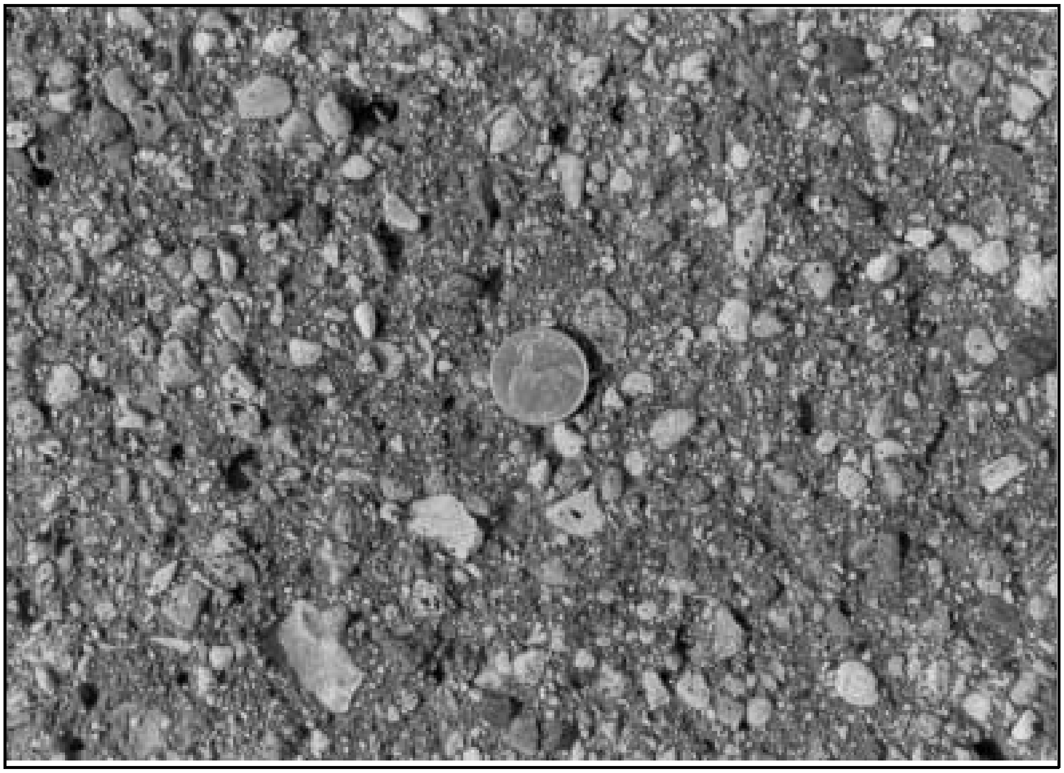

Figure 4.11. Example of a badly pocked, porous and oxidized surface.

McLEOD SEAL COAT DESIGN EQUATIONS

Once all of the lab testing is 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:

$$C = 46.8(1 - 0.4V)HGE \tag{4}$$

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:

$$C = (1 - 0.4V)HGE \tag{5}$$

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)

Binder Design Equation

Binder application rates are determined from the following equations:

U.S. Customary Units:

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

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, gal/yd^2 (based on existing surface, Table 4.6)
A = Aggregate Absorption Factor, gallons/yd^2
R = Residual Asphalt Content of Binder, in percent expressed as a decimal.

S.I. Metric Units:

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

Where:

B = Binder Application Rate, liters/m^2
H = Average Least Dimension, mm
T = Traffic Factor (based on expected vehicles per day, Table 4.4)
V = Voids in Loose Aggregate, in decimal percent (Equation 3)
S = Surface Condition Factor, liters/m^2 (based on existing surface, Table 4.6)
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 snow plow 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 give 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 5 of this manual. It has been found that if this is not done, insufficient binder will exist in the non-traffic areas and snow plows 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.

SEAL COAT DESIGN EXAMPLE

A 150 pound (68 kg) sample if an FA-3 granite seal coat 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 the 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 to be theoretical because there may not actually be any stones that size.

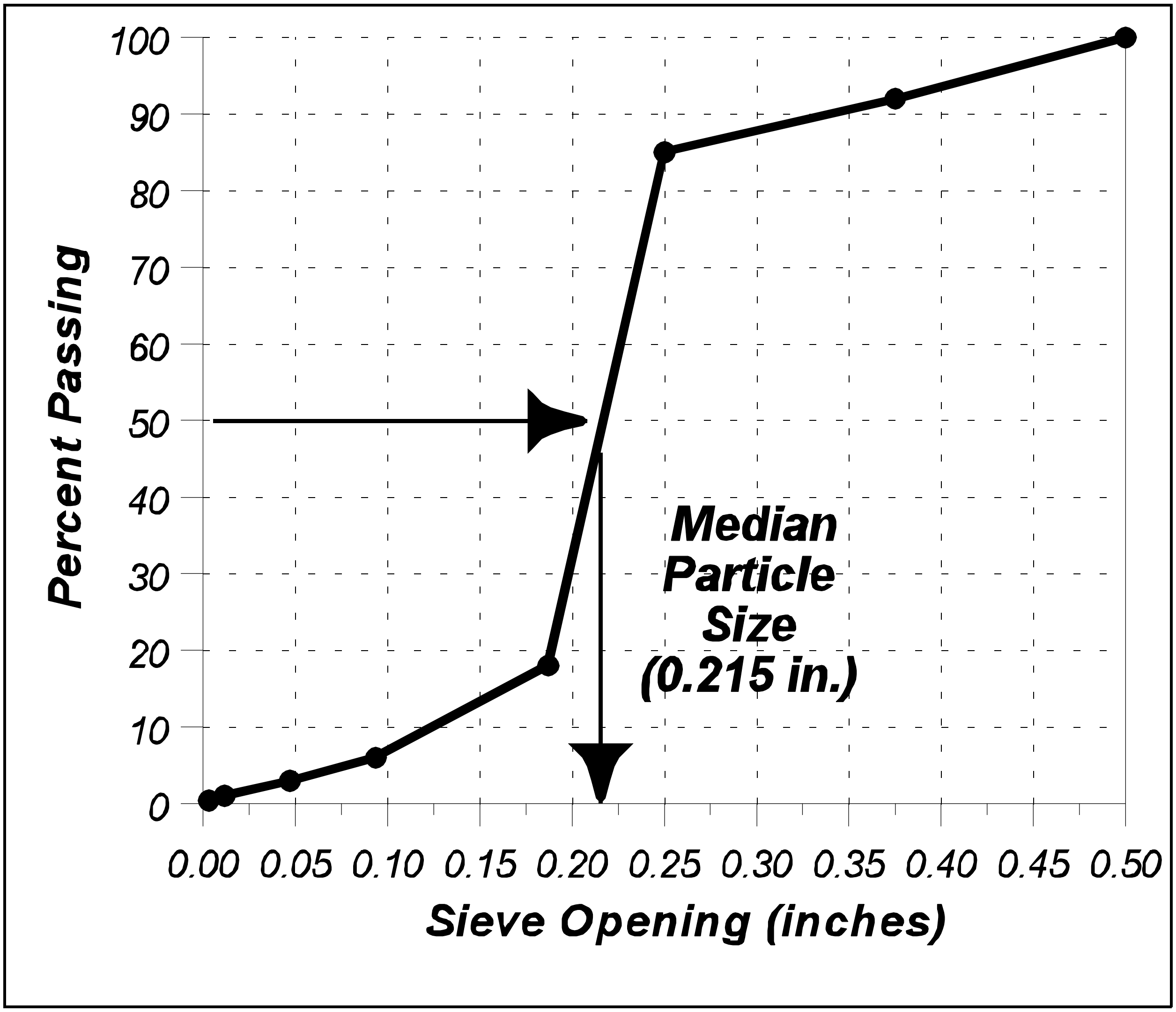

Figure 4.12. Gradation Chart for the Design Example showing the Median Particle Size.

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 ½ in. sieve;
(3) Passing the ½ 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 ½ 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 4.6). The results are shown in the next table.

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:

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

Step 4. Determine the Average Least Dimension (H)

The Average Least Dimension, or ALD, is the expected thickness of the seal coat in the wheelpaths 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:

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

S.I. Metric Units:

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

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

A metal cylinder with a volume of 0.50 ft^3 (0.014 m^3) was loosely filled with aggregate until full as shown in Figure 4.7. The weight of the aggregate was then determined. This was repeated three times with the results in the following table. The average of the three is then used to determine the Loose Unit Weight of the aggregate.

Loose Unit 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

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

S.I. Metric Units

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

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:

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

S.I. Metric Units:

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

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 Use 5% whip-off	500 - 1000 vehicles/day Use 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:

$$C = 46.8(1 - 0.4 \times V)(H)(G)(E) = 46.8(1 - 0.4 \times 0.46)(0.146\ in.)(2.71)(1.05) = 15.8\ lbs/yd^2 \quad (15)$$

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:

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

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 over 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 seal coat should look in the field. **In the field, the aggregate application rate does not need to be adjusted to account for traffic or surface condition as does the binder.**

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, gal/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 Wheelpaths:

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

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-wheelpath areas:

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

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

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

S.I. Metric Units:

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

Where:

B = Binder Application Rate, liters/m^2
H = Average Least Dimension, mm
T = Traffic Factor (based on expected vehicles per day, Table 4.4)
V = Voids in Loose Aggregate, in decimal percent (Equation 3)
S = Surface Condition Factor, liters/m^2 (based on existing surface, Table 4.6)
A = Aggregate Absorption Factor, liters/m^2
R = Residual Asphalt Content of Binder, in decimal percent.

Application rate in the wheelpaths:

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

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

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

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

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

SUMMARY

In summary, a good seal coat design incorporates many factors of the binder and aggregate. The results should yield a good starting point for field test sections. Experience has shown that the aggregate application rate determined from the equations is almost always the correct rate to apply in the field. However, 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. Most of the time it will need to be adjusted upward (apply more binder).

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 4.4) and surface condition (Table 4.6). It can be used by the inspector to make adjustments in the field. Figure 4.13 shows the binder adjustment chart for the above example.

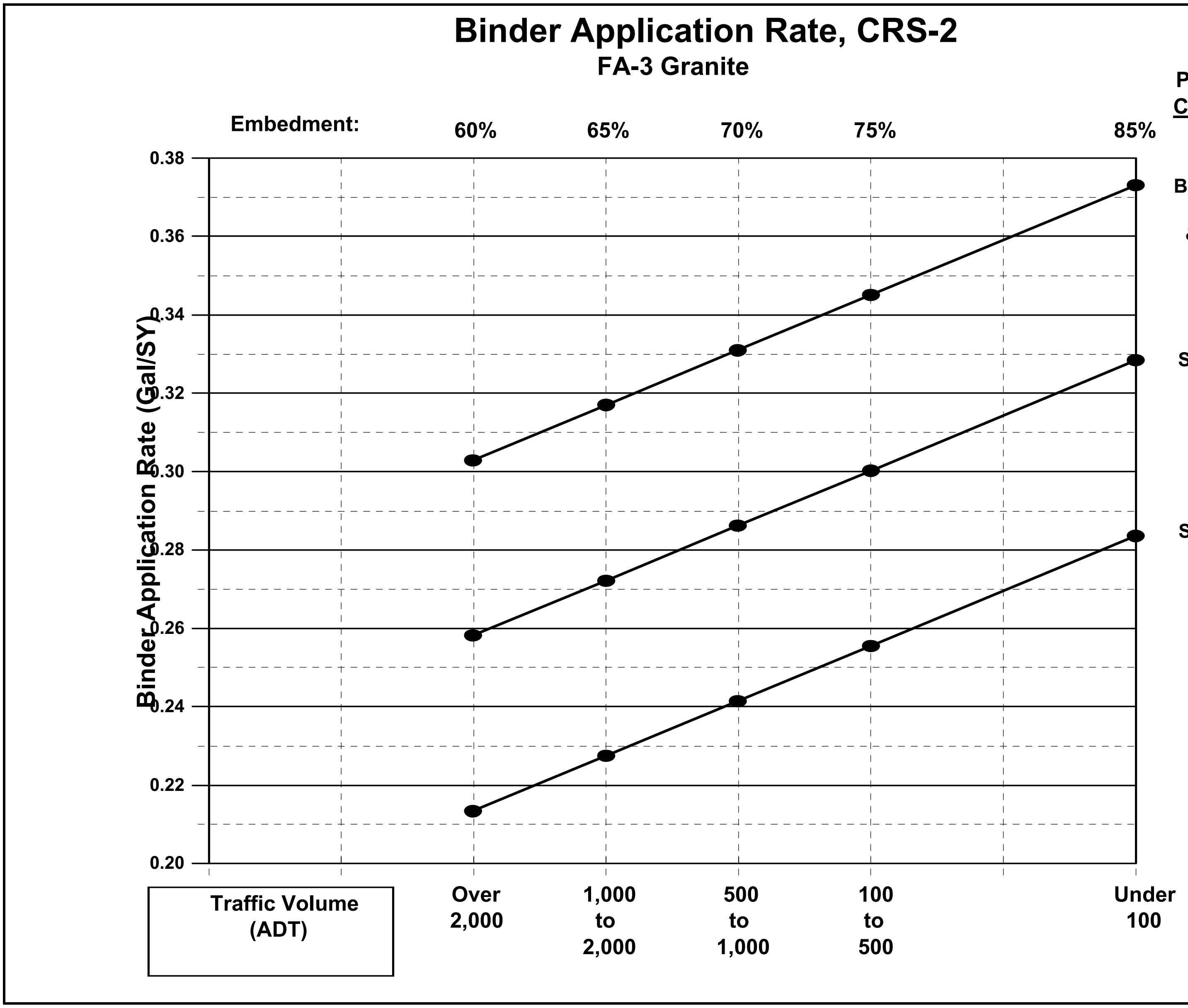

Figure 4.13. Example of a Binder Adjustment Chart

CHAPTER 5. FIELD INSPECTOR RESPONSIBILITIES

Inspecting seal coat 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. The key to a successful seal coat project is to have a knowledgeable field inspector who can calibrate the equipment, determine if enough material is being applied to the roadway and recognize and correct any problems that arise. In addition, the field inspector sets the quality standards for the project.

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
- The owner or designated person representing the contractor
- Field supervisor (who should not double as a member of the crew doing the work and have the 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.

The Field Inspector

- Distributes maps of the area(s) to be seal coated.
- Points out roads not to be seal coated 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 for seal coat portion and pick-up sweeping process.

- Reviews material delivery schedules.

A TYPICAL SEAL COAT PROJECT

While not every seal coat 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 in order for the project to proceed smoothly. The following section will give the field inspector a good overview of what typically occurs during a seal coat 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 seal coated 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.

Calibrating the distributor(s) and the chip spreader and notifying the field supervisor of adjustments of application rates are done 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 seal coat crew is assembled, the first task performed by the inspector is to calibrate the chip spreader. Calibrating the spreader will ensure that all of 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 6 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 quantities and design standards.

Lastly, the spreader needs to be calibrated before the binder application rate can be evaluated. If the cover aggregate is applied too heavy (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 5.1. Too much aggregate (no binder is visible)

Determine the Proper Binder Application Rate

Because certain assumptions are made in the seal coat 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 due to raveling or popouts 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 seal coat to be successful, the inspector must be able to determine if the proper embedment is being obtained.

This is done by the following:

- Spray approximately 50 feet (15 meters) of one lane of pavement at the design application rate.
- 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 wheelpaths 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 5.3 of Chapter 5.
- Record the setting on the distributor's computer for comparison with the actual application rate later that day.

Figure 5.2. Not enough binder (binder is too low)

Figure 5.3. Correct amount of binder (binder has risen to top of chips)

Figure 5.4. 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 time <u>walking</u> behind and ahead of the operation checking for the following:

- Making decisions on application rate adjustments.
- Ensuring full width application of seal coat.
- 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, the distributor is too far ahead).
- Ensuring the roller operation is not more than five minutes 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 diary of the project's process, quantities of aggregate and binder placed, weather conditions, note any problems that occurred, and note the performance of the equipment and operators. The inspector and field supervisor should agree on pay item quantities daily to minimize overruns, calculate yields and avoid disagreements at closing of the project.

The Last Day

On the last day of the seal coat 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 from 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 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 of 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 6 for details.

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

- The rock chips must be applied prior to binder “breaking” to ensure the bond between the aggregate, the binder and the road occurs.

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

- The field inspector will get a strong indication of the success of the seal coat by touring the areas the next spring after a winter of plowing and freeze-thaw cycles.

Weather Problems

The field inspector and the supervisor should agree daily if weather conditions are conducive for seal coating. Threatening weather conditions often result in a “wait and see what happens” posture. If rainfall occurs, no seal coating should take place until the roads are totally dry and clean (re-sweeping with a pick-up sweeper may be required prior to resuming project).

- If an unexpected rainfall occurs, discontinue seal coating immediately - inspect areas sealed that have not yet cured for puddles of brownish colored water bleeding out of chips. “Blotting” with 1/8 inch (3.2 mm) minus rock of the same type as the seal coat usually will save the seal coat and “heal” it satisfactorily. Other material to use for “blotting” includes clean washed sand or natural pit run gravel but they leave a contrasting color on the aggregate and do not have as pleasing an appearance.

- 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”-, 3 mm -) aggregate of the same type as the seal coat 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 on a daily basis. A clean and dry road is critical to the success of the seal coat.

- Maintaining close proximity of the asphalt distributor, the chip spreader and the rollers are vital to the lasting adherence of the seal coat to the road surface.

Sweeping

Pick-up sweeping should occur 24 to 72 hours after application of the seal coat. The field inspector should inspect the equipment for leaks. Fuel or hydraulic leaks will destroy the bond between the seal coat 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 seal coat.

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 seal coat requiring attention by contractor.

- To check to see that all structures are uncovered.

- To monitor the progress and quality of the sweeping operation.

SUMMARY

The field inspector is key to the success of a seal coat 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. Seal coat field inspection requires full-time attention and hands-on involvement to accomplish the desired quality of the end product and 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.

2. 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____
- ❑ Equipment Inspected: . . . . Yes___ No____

  Comment:____

- ❑ Calibrate distributor: . . . . Yes___ No____

  Comment:____

- ❑ Calibrate chip spreader: . . . . 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 seal coated
- ❑ 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 seal coat.
- ❑ Verify schedule and inspect operation as it proceeds in addition to the seal coat operation.

3. 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.

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CHAPTER 6. EQUIPMENT CALIBRATION

Calibrating and maintaining the equipment used in seal coating is an important step in achieving good results. Poorly calibrated or mis-calibrated equipment can negate what would otherwise be a quality seal coat 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 twelve to sixteen 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 1 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 all of the above.

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 6.1.

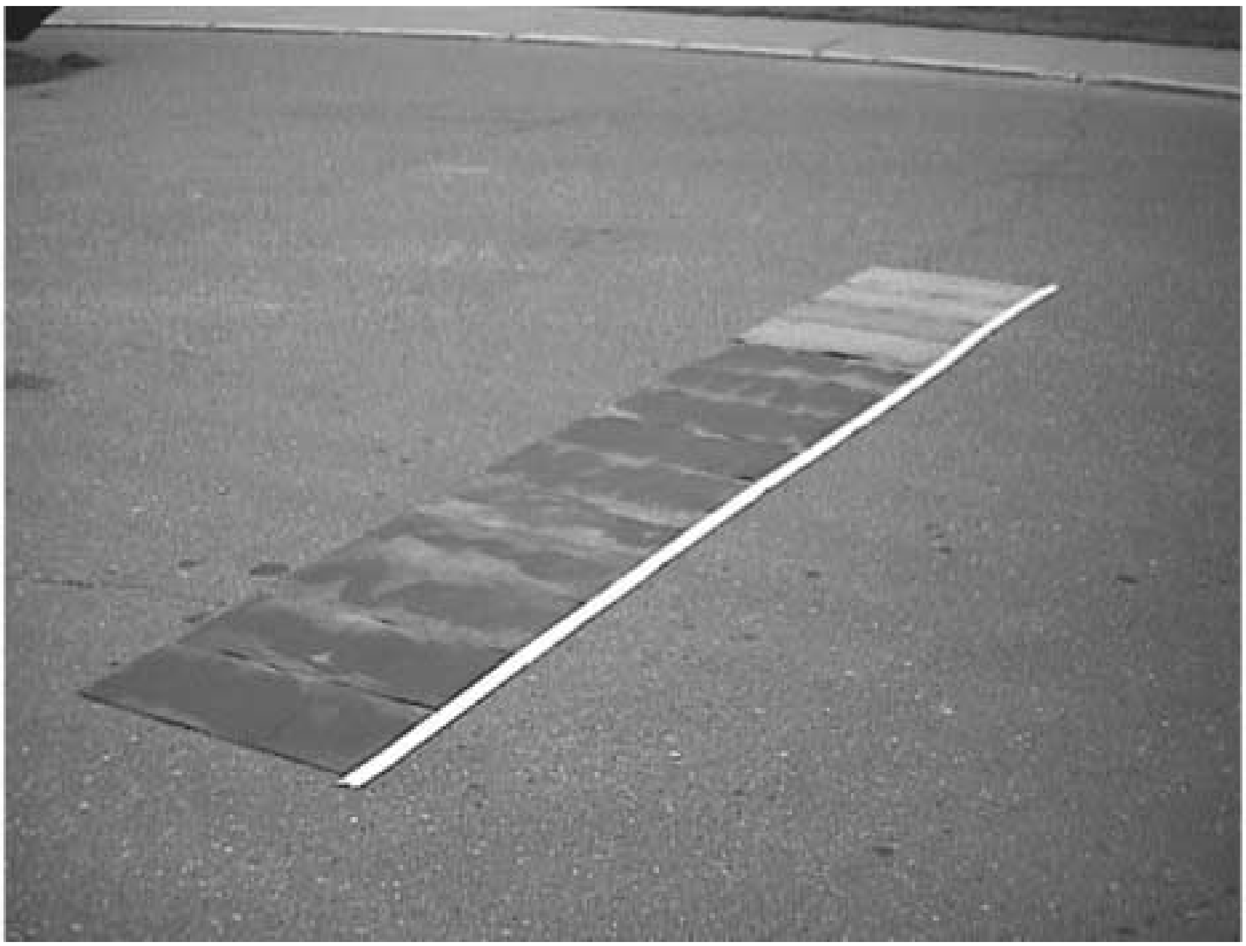

Figure 6.1. One-foot wide rubber mats are placed into position

Step 2

The chip spreader is driven over the mats. The spreader should begin dropping chips about 6-8 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 6.2. 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 6.3. The aggregate on each mat is 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 6.4. The contents of each bag are weighed and recorded

Step 5

The first adjustment made is to get all of the gates 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 6.5. A spreader gate opening is adjusted

The test is repeated until all of the gates are placing the same amount of aggregate, plus or minus one pound per square yard. Once all of the gates are 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 the same amount and the amount they are dropping is the target amount.

The calibration can be done the day before construction to reduce any delays. If possible do the calibration off-site so that all of the equipment and personnel are not waiting on the roadway while the calibration is done. This procedure will normally take between 30 and 60 minutes to complete. One way to speed up the calibration procedure it to adjust as must as possible before loading the hopper with aggregate. With the hopper empty and all the gates opened, the distance between the roller and the bottom edge of each gate should be the same.

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 a non-uniform application of binder that not only affects the appearance of the seal coat but also its performance.

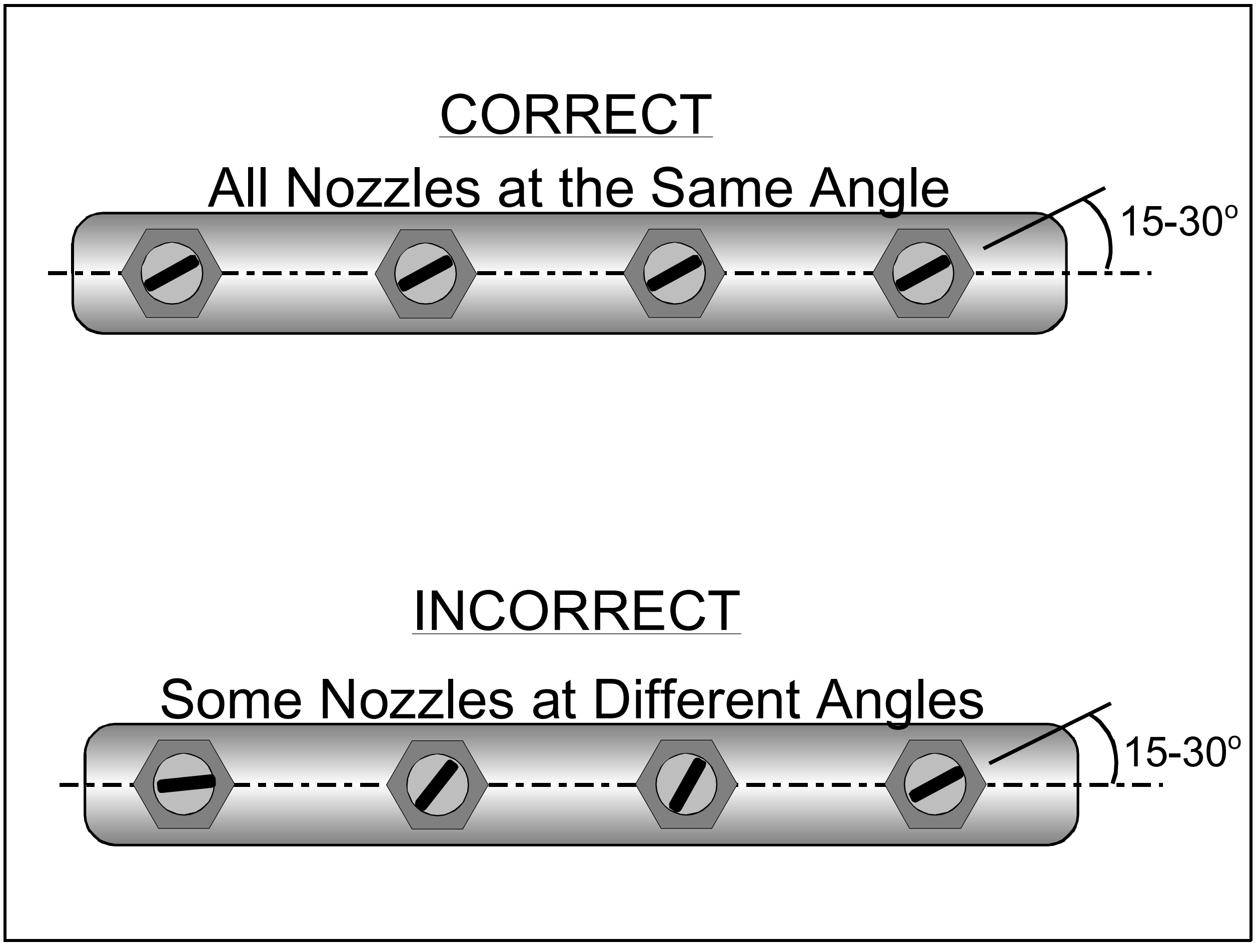

Figure 6.6. Spray bar nozzle alignment

Spray Bar Nozzle Alignment

The first thing that should be done to the distributor is to check the spray nozzles. In order for 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. Before beginning a seal coat project, the angle of each nozzle should be checked and adjusted as needed. Adjustment is very easy to do, typically only involving the slight turn of a wrench or other tool provided by the distributor manufacturer. In addition, each nozzle opening should be checked for grass or other debris that may be obstructing the opening.

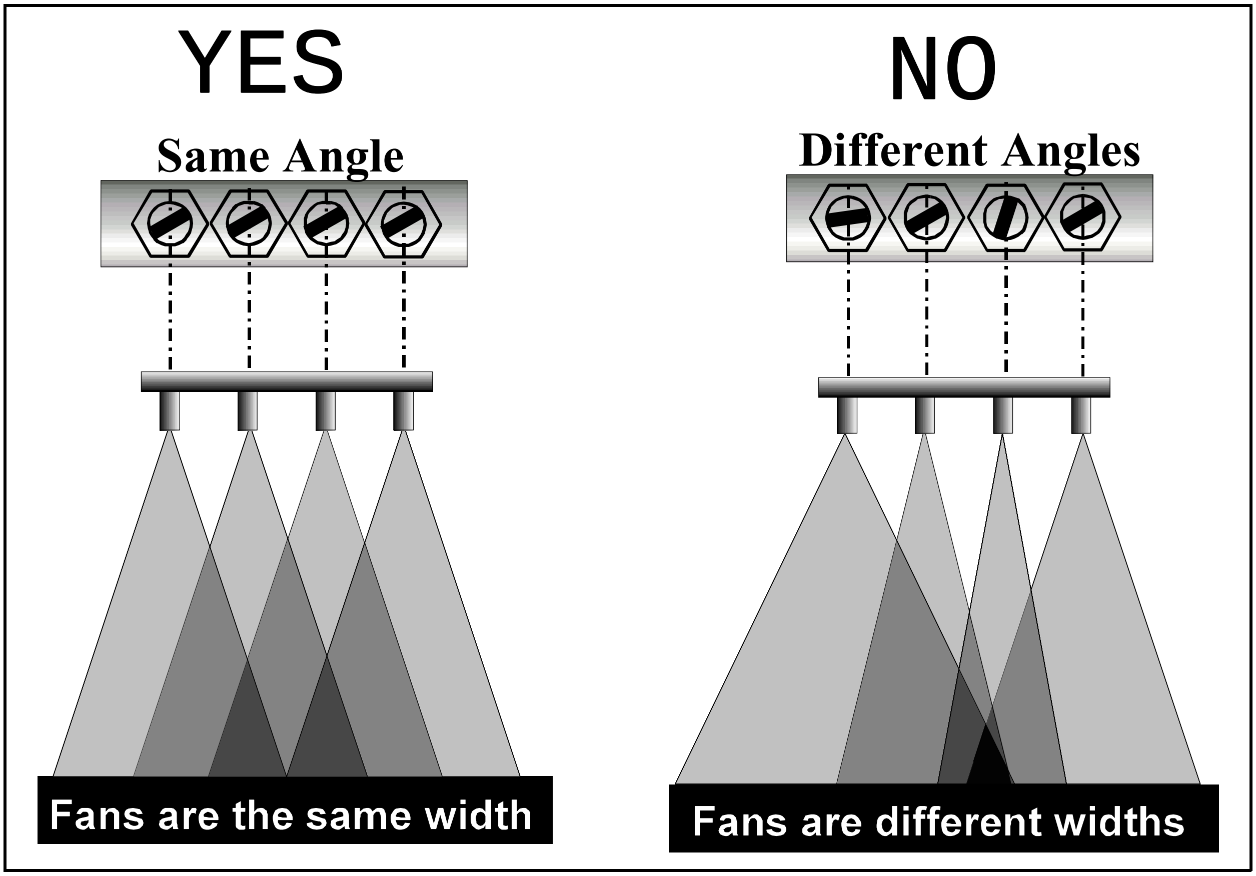

Figure 6.7. Spray bar nozzle alignment

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 of 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.

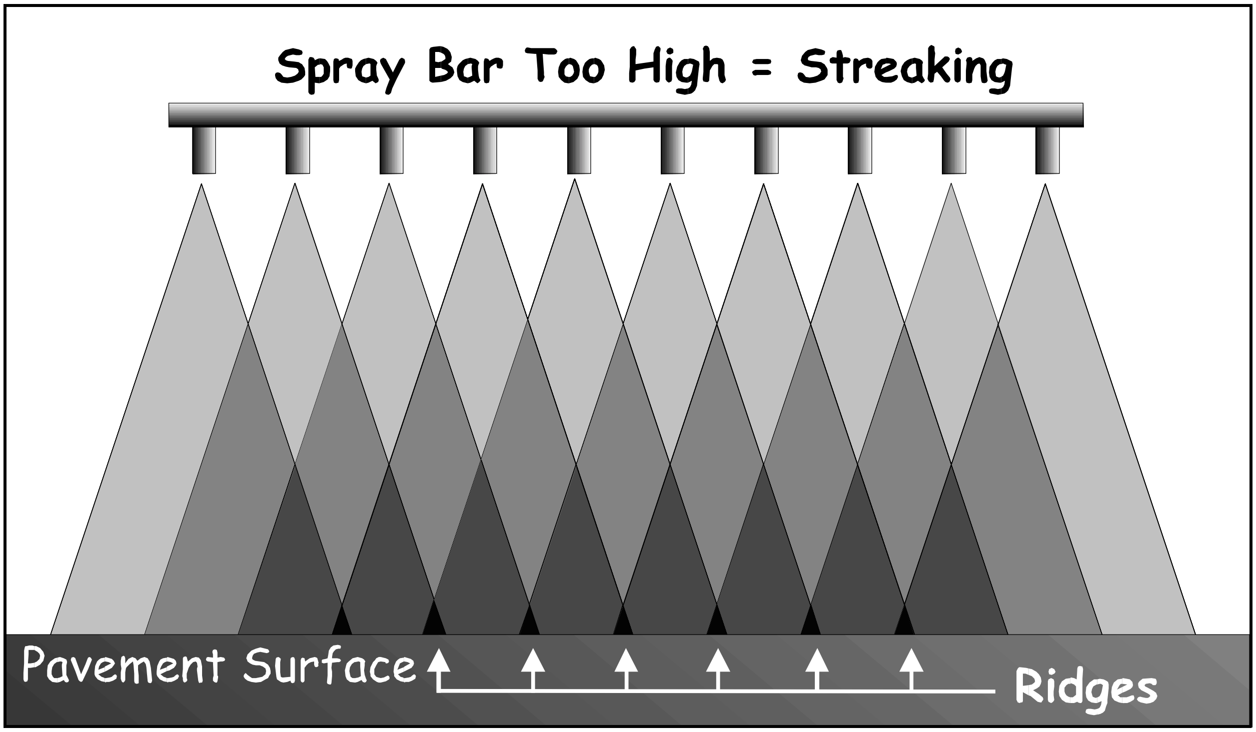

Figure 6.8. Spray bar is too high (ridges)

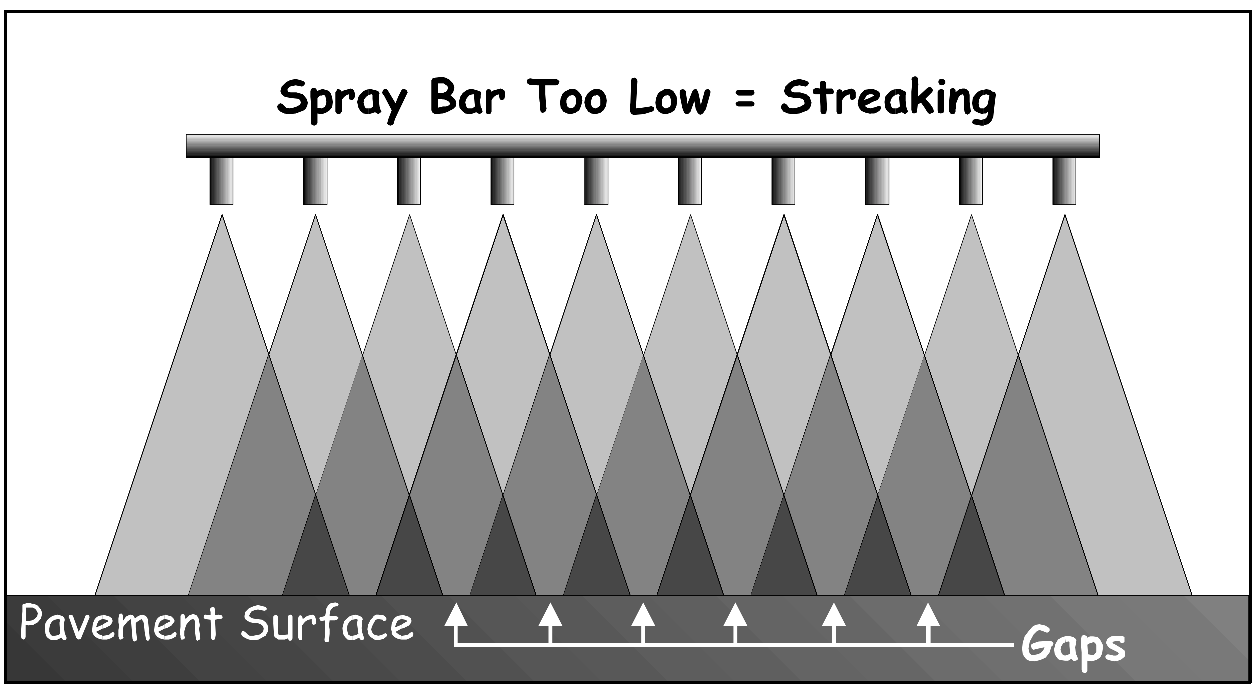

Figure 6.9. Spray bar is too low (gaps)

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) Make sure all of the nozzles are aligned to the same angle.

2) Shut off *two consecutive nozzles* for each that is left open (Figure 6.10).

3) Spray binder for a brief moment 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 as needed and repeat until the fans meet the pavement at the same point.

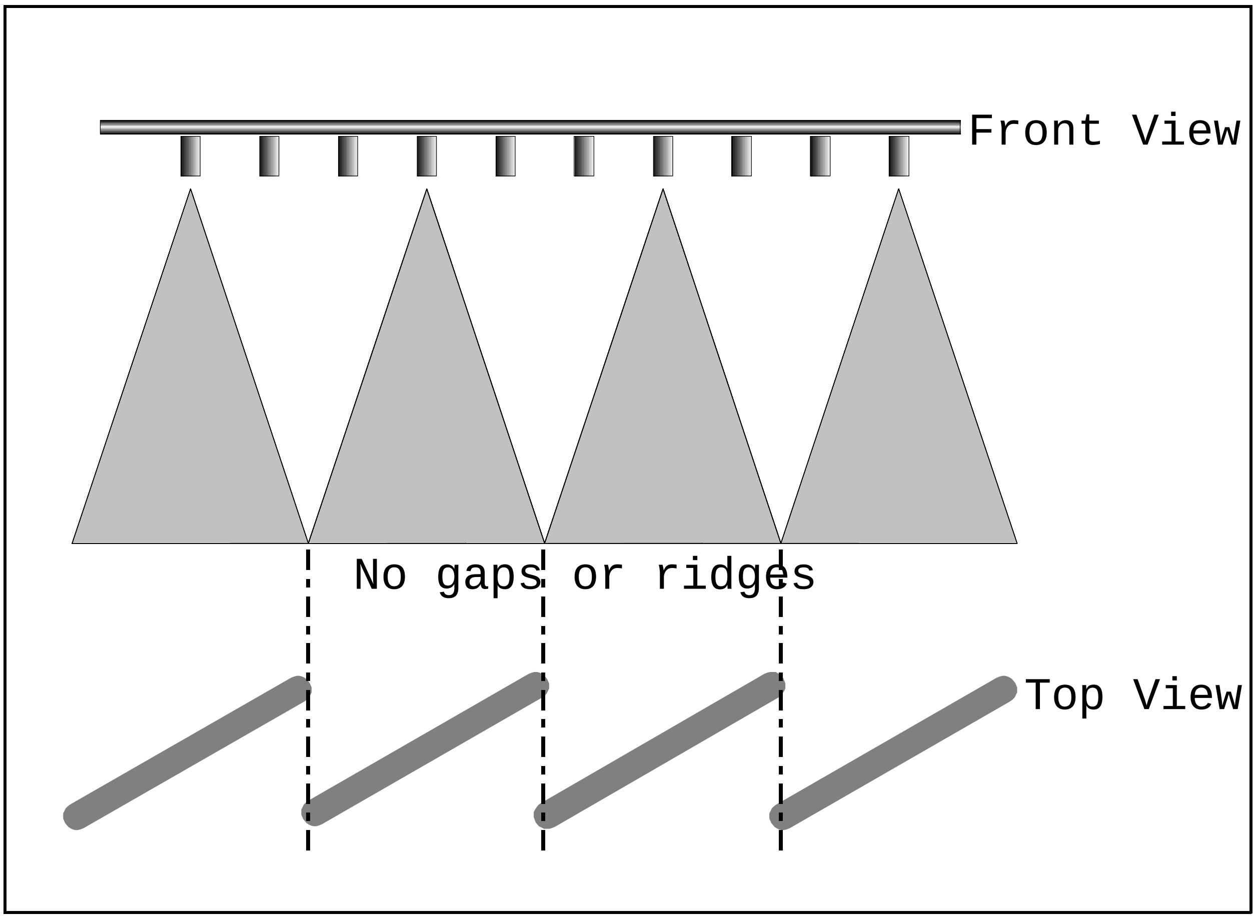

Figure 6.10. Spray bar height test for a triple lap seal

For a Double Lap Application:

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

1) Make sure all of the nozzles are aligned to the same angle.

2) Shut off *every other* nozzle (Figure 6.11).

3) Spray binder for a brief moment 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 as needed and repeat until the fans meet the pavement at the same point.

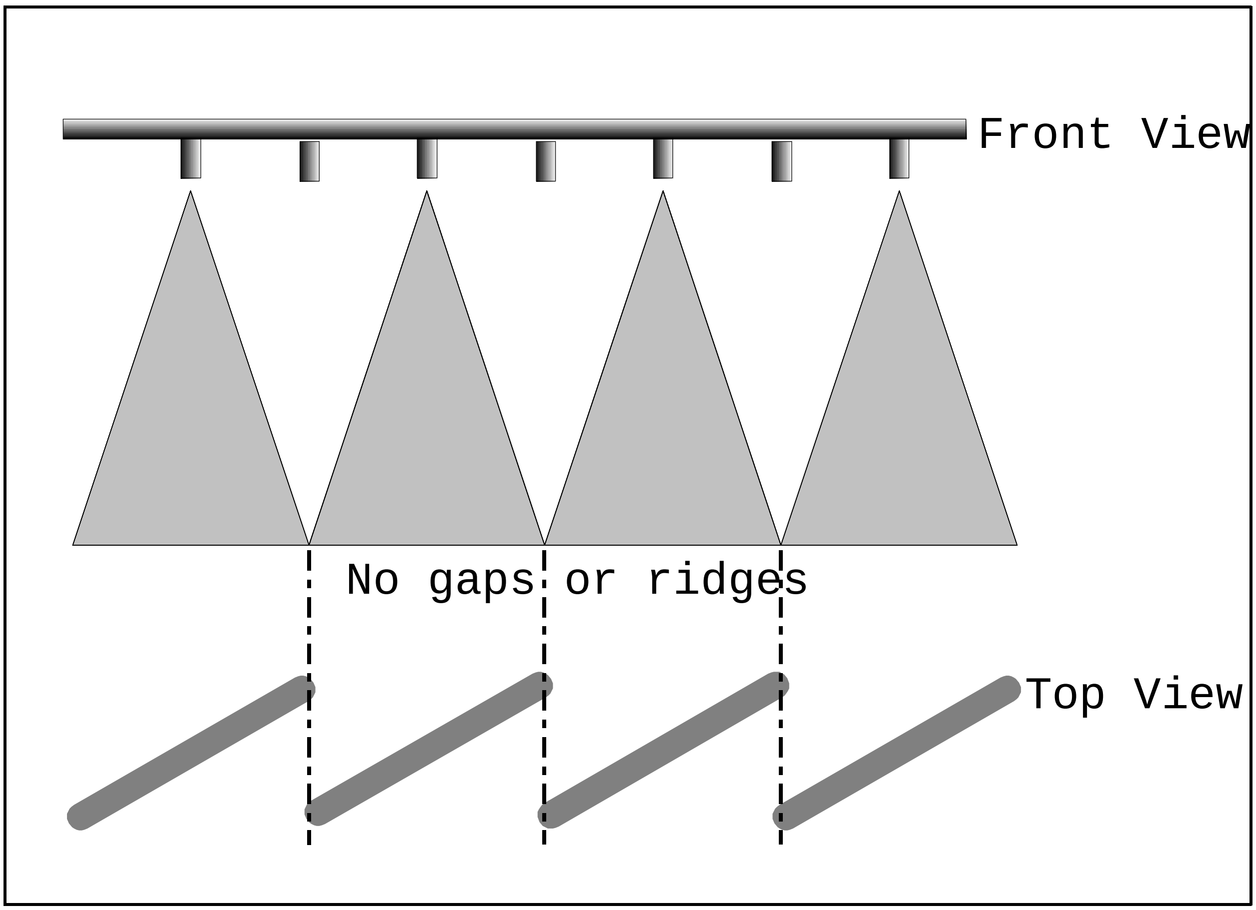

Figure 6.11. Spray bar height test for a double lap seal

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CHAPTER 7. COMMON PROBLEMS and SOLUTIONS

Construction of a good seal coat depends on a number of factors, including the following:

- Aggregate gradation, hardness, size and shape
- Asphalt binder grade, viscosity and electrical charge
- Existing pavement condition
- Weather conditions
- 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 seal coat aggregate. The three most common problems that occur in the construction of a seal coat are:

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

PROBLEM: *STREAKED APPEARANCE*

Streaking is identified by longitudinal grooves or ridges in the seal coat surface. Though streaking is primarily a cosmetic problem it is an undesirable one none the less. If the distributor is calibrated properly, streaking can virtually be eliminated. Figure 7.1 shows an example of streaking.

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

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

Figure 7.1. Example of streaking caused by incorrect spray bar height (notice streaks)

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 small aggregate, such as FA-2, the problem is much more noticeable because the chips can become securely embedded in the areas where the ridges of binder exist. In Figure 7.2, notice that for a triple lap application, every fourth nozzle should hit the pavement at the same point. For a 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.

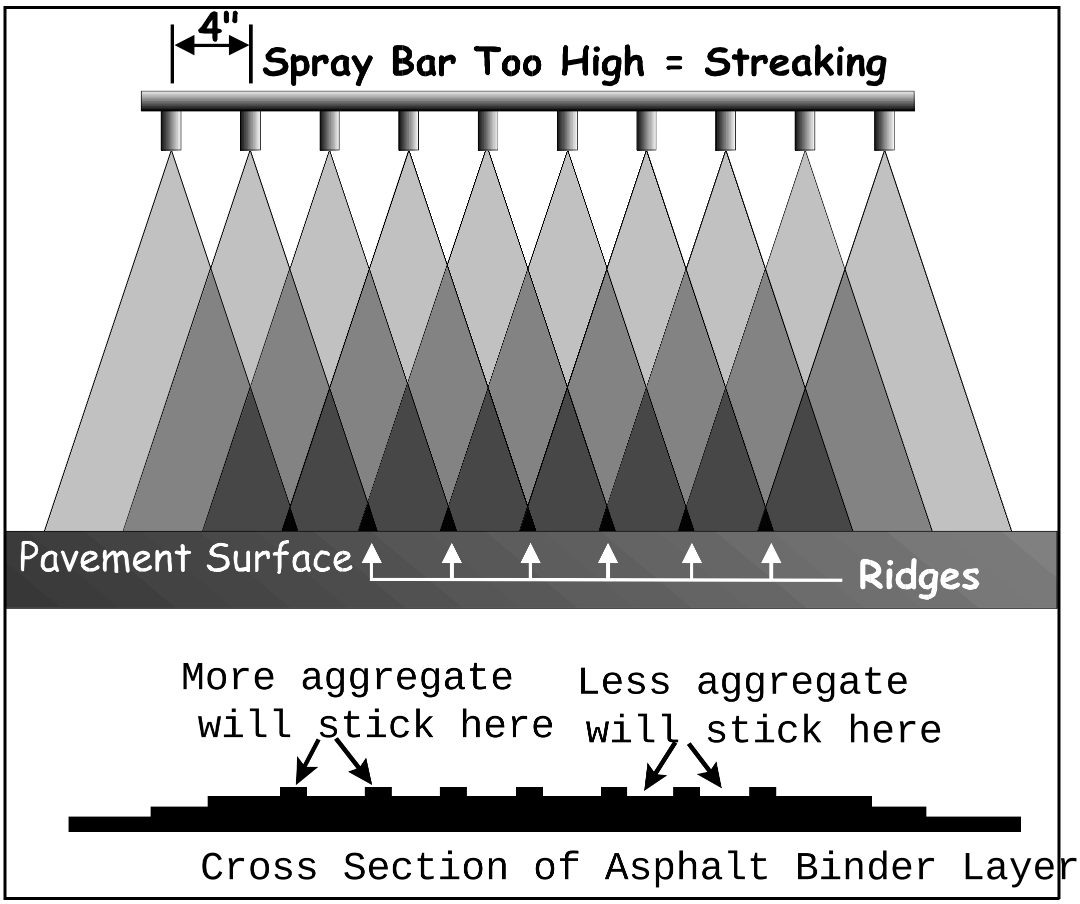

Figure 7.2. Schematic of incorrect spray bar height

SOLUTION #2: *ALIGN THE NOZZLES PROPERLY*

In order for the asphalt binder to be 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. Normally, the angle of the nozzles can be adjusted with a simple turn of a wrench.

SOLUTION #3: *MAKE SURE THE NOZZLES ARE NOT CLOGGED*
Because asphalt cement is sticky, and its viscosity increases as 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 seal coat project, the nozzles of the spray bar should be inspected and cleared of any debris. The emulsion must be heated to approximately 150 degrees F. (66 deg. 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 checked often and any noticeable blockage should be cleared immediately.

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 for the aggregate. 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 summer days.

SOLUTION #1: *USE A CUBICAL 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.

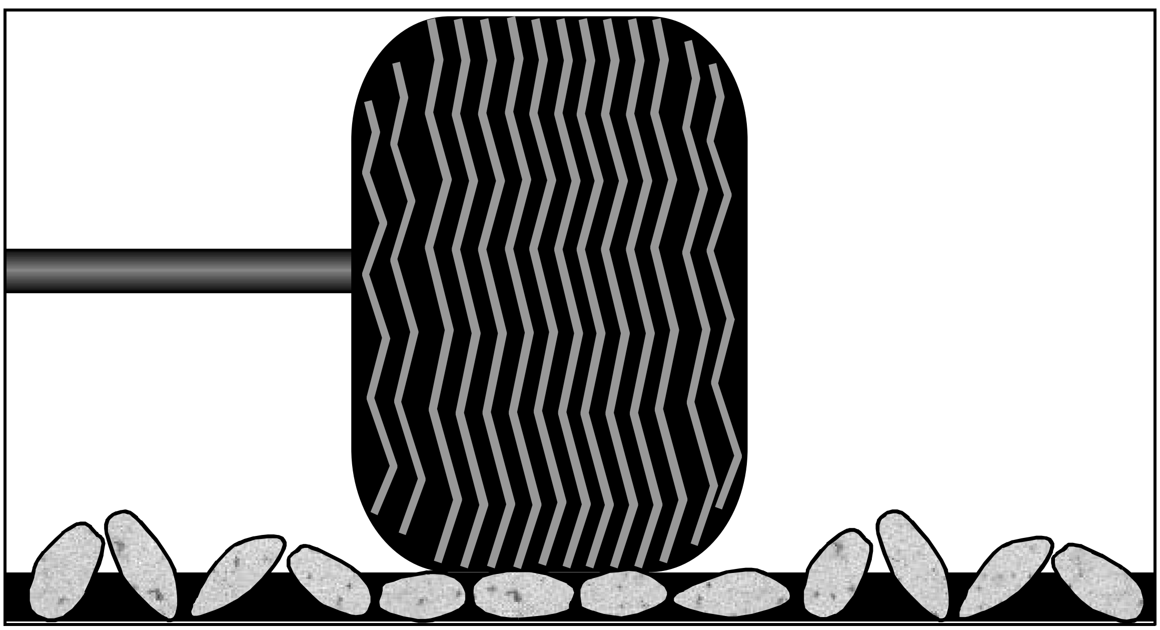

Figure 7.3. Traffic causes flat chips in the wheelpath to lay down on their flattest side

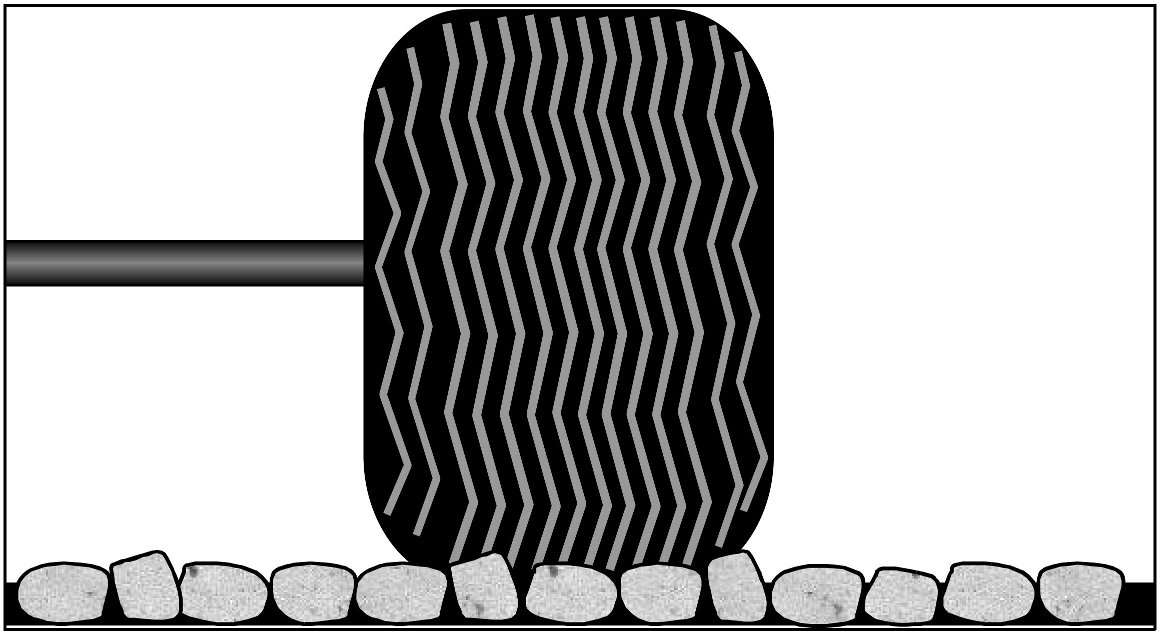

Figure 7.4. Traffic has little effect on cubical aggregate

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. All of the above point out the need for performing a seal coat design and constructing test sections prior to construction.

For more details on seal coat design, refer to the design portion of this handbook.

PROBLEM: *LOSS OF COVER AGGREGATE*

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

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

SOLUTION #1: *APPLY MORE ASPHALT BINDER*

Without a doubt, the most common reason for the loss of seal coat 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 the 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 7.6).

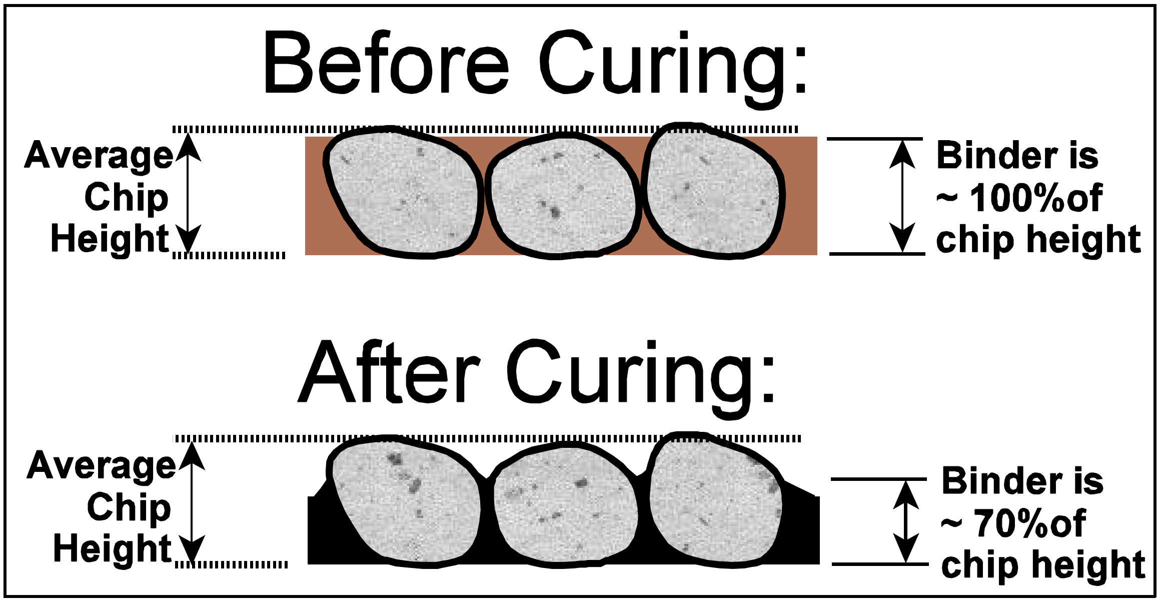

Figure 7.5. Change in volume after emulsion has cured

In addition, old and/or porous pavements, as well as the cover aggregate itself, can absorb some of the binder intended for holding onto the 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 <u>residual asphalt</u>. The residual asphalt is the asphalt cement remaining on the pavement after the water and emulsifier have evaporated.

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

SOLUTION #2: *USE A CLEAN, DUST-FREE AGGREGATE*

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

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

More detail can be found in Chapter 2 of this handbook.

Figure 7.6. Evidence of a dusty aggregate

PROBLEM: *BAD CENTERLINE JOINT*
If the existing roadway has a deteriorated centerline joint it should be repaired prior to seal coating. 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 snow plows tend to ride on this high spot of the pavement, having a good longitudinal seam is important to the longevity of a seal coat project.

Figure 7.7. Fog seal on centerline prior to seal coat to prevent excess absorption

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 0.1 - 0.2 gallons/sq.yd. has worked well as shown in Figure 7.8. The emulsion should be allowed to cure prior to placing the seal coat.

PROBLEM: ***LOSS OF AGGREGATE AND/OR BLEEDING IN CUL-DE-SACS***
One of the most common problems encountered when seal coating in urban areas is the loss of cover aggregate, and subsequent bleeding in cul-de-sacs.

Figure 7.8. Wrong way to sealcoat a cul-de-sac (emulsion will "break" before chips are placed and rolled)

SOLUTION: ***USE PROPER TECHNIQUE AND 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 seal coating 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 seal coat to be very tender which will cause scuffing as vehicles stop and turn.

Refer to the next chapter for the recommended way to seal a cul-de-sac.

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

When seal coating 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. Some agencies use the same type of aggregate for covering the utilities as they do for the seal coat, only much smaller. 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 seal coat being placed.

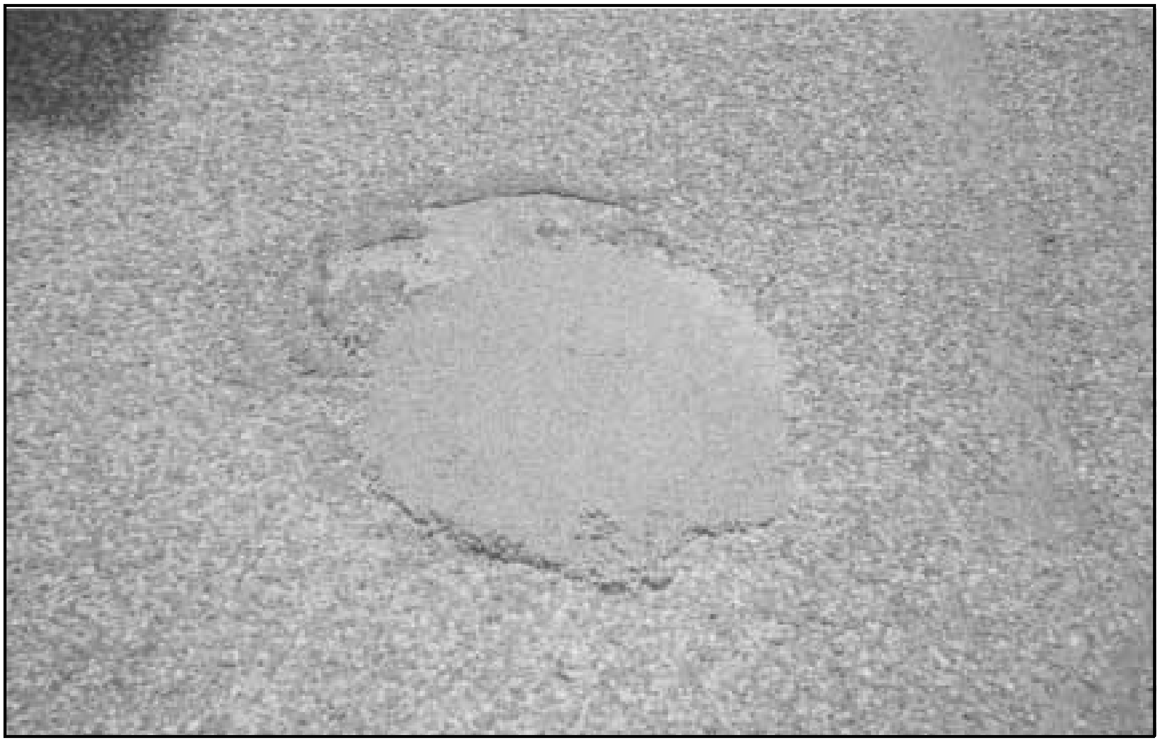

Figure 7.9. Sand cover on manholes

CHAPTER 8. SPECIAL SITUATIONS

There are certain situations that can occur that will present special challenges on seal coat 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 seal coat 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 overlaping 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.

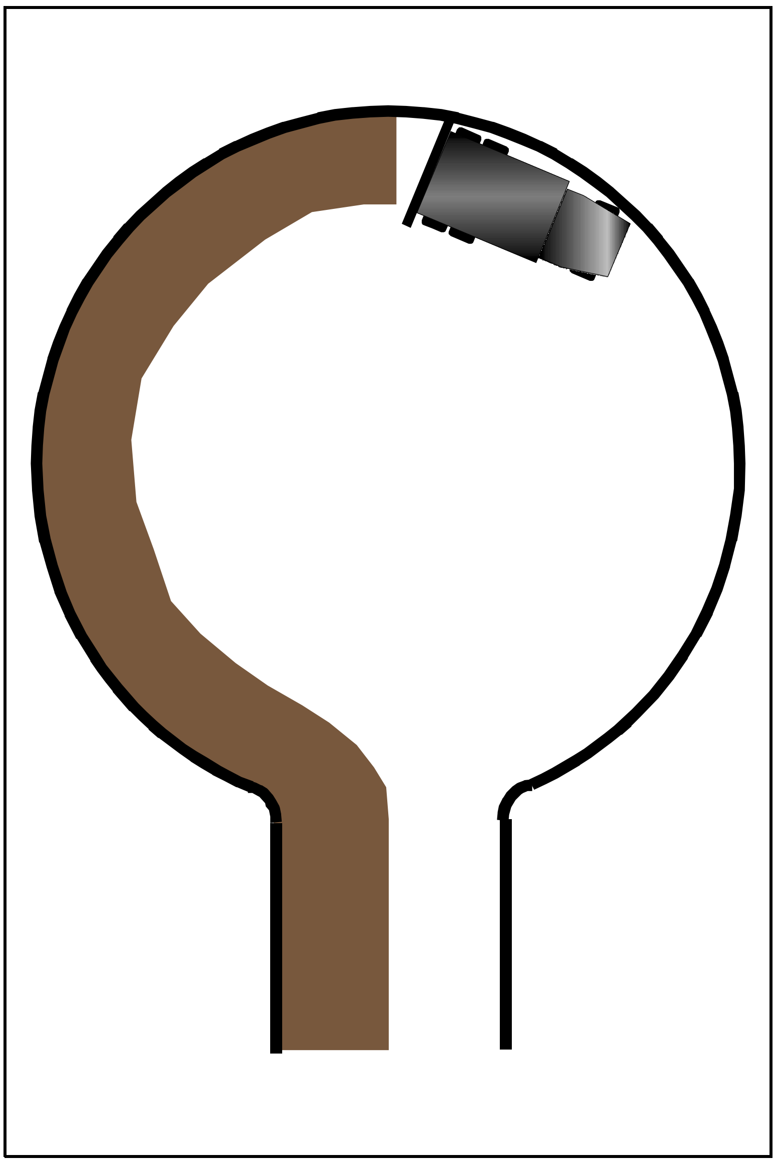

Figure 8.1. Distributor sprays halfway around the perimeter of the cul-de-sac.

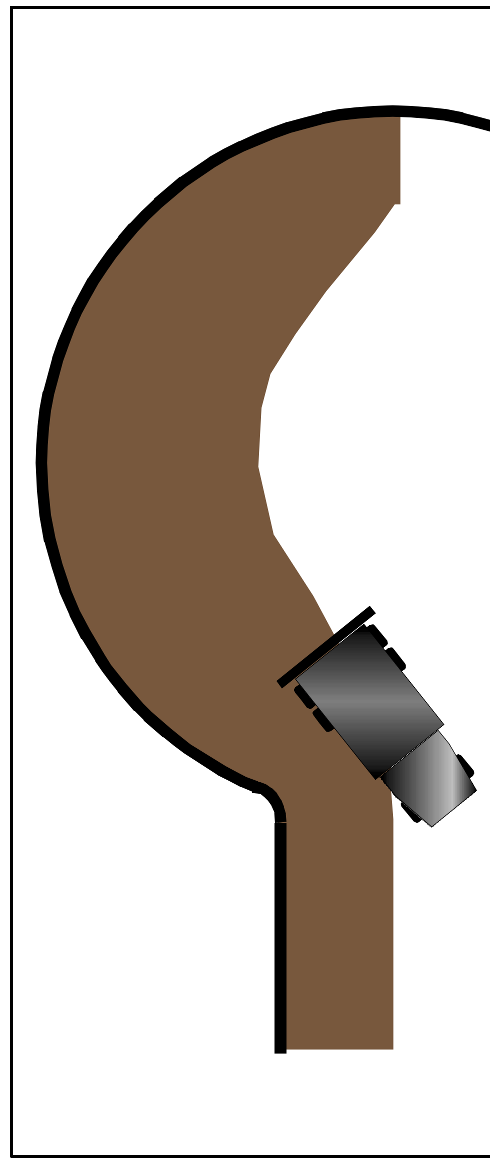

Figure 8.2. After backing into posit
sprays adjacent to the previous pass

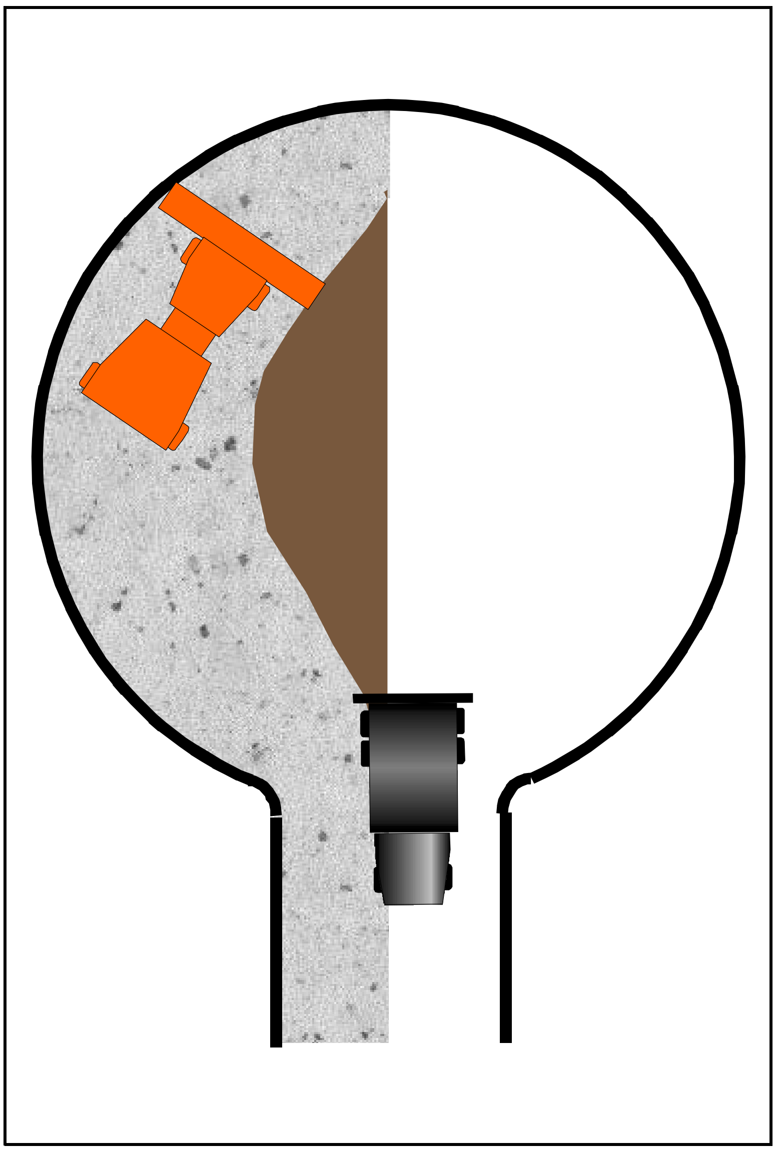

Figure 8.3. After backing into place, the distributor completes half of the cul-de-sac. The chip spreader and rollers begin working.

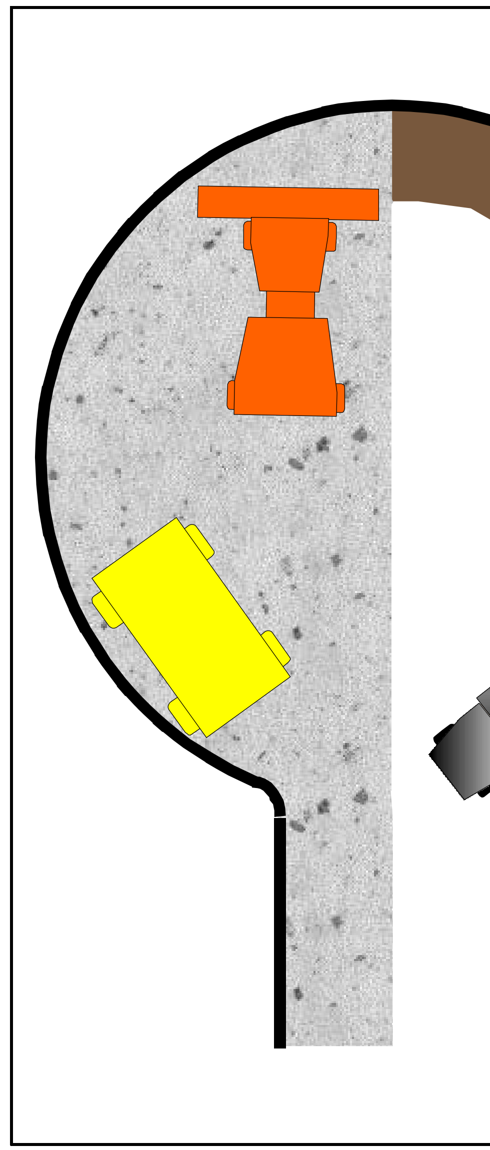

Figure 8.4. Distributor backs up to p
pass and completes spraying arounc
cul-de-sac. The spreader and rollers

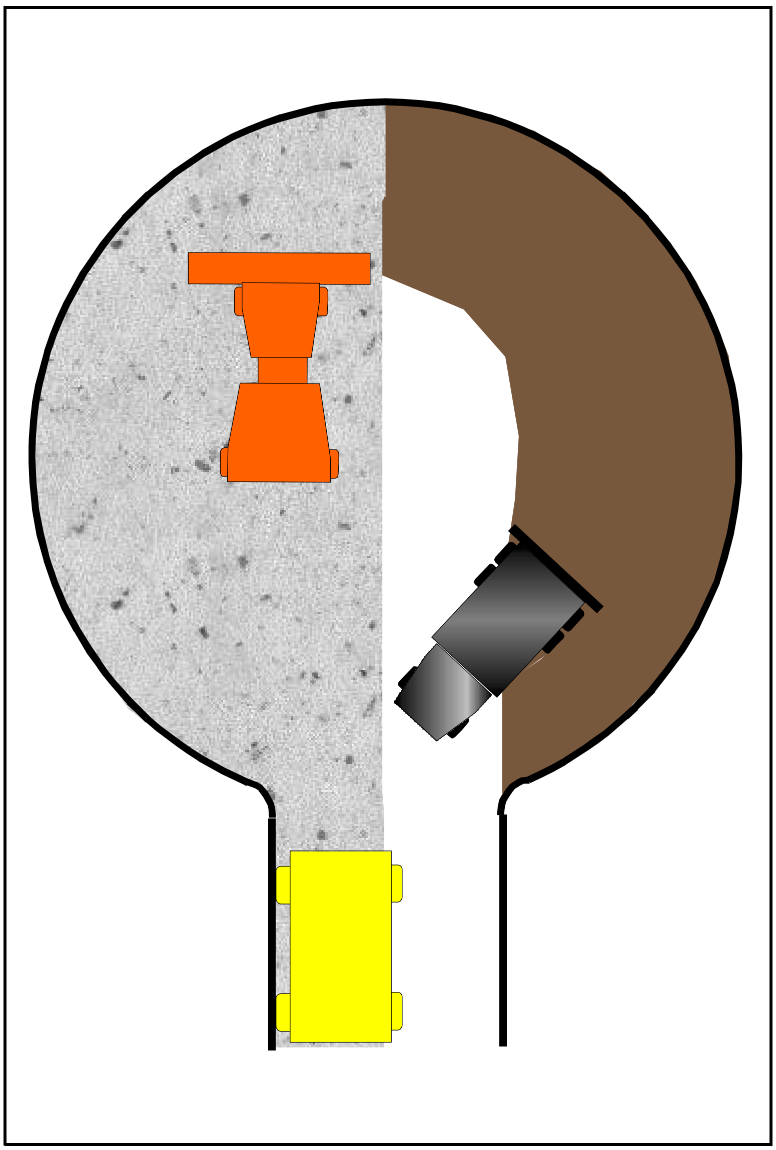

Figure 8.5. Distributor continues matching up with previous pass around the outer perimeter. Spreader and rollers finish the first half of the cul-de-sac.

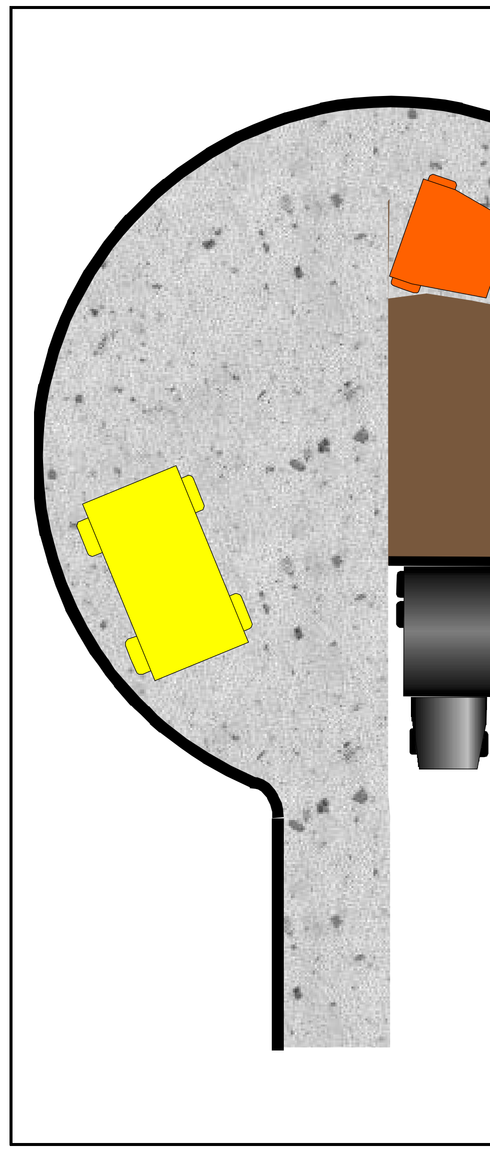

Figure 8.6. Distributor is ready to m
of the cul-de-sac. The spreader beg
half of the cul-se-sac while the roller

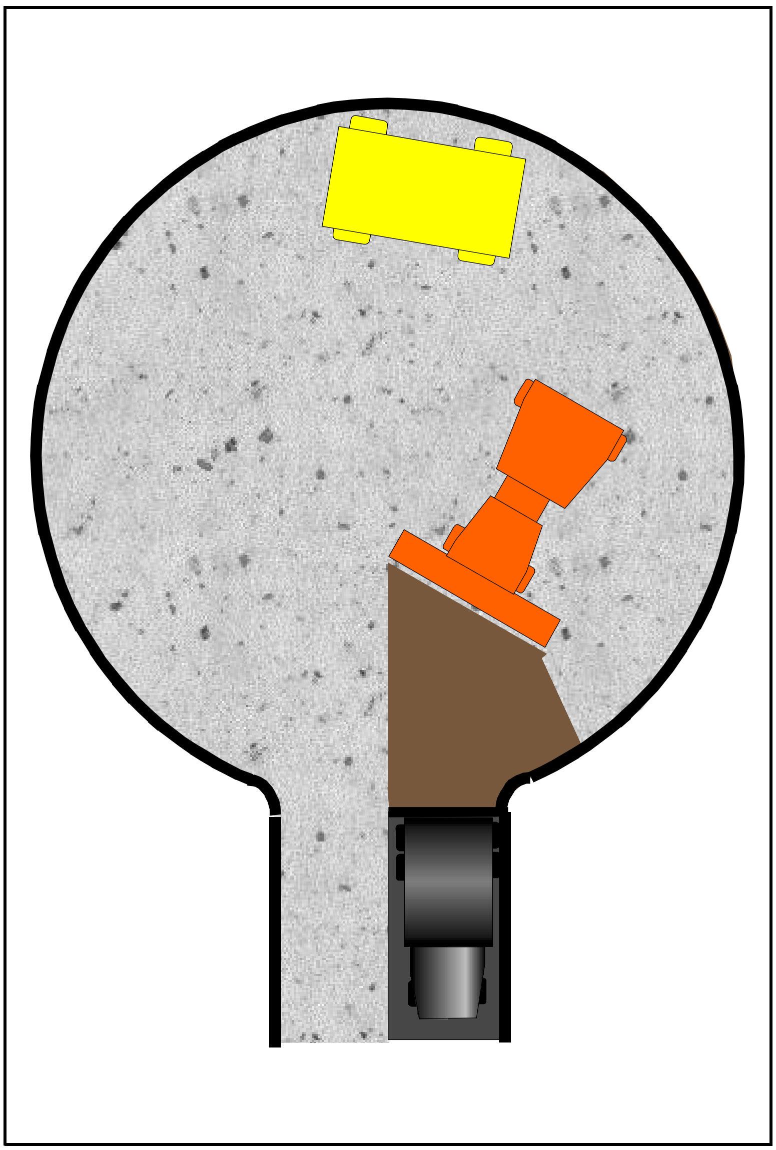

Figure 8.7. Distributor makes its final pass out of the cul-de-sac and completes the other entrance lane into the cul-de-sac. The spreader and rollers are nearly finished.

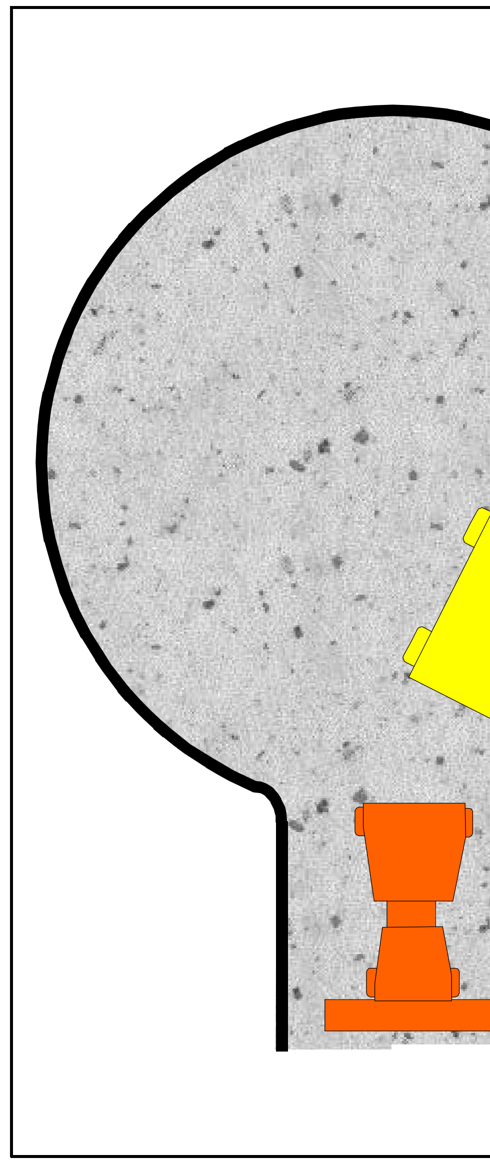

Figure 8.8. Chips spreader and rolle sac and head out to finish the rest of

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 seal coating 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 seal coat. The aggregate in this top layer is 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.

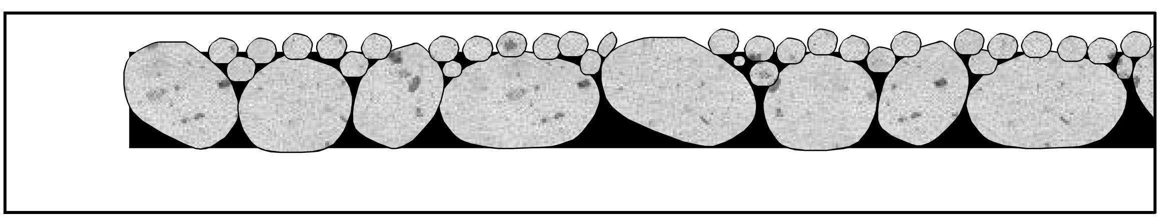

Figure 8.9. Schematic of a Choke Seal (One layer of binder two layers of aggregate)

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.

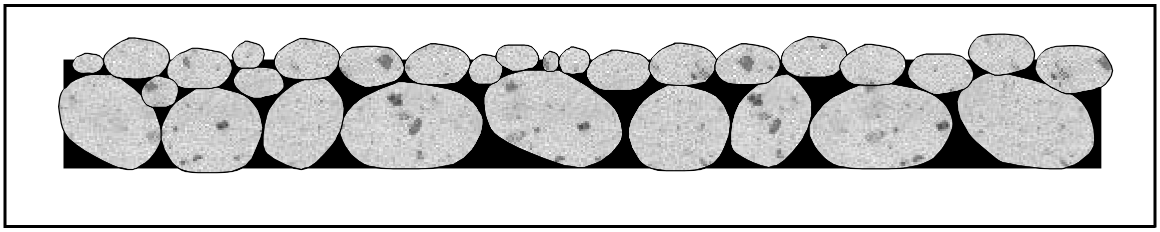

Figure 8.10. Schematic of a Double Seal (two layers of binder and aggregate)

3) **Use a smaller aggregate such as Mn/DOT 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.

4) **Fit the spray bar with smaller nozzles in the wheel path than in the non-traffic areas**. Since the wheel path chips will be laying flatter, the amount of binder required will be less than in the other areas of the lane. By using smaller nozzles in the wheel paths, both the traffic and non-traffic areas will get the amount of binder necessary for proper embedment. This has been done in Texas with good results (4).

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APPENDIX

Appendix A. Special Provisions for Bituminous Seal Coat

1. DESCRIPTION

This work will consist of an application of bituminous material followed by an application of cover aggregate on designated areas of an existing pavement.

2. MATERIALS

A Bituminous Material

The bituminous material for seal coat will be one of the following kinds and grades conforming to Mn/DOT standard specification 3151. When the Contract quantity exceeds 2000 gallons (7,570 L), and unless other options are permitted by the Plans or Special Provisions, the kind to be used will be Emulsified Asphalt, Cationic grades. In all cases the grade to be used will be as designated by the Engineer.

B Seal Coat Aggregate

Aggregate for bituminous seal coat shall conform to the requirements in the table below for grading and quality. The particular type or grading to be used shall be as shown in the Plans. All percentages are by weight.

The material shall meet the requirements for grading and quality when placed in hauling vehicles for delivery to the roadway, or during manufacture and placement into a temporary stockpile.

B1 Composition

The aggregate shall consist of sound, durable particles of sand, gravel or crushed stone, or combination thereof. It shall be clean, uniform in quality and free from wood, bark, roots and other deleterious materials. All aggregate to be used for bituminous seal coat shall conform to Class A, B, C or D as described in Mn/DOT standard specification 3137.2B.

B2 Gradation and Quality

Sieve Size	Total Percent Passing				
	FA-1	FA-2	FA-3	FA-4	FA-5
1 inch (25 mm)	100	100	100	100	100
3/4 inch (19 mm)	100	100	100	100	90-100
½ inch (12.5 mm)	100	100	100	90-100	20-55
3/8 inch (9.5 mm)	100	100	90-100	40-70	0-15
1/4 inch (6.3 mm)	100	100	40-70	0-15	0-5
U.S. No. 4 (4.75 mm)	95-100	85-100	0-15	0-5	---
U.S. No. 8 (2.36 mm)	---	10-40	0-5	---	---
U.S. No. 16 (1.18 mm)	45-80	0-10	---	---	---
U.S. No. 50 (300 μm)	10-30	0-5	---	---	---
U.S. No. 100 (150 μm)	2-10	---	---	---	---
U.S. No. 200 (75 μm)	0-1	0-1	0-1	0-1	0-1
% Shale, Max. by weight	5	5	3	2	2
Static Stripping Test	Pass	Pass	Pass	Pass	Pass
Flakiness Index, Maximum	N/A	30	30	30	30
Los Angeles Rattler Loss, %, Max., On Plus No. 4 Fraction			30	30	30

B3 Sampling and Testing

A	Sampling, Sieve Analysis, and Shale Test	Department's Bituminous Manual
B	Static Stripping Test	AASHTO T 182
C	Flakiness Index	FLH T 508
D	Los Angeles Rattler Loss	AASHTO T 96

C Water

All water will be potable and compatible with the chip seal. Compatibility must be ensured by the Contractor.

D Mix Design

The chip seal coat will be designed in accordance with the Asphalt Institute design method found in their Manual Series No. 19, 1979 Edition. The chip seal design will be prepared by qualified personnel experienced in asphalt surface treatment design.

The surface design will be based on the traffic volume(s) and pavement conditions contained in the plans. The final application rate for the asphalt binder and cover aggregate will be determined after the source of the material is known and field adjustments are made.

The design will include the following information:

(1) Aggregate gradation.
(2) Bulk specific gravity of the aggregate.
(3) Loose unit weight of the aggregate.
(4) Asphalt type and rate of application.
(5) Aggregate rate of application.

In addition to the above data, the Contractor will submit with the design of the seal coat a sample of the aggregate and emulsion for use by the Engineer for verifying the test results. The design may be verified by the Department.

After the mix design has been established, the mixture supplied to the project will conform to the following tolerances:

Passing U.S. No. 4 and larger sieves:	± 7%
Passing U.S. No. 8 to U.S. No. 100 sieves:	± 4%
Passing U.S. No. 200 sieve:	± 2%
Residual Asphalt (by extraction):	± 0.4%

3. CONSTRUCTION REQUIREMENTS

A Weather Limitations

Seal coating operations (including traffic restrictions on the freshly constructed seal coat) will be conducted:

(1) Not before May 15 nor after August 31;
(2) Only during daylight hours;
(3) When the pavement and air temperature is 60°F or higher;
(4) When the relative humidity is less than 75 percent; and
(5) When the road surface is dry and clean.

In addition, seal coat operations will not be done in foggy or rainy weather. The seal coating operations will not be started, and will be suspended, when any of the above conditions cannot be met.

B Equipment

B1 Distributor

The bituminous material will be applied with a distributor meeting the requirements of Mn/DOT standard specification 2321.3C1.

B2 Aggregate Spreader

The cover aggregate will be applied with an approved mechanical type aggregate spreader that is capable of distributing the aggregate uniformly to the required width and at the designated rate, with the application being sharply defined at the edges. The aggregate spreader will be a self-spreader type mounted on pneumatic-tired wheels that are so located as to operate on the freshly applied aggregate.

Prior to construction, the aggregate spreader will be calibrated in accordance with ASTM D5624-95 in the presence of the Engineer. The allowable deviation in the amount of aggregate spread on each of the rubber mats will not be more than ±1 lb./sq.yd. in the transverse direction or deviate more than ±1 lb./sq.yd. from the design application rate in the longitudinal direction.

B3 Pneumatic-Tired Roller

A sufficient number of self-propelled pneumatic-tired rollers will be used for rolling aggregates after spreading such that the entire width of the treatment area is covered in one pass of the rollers. In most cases this will require a minimum of three rollers. Each pneumatic-tired roller will have a total compacting width of not less than 60 inches and will have a minimum ground contact pressure of 80 pounds per square inch.

B4 Brooms

Brooms shall be motorized with a positive means of controlling vertical pressure and capable of cleaning the road surface prior to spraying bituminous material and removing loose particles after treatment as required.

C Road Surface Preparations

All roadway surfaces to be sealed will be cleaned by the Contractor. The Contractor will sweep the pavement with a motorized broom to remove all loose material. All depressions not reached by the power broom will be cleaned by the Contractor using hand brooming. The Contractor will ensure that the outer edges of the pavement to be sealed including 1-foot of the shoulder width, if applicable, are thoroughly cleaned. Work will not continue until the surface is approved by the Engineer.

All iron (manholes, gate valves, catch basins, etc.) shall be covered to prevent adherence of the asphalt binder. Suitable covering includes plywood disks, sand, kraft paper, roofing felt or other approved methods. The Contractor shall remove the protective coverings within two (2) hours after the seal coating operation and dispose of properly.

When specified in the Contract or ordered by the Engineer, a tack coat will be applied to the prepared road surface in accordance with Mn/DOT standard specification 2357.

D Traffic Control Plan

The Contractor shall submit a detailed traffic control plan to the Engineer for approval prior to beginning construction. The traffic control plan shall include the type and locations of all signs, barricades, temporary lane markers, flag persons and pilot vehicles, as necessary. All barricades and signs shall meet the requirements of the Minnesota Manual on Uniform Traffic Control Devices.

E Application of Bituminous Seal Material

Emulsified asphalt will not be placed on any wet surface or when weather conditions will otherwise prevent its proper handling or finishing. Application of the bituminous material will be made only when the surface is dry as determined by the Engineer.

The beginning rate of application for the bituminous material will be at the rate determined by the surface treatment design. A short test strip (50-100 feet long) shall be constructed to ensure the binder application rate is adequate. After applying the binder to this test strip, the chip spreader will place the cover aggregate at the design application rate. The aggregate in the wheel paths of the chip spreader should be inspected for proper embedment. The Engineer will make adjustments to the rate of application if necessary. Application of the bituminous material will be made uniformly at this rate with the pressure distributor, one full lane width at a time (including shoulder). Further adjustments in the rate of application will be made by the Engineer, if needed, during the course of the work.

The temperature of the bituminous material at the time of application will be as approved by the Engineer, within the limits specified below:

Binder Type	Temperature Range (Deg.F)	Temperature Range (Deg.C)
CRS-1, CRS-2, CRS-2P	125 - 185	52 - 85
RS-1	70 - 140	21 - 60
RS-2, HFMS-2	125 - 185	52 - 85
RC-250	165 - 220	74 - 105
RC-800	200 - 225	93 - 107
RC-3000	230 - 290	110 - 145

F Application of Cover Aggregate

Immediately after the emulsified asphalt has been sprayed evenly over the roadway surface, aggregates of the type specified will be evenly applied to the roadway surface by self-propelled spreader equipment. The aggregate will be distributed uniformly by a spreader within 1-minute of the emulsified asphalt application. The speed of the spreader will be such that stones are not rolling over.

All aggregate will be moistened prior to placement to provide aggregates that are uniformly damp at the time of placement on the roadway.

The aggregate will be spread in one operation in such a manner that an 8-inch strip of emulsified asphalt is left exposed along the longitudinal center to form a lap for succeeding applications of emulsion. If necessary, thin or bare spots in the spread of aggregates will be corrected by hand spreading or other methods subject to approval of the Engineer.

G Rolling Operations

The aggregate will be rolled following spreading. A maximum time of 3 minutes will be allowed between the spreading of the aggregate and completion of the initial rolling of the aggregate. The rollers will proceed in a longitudinal direction at a speed less than or equal to 5 miles per hour. The rollers will make three complete coverages of the aggregate with the final pass being in the direction of traffic. The Engineer may require more rollers to ensure the rolling is being done quickly enough to embed the aggregate before the binder breaks.

I Protection of the Surface

No traffic will be permitted on the sealed road surface until after all rolling has been completed and the bituminous material has set to a degree satisfactory to the Engineer and will not pick up on vehicle tires.

In addition to other barricades and warning signs required by the Contract, the Contractor will furnish and deliver to the Project such other barricades and warning signs as the Engineer deems necessary for use in conjunction with seal coat construction. The Contractor will erect and maintain those barricades and signs at locations directed by the Engineer.

When the road under construction is open to traffic during daylight hours, the Contractor will furnish a minimum of two flag persons and a pilot vehicle to direct and guide traffic through the construction zone. One flagger will be stationed in advance of the seal coat operations and another at the rear barricade at the beginning of the uncovered bituminous material. It will be the duty of the flagger to stop all traffic and to acquaint the traveling public with the nature of the work underway, the limitations on the road surface available for traffic use, and the reason for reduced driving speed. All traffic, including construction traffic, will be held to speeds not exceeding 25 miles per hour. Advisory signing will be provided for a period of 24 hours after seal coat operations are completed to maintain vehicle speed to 25 mph.

On the morning following each day of seal coat operations the Contractor will sweep off the surplus aggregate from the previous day's seal coat construction. This operation will be conducted while the road surface is still cool, and care will be exercised that the aggregate which has set is not disturbed. Where sealing is done in municipalities, the Contractor will dispose of the surplus aggregate in a manner satisfactory to the Engineer.

4. METHOD OF MEASUREMENT

A Bituminous Material

Bituminous material applied on the road will be measured by volume in gallons at 60 degrees F.

B Seal Coat Aggregate

Seal coat aggregate will be measured as indicated in the Proposal, by weight or by volume (vehicular measure) of material deposited on the road.

5. BASIS OF PAYMENT

Payment for the accepted quantities of bituminous material (including any required additives) and seal coat aggregate at the appropriate Contract prices will be compensated in full for all costs of constructing the seal coat as specified.

Payment for the bituminous seal coat will be made on the basis of the following schedule:

Item No.	Item	Unit
2356.505	Bituminous Material for Seal Coat	Gallon
2356.507	Seal Coat Aggregate	Ton

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Appendix B. REFERENCES

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9. *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.

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