Design and Construction
of Seal Coats

In cooperation with the Local Road Research Board
"Sponsoring research for county and municipal roads and streets"
**Design and Construction of Seal Coats**

**Abstract (Limit: 200 words)**

In the past, Mn/DOT has placed emphasis on improving the structural adequacy of many rural trunk highways. These improvements were usually made by plant mix bituminous overlays since seal coats do little or nothing to improve the structure of a roadway. Future emphasis will likely shift more toward prolonging the life of existing pavements. Seal coats provide an economical means of extending pavement life on roadways below 5000 average daily traffic (ADT). Research on the use of seal coats is warranted since 75% of Mn/DOT highway miles and virtually all county and municipal roadways fit this criteria.

This paper covers the basic fundamentals and current practices of this technology in Minnesota along with several alternatives. Its main purpose is to provide recommendations for developing and implementing a seal coat program. The references identified in the bibliography are recommended for review by readers with limited knowledge of this technology. Additional information can also be obtained through the Mn/DOT Physical Research Office or the Mn/DOT Bituminous Office.
DESIGN AND CONSTRUCTION
OF SEAL COATS
FINAL REPORT

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EXECUTIVE SUMMARY

In the past, MN/DOT has placed emphasis on improving the structural adequacy of many rural trunk highways. Future emphasis will likely shift more toward prolonging the life of existing pavements. Seal coats do little to improve the structure of a roadway but are an economical means of extending pavement life, particularly, on roadways below 5000 average daily traffic (ADT). Research on the use of seal coats is warranted since 75% of MN/DOT highway miles and virtually all county and municipal roadways fit this criteria.

Seal coats can reduce life cycle costs, provide a skid resistant surface, improve demarcation of traffic lanes, increase nighttime visibility and improve the roadways appearance. The key to attaining these benefits is in the proper application of the seal coat. A great number of variables must be considered in obtaining optimum results. Difficulty arises because the variables are interdependent. These variables emphasize the importance of developing a comprehensive seal coat program with qualified personnel.

This paper covers basic fundamentals and current practices of seal coat technology in Minnesota. Recommendations for developing and implementing a seal coat program are provided along with seal coat alternatives which should be considered for various special applications. Materials, equipment, planning and construction operations are emphasized. Highlights and recommendations are provided at the end of the paper.
INTRODUCTION

When properly applied, seal coats offer an economical means of protecting an existing pavement against the wear of traffic and weather over time. Periodic seal coats can extend a pavement's life at a low cost with relatively minor traffic disruptions. In addition to reducing life cycle costs, seal coats can provide a skid resistant surface, improve demarcation of traffic lanes, increase nighttime visibility, and improve the roadway's appearance by providing a uniform surface. The key to attaining these benefits is the proper application of the seal coat.

A great number of variables must be considered for proper application of a seal coat. Difficulty arises because the variables are interdependent. The binder application rate, for example, is dependent on the aggregate used, the pavement surface and also the amount of traffic.

These interdependent variables illustrate why seal coating is often referred to as an art instead of a science. They also emphasize the importance of developing a comprehensive seal coating program with qualified personnel.

A pavement management program, well trained personnel and the proper equipment are needed for obtaining optimum results. The amount of personnel and equipment needed will, of course, depend upon whether seal coats are done by contract or in house. This paper covers the aspects deemed most important to an overall seal coat program and is geared toward the use of this technology within Minnesota.

Some alternatives to chip seal coating are also discussed.
SEAL COAT ALTERNATIVES

While this paper deals primarily with aggregate seal coats or "chip" seals there are other seal coat alternatives that warrant discussion. They are:

1. Fog seals
2. Sand seals
3. Double seals
4. Slurry seals
5. Thin lift overlays
6. Do nothing

FOG SEAL

A fog seal is a light application of a slow setting asphalt emulsion to an existing pavement surface. It is used to renew old asphalt surfaces that have become dry and brittle. It will also seal small cracks and fill surface voids. This action will prolong pavement life and delay the need for major maintenance or reconstruction. A fog seal is inexpensive since only 0.1 to 0.2 gal/yd² of diluted material is used. The exact application rate should be determined by surface texture, dryness and degree of cracking of the pavement to be treated.

An excellent application for fog seals is on paved roadway shoulders since the surfaces quickly dry up and become brittle because of limited traffic. Two added benefits in using fog seals are better mainline/shoulder delineation and improved solar flux for snow and ice melt.

Fog seals can also be used to prime a very dry roadway prior to seal coating.

SAND SEALS

A sand seal functions a lot like a fog seal except sand is spread over the surface after spraying the emulsion. The emulsion is usually a CRS-2. The sand acts as a surface matrix which allows higher emulsion application rates without bleeding. It also increases friction. Mn/DOT's experience with sand seals has been marginal at best. Problems include non uniform sand distribution and flushing.

DOUBLE SEAL

A double chip seal consists of an initial seal with one aggregate followed by another seal with a smaller aggregate. This typically consist of a FA-3 seal followed by a FA-1 or FA-2 seal. The second application of emulsion helps embed the initial aggregate and the smaller aggregate helps lock the underlying
course inplace improving the durability of the seal coat. The binder rate for the second seal is critical and must be lighter than usual to avoid flushing. Double seals cost about 50% more than single chips seals.

SLURRY SEALS

A conventional slurry is a continuously proportioned mineral filler/asphalt binder/aggregate mixture that is spread by a slurry seal machine. These machines are equipped with a "slurry box" which squeegees the slurry mixture. The squeegee action forces the fine asphalt binder/aggregate mixture into small cracks and voids thus acting as a filler and surface seal in one operation.

Recently a new type of slurry seal called microsurfacing has been introduced. Microsurfacing slurry seals cure chemically rather than through evaporation that takes place with other surface seals. The material can be placed in excess of 1 inch depths and has the hardness and resiliency required for use on rutted pavements. Since conventional seal coats cannot be placed nearly this thick, microsurfacing is being evaluated for use on rutted pavements. Mn/DOT has placed two research sections using Ralumac, a type of microsurfacing. To date, these sections are performing as well as a new pavement section. Two drawbacks of this technology are strict limitations on the type of aggregates which are compatible with the process and its proprietary nature. These factors make microsurfacing considerably more expensive than conventional seal coats.

THIN LIFT OVERLAYS

A thin lift overlay (1" or less) utilizes hot mix asphalt (HMA) and is placed by conventional asphalt paving equipment. Mn/DOT specification 2361 is a durable mixture that works well as a thin lift overlay because of the fine nature of the mix. The mixture contains a very hard, durable, 100% crushed aggregate and a low penetration asphalt. Thin lift overlays are best suited for high traffic volume roads (>10,000 ADT) which are structurally sound but require improved ride quality and/or skid resistance. This type of treatment is normally not used on lower volume roads because of its relatively high cost.

DO NOTHING

This alternative is considered in all highway planning programs. It is also an alternative frequently utilized when considering seal coats on state roadways. Reasons for choosing this alternative are diverse but the most common seem to be:
1. Funding constraints
2. Shortage of qualified personnel
3. Lack of proper equipment
4. No programming system to schedule seal coats
5. A limited familiarity with the technology
6. Best decision

Funding Constraints

Placing a seal coat at the optimum time is critical in order to maximize the economic benefits. When an existing roadway is in need of a seal coat and funds are unavailable the seal coat is usually postponed. If the seal coat is postponed too long, the option of seal coating will be lost. Another problem arises when funds come from a fund earmarked for a variety of maintenance needs. Other requirements may be given priority over seal coating since seal coats are most effective when an existing roadway is in good shape. The appropriate time frame of maintenance funds is another concern because seal coats should only be applied in the warmest summer months in Minnesota. These factors point out the need for establishing a comprehensive seal coat program with separate funding.

Shortage of Qualified Personnel

This problem is inherent in all agencies which are responsible for an expansive roadway network. Most agencies do not have enough people available for a crew specifically used for seal coating because of many summertime maintenance activities. The number of large contractors doing seal coat work in the state is small partly because of the lack of Mn/DOT projects. Mn/DOT could provide incentive for more companies to become proficient in this technology by establishing comprehensive seal coat programs. Mn/DOT inspectors should be well trained to ensure satisfactory results.

Lack of Proper Equipment

Seal coat research has been conducted on both contracted and maintenance seal coat projects. The primary cause of failures on the maintenance projects was the lack of proper equipment. Faulty distributors and chip spreader breakdowns created problems ranging from small areas to complete project failures. Failures can be devastating considering time and materials wasted along with windshield damage and poor public perception. The bottom line is don't seal coat if you don't have the proper equipment. A comprehensive seal coat program would encourage districts and contractors to upgrade their equipment.

No Programming System to Schedule Seal Coats

A programming system to identify the optimum timing for a seal coat is necessary to maximize the economic benefits. Mn/DOT does not currently have a seal coat program within its pavement management system. Implementing such a program would be simple
because of the flexibility the pavement management system offers. The districts perform a condition rating survey of their roadways, rating all roads at least once every three years. Bituminous roadways are surveyed for cracks, rutting, raveling, weathering and patching. These deficiencies are weighted and a surface rating (SR) is determined. A present serviceability rating (PSR) is determined on the basis of ride. The SR and PSR are averaged to give a condition rating (CR). These numbers are used in the pavement management system. A seal coat program could be established by using the factors that make up the surface rating to determine the optimum time for seal coating a road. The surface rating factors would also provide a means for identifying preliminary maintenance needs such as pothole patching and crack sealing which should be completed before the seal coat. These rating factors would be compiled within the districts to determine a seal coat priority number. This number could then be provided to the pavement management section to analyze optimum seal coat time frames based on when the seal coat is actually applied. The process could be refined over time to a point where pavements are automatically flagged for seal coats.

County and municipal agencies may have a more simplified pavement management program or in some cases no pavement management program at all. The development of a good pavement management program requires two things.

1. Criteria for establishing the optimum timing for application of a seal coat.
2. Policies for determining the right type of seal coat, materials and application procedures for each individual pavement.

A seal coat programming guide which addresses both of these requirements is ideal. Unfortunately, many times rating system recommendations are preempted by the budget of the governmental unit. This can lead to pavements deteriorating past the point where a seal coat is cost effective. Not having money available at the time needed will increase rehabilitation costs considerably at a later date. This progression can continue for several years creating a budget crunch along the way. Funds should be budgeted for a seal coat program that is incorporated within the existing pavement management/maintenance system to avoid this dilemma.

A recommended publication for local government units where no seal coat programming system exists is:


This work was sponsored by the American Association of State Highway Officials (AASHO) and was conducted through the National
Cooperative Highway Research Program (NCHRP). The report also provides a surface condition rating system that can be used in lieu of an existing pavement management system.

Another recommended publication is:

"Pavement Rehabilitation - A Guide for Minnesota Cities and Counties"

This manual describes the evaluation and design procedures for pavement rehabilitation. It is a working reference to help identify and classify surface distress with recommendations on various rehabilitation alternatives. This publication is sponsored by the Local Road Research Board (LRRB) and can be obtained from the Mn/DOT Research and Development office.

Limited Familiarity with the Technology

Another reason for not seal coating is probably a limited familiarity with the technology. Numerous variables must be considered and dealt with simultaneously to properly apply a seal coat. The economics are not fully understood because of the difficulty in determining life cycle costs in relation to each particular roadway application. Understanding and dealing with the numerous variables can be learned by reading the publications referred to here and by experience gained from placing seal coats in the field.

While the economic benefit of seal coating can be debated the opinion of many pavement maintenance experts is that seal coating (when properly applied) can increase a pavements life well beyond the point needed to payback the expenditure. The type of seal coat applied, availability of materials and condition of the existing roadway will affect economic and performance aspects of each particular project. Understanding of the technology is extremely important for realizing the many benefits a seal coat program offers.

Best Decision

Sometimes seal coats are not the best pavement maintenance technique. They are not nearly as effective on pavements needing major repair. Seal coats should also be postponed on roadways that will need additional structure in the near future. The primary objective in selecting a rehabilitation is to get the best return for the money spent. Overlays or more extensive rehabilitation are, at times, the only way of achieving the desired results when interim maintenance will not help.

Seal coats under certain rare circumstances can also do more harm than good. On pavements where moisture enters from the bottom and sides a seal coat can literally trap this moisture in the pavement promoting stripping. It is always a good idea to
check the water table in each location and look for signs of stripping in the existing roadway.
SEAL COAT CONSTRUCTION

High quality, long service life seal coats require good accurate equipment and the use of proper construction operations in the field. Equipment, operations and weather are by far the most important aspects of a successful seal coat. Good equipment and procedures can, in many instances, overcome marginal or even poor materials to produce a successful seal coat. On the other hand, even the best materials cannot surmount poor equipment and construction practices to avoid a failure.

Two of the big advantages of utilizing seal coats are the relatively small amounts of equipment required and the ease and simplicity of performing the construction operation. Seal coats can be placed considerably faster and at a significantly lower expense than overlays because of these advantages.

An overview of the equipment and operations required in seal coat construction is provided below.

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CONSTRUCTION EQUIPMENT

Asphalt Distributor

The asphalt distributor must be able to apply asphalt binder uniformly in both longitudinal and transverse directions at a specified coverage rate. Non-uniform transverse coverage causes streaking where too much and too little binder alternate across the road surface. Streaking is usually the result of nozzles which are improperly positioned or sized or by spraying the binder at a temperature which is too low. Improper equipment calibration, faulty pressure regulators and poor operating practices are some of the causes of nonuniform longitudinal streaking. Uniform coverage in both directions is essential to avoid both flushing and loss of cover aggregate.

A checklist for the asphalt distributor is included in the appendix.
Broom(s)

Brooms are needed for cleaning the roadway before the seal coat and also for removing excess aggregate. If the loose aggregate is going to be swept onto a shoulder area any broom will suffice. In urban areas or where aggregate is being recycled a pickup broom should be used.

Chip Spreader

The cover aggregate or "chip" spreader should be a mechanical self propelled type. Its function is to uniformly spread the aggregate immediately after the binder is placed. The gates of the spreader are adjustable to calibrate the amount of aggregate placed at the speed it is driven. The chip spreader should be calibrated for each job and whenever a change in cover aggregate is made.

A checklist for the chip spreader is included in the appendix.

Rollers

Rollers are used to press the cover aggregate to an adequate embedment depth into the binder. Rolling also functions to promote better adhesion and particle interlock. Pneumatic rollers should be utilized in order to prevent bridging over and/or crushing the aggregate. These problems occur if steel rollers are used. A sufficient number of rollers, three or more should be used to allow the first pass to be made before the asphalt emulsion breaks. The rollers should follow directly behind the chip spreader. Ten ton, eleven wheeled rollers are preferred in order to get good embedment of the aggregate and allow complete coverage of a 12 foot lane with two passes.

Haul Trucks

Haul trucks are needed to transport the cover aggregate to the chip spreader. The number of trucks required will depend upon a number of factors including capacity and haul length. It is advantageous to have more than one stockpile on a job to reduce the haul length and to keep haul trucks off of the fresh seal coat.

Pilot Vehicle

A pilot vehicle is recommended to provide safety for the traveling public during construction. A pilot vehicle will slow traffic down and also keep traffic off the seal coat until it has cured sufficiently. Any well marked vehicle can be used for this purpose. The pilot vehicle is a very good supplement to a well designed traffic program.
Equipment Considerations

The need for equipment which is accurate and operates well is essential. Periodic maintenance and calibration checks are crucial for ensuring a successful seal coat. New "state of the art" equipment allows operators to easily make adjustments.

CONSTRUCTION OPERATIONS

An advantage of establishing a comprehensive seal coat program is that good construction operations will become common practice as the crews gain experience in the art of seal coating. It is nearly impossible to write a recipe that guarantees success because of the many variables involved. Problems can be avoided by following a logical sequence and making necessary adjustments in the field. While this paper provides a summary of good seal coat operations, the importance of continual research and on the job experience cannot be overemphasized.

Planning

Planning is a function that is primarily performed in the pavement management or rehabilitation selection phase. Planning is also an important aspect of construction operations since many decisions must be made prior to performing the actual seal coat construction. Most of these decisions deal with surface analysis and preparations of the existing roadway. Surface analysis includes such things as pavement porosity, hardness, texture, cleanliness and condition. Surface preparations would include crack sealing/repair, pothole patching and sweeping the roadway. Crack sealing and patching should be completed as far ahead of the seal coat as possible. Cleaning and sweeping should be accomplished just prior to the seal. Proper timing as in most construction operations is essential to obtaining the best possible product.

Developing the Recipe

A seal coat design is like a recipe because many variables require adjustments to be made for each particular project and each particular day that construction takes place. Some of these variables are addressed in the planning stages such as the surface porosity, texture and hardness. Others are material related such as aggregate availability. These variables affect the type and amount of binder to be used. Additional variables, such as the weather, change daily and must be evaluated in the field.

Several manuals and research papers exist which provide various equations to determine application rates for both binder and aggregate. These may or may not work due to climatic and
other factors. The Minnesota Department of Transportation is currently developing new guidelines for application rates applicable to Minnesota's climate and materials.

While these guidelines are being developed, two publications recommended for use in establishing application rates are:

"Field Manual on Design and Construction of Seal Coats" July 1981 Epps, Gallaway, Hughes


When establishing guidelines for application rates, it is important to remember that equipment and other errors can be up to ± 10 %.

Optimum application rates should be set so that the aggregate is one stone deep and is covered to a depth of 50 % initially and 70 % after one year by the residual asphalt. Observations and adjustments should be made in the field to meet these criteria. Embedment should be checked by prying aggregate particles from the mat after rolling to observe the amount of asphalt on the aggregate profile.

The aggregate coverage of one stone depth can also be observed in the field. Asphalt should be visible around the aggregate from the surface. Excess aggregate, a common mistake, is not only a waste of material but is detrimental. Excess aggregate under traffic will loosen stones embedded in the asphalt.

Asphalt Application

Each project should begin with a short test section bearing in mind that application rates can vary ± 10 %. This will allow the inspectors to observe equipment operation and to check field performance with the application rates. Rate checks (gal/yd², temp corrected) should be done with each distributor load. Rates should be changed as necessary.

Applying the Cover Aggregate

The initial application rate setting on the chip spreader should be determined by a board test prior to construction or by using mats in the field. The aggregate in the board test is spread on a measured area usually 1 square yard to a depth of one stone and weighed. The field test is trial and error adjusted to a depth of one stone. The cover aggregate should be applied at a rate so that the binder is visible after application.
Rolling

Seal coats should be rolled a minimum of five passes with pneumatic rollers. Rolling seats the aggregate and promotes the necessary bond. Overrolling is nearly impossible with good quality aggregates. Two rollers should be kept close to the chip spreader to make the first pass before the emulsion breaks. The third roller should be used for back rolling and acts as a spare. Roller speed should be slow enough so that tires do not pick up or shove aggregate particles, about 5 mph.

Brooming Excess Aggregate

All loose and excess aggregate from the newly constructed seal coats should be swept off or picked up as soon as possible to prevent stone damage to vehicles and prevent dislodgement of the embedded aggregate. It is important that this operation be performed when the binder is hard. It is usually advantageous to perform the brooming operation in the early morning the day after the seal was placed. When additives are used brooming can be accomplished the same day as the seal.

Very little excess aggregate should be left after a seal coat operation. Excess aggregate can dislodge embedded aggregate.

Overview

The seal coat operation should be continuous with the rollers following closely behind the chip spreader which is following closely behind the distributor. The aggregate should be rolled into the asphalt before it breaks. This can be a matter of seconds. Asphalt suppliers will be able to estimate this time depending on the binder being used.

Detouring traffic from the fresh seal coat is the best means of traffic control, if this is not possible traffic speed should be limited to 25 mph. Additives can be used to reduce the time to open the seal coat to traffic if the speed limit is not feasible.
MATERIALS

ASPHALT BINDERS

The three main types of asphalts used in seal coating are asphalt cements, asphalt emulsions and cut-back asphalt. In Minnesota asphalt emulsions are most commonly used and asphalt cements are virtually never used. Asphalt emulsions, particularly cationic rapid set (CRS), will be the binder discussed because of its prevalent use in Minnesota.

Asphalt emulsions normally consist of 55 to 70 percent asphalt with the remainder being the water and emulsifier solution. When an asphalt emulsion "breaks" the asphalt globules join together to provide the asphalt films that coat the aggregate particles. There are three types of emulsions depending upon the electrical charge. The types are anionic, cationic and nonionic. The charge should be the opposite of the aggregate so they will attract. Cationic emulsions are used mainly in Minnesota because most aggregates are anionic. Emulsions are also distinguished by the time required to "break". They are classified as rapid (R), medium (M) or slow (S) set. A CRS emulsion is cationic rapid setting and is the emulsion used most for seal coats. The advantage of a rapid set emulsion is that it adheres to the aggregate faster and traffic can be allowed sooner. A disadvantage is that the cover aggregate must be placed faster. Medium setting emulsions are used only on very low traffic roads, when there is little chance of rain. Slow setting emulsions are used for fog seals to allow the emulsion time to soak into the road.

Two other asphalt binders are high float emulsions and cut-back asphalt. High float emulsions were developed for low volume roads in areas where a graded cover aggregate is used. They are able to penetrate upward uniformly into the applied layer of graded aggregate. High float emulsions can also be applied more heavily because they do not flow as readily as conventional emulsions. They produce a higher viscosity residue after curing which makes them less likely to bleed.

Cut-back asphalts are thinned with solvents such as kerosene or naphtha. These binders are particularly useful when penetration of a hard pavement surface is needed. They are also useful when seal coats must be extended into the late season. A disadvantage of cut-back asphalts is that they pose environmental and safety problems because of the solvents used.

AGGREGATES

When considering an aggregate for a seal coat, its availability and characteristics must be carefully evaluated.
The ideal cover aggregate is a one sized cubical or pyramidal stone with a rough surface texture. This type of aggregate is not common and therefore is usually not economical to use. It is therefore important to first look at the characteristics of the available and low cost aggregates when designing a seal coat. These characteristics include:

1. Size and gradation
2. Cleanliness
3. Toughness and soundness
4. Particle shape
5. Surface texture
6. Absorption
7. Affinity for asphalt

Size and gradation

A one size aggregate between the 1/2-inch and No. 4 sieve is optimum for most seal coats. The one size aggregate produces superior particle interlocking and provides for better contact area between the tire and road surface. A larger size aggregate offers a better seal for high traffic volume roads because of a higher asphalt binder application rate and improved surface drainage. Drawbacks of larger aggregates are windshield damage and loss of the aggregate when snow plowing with shoeless plows.

Mn/DOT currently specifies five different gradations of fine aggregate for use on seal coats, FA-1,2,3,4,5. FA-2, FA-2 modified and FA-3 gradations are used on virtually all Mn/DOT seals. The FA-2 Modified is a gradation between FA-2 and FA-3. Local aggregate sources often dictate the use of FA-2 Modified. These specifications should be supplemented with requirements for one size cover aggregates and the FA-1,4,5 specifications used only for special cases. Limiting the gradation choices will simplify the determination of an optimum asphalt binder application.

Cleanliness

Dust on aggregate prevents adhesion of asphalt and can lead to an unsuccessful seal coat. Precoating involves placing a thin asphalt film around the aggregate particles and is more expensive than washing. Mn/DOT aggregate specifications should be updated to include precoating or less than 2% of the material passing the No. 200 sieve as determined by a wash test. An alternative is to use high float emulsions which tend to penetrate dirty aggregates.

Toughness and soundness

Toughness is a measure of resistance to abrasion and is
tested by the Los Angeles rattler. (ASTM C136) Soundness is a measure of resistance to weathering. It is tested by determining weight loss after repeated cycles of immersion in a sulfate solution. (ASTM C88) These tests should be used for marginal aggregates.

Particle shape

The ideal cover aggregate particle shape is cubical or pyramidal. Crushed aggregates provide improved performance as compared to rounded gravels. Flat and elongated particles should be avoided. Some states use a flakiness index to avoid the presence of these particles. Their specifications call for a maximum percentage of particles having a ratio of width (largest dimension) to average particle size of less than 0.5. Angular aggregates interlock better than smooth.

Surface texture

Aggregates with a rough gritty texture will bond better than smooth aggregates in a seal coat. Toughness, shape and texture are critical in determining the rate of wear and polish of the road surface. These factors dictate how well a seal coat will perform in improving and maintaining a skid resistant surface.

Absorption

Porosity of an aggregate can affect the performance and economics of a seal coat. More asphalt, in general, will be absorbed into the aggregate as the porosity gets higher. This increases the asphalt needed and increases costs. Another factor of porous aggregate is that the time of set is reduced because of the water absorbed.

Affinity for asphalt

Aggregates vary in their surface charges. Dolomite and some limestones have a predominately electro-positive charge and should be used with anionic asphalt emulsions. Silica, quartz and most gravels are hydrophilic, with electro-negative charges, and should be used with cationic asphalt.

Many of these aggregate characteristics may be moot when applied to a particular seal coat project. The cost and availability of the local aggregates must be the first consideration when planning any significant seal coat operation. A good economical seal can usually be designed with locally available aggregate. This emphasizes the importance of making the aggregate choice the first step in designing cost effective seal coats.

ADDITIVES
Mn/DOT has placed several seal coat test sections using various types of asphalt binder additives from many manufacturers. Dupont and Polysar latex modifiers as well as Lubrizol's Ductilad have been incorporated into emulsion seals. Ductilad was also utilized in a cutback seal coat which successfully repaired a flushed surface. We are extremely grateful to these companies for supplying their materials for use in our research.

The main advantage in using additives appears to be early chip retention and more forgiveness in establishing asphalt binder application rates. The early chip retention allows earlier sweeping which decreases windshield damage. An example of the broader application range was noted on one project where flushing was visible on a control section and not on an adjacent section with the same rate utilizing an additive.

The cost of utilizing additives varies with the percentage used and the asphalt binder supplier. A probable cost would be an additional 20 to 35 percent of the cost of the asphalt binder. Observations to date do not show a prolonged life of seal coats with additives when compared to standard seal coats with the proper asphalt binder application rate.

These factors suggest that additives are best utilized:

1. When the aggregate makes determining an optimum asphalt application rate difficult.
2. For high traffic volume roads.
3. For late season work.

Sample specifications for using polymer additives in seal coats can be obtained from the Mn/DOT bituminous office.
CLIMATE AND WEATHER

The main climatic factor affecting seal coats is seasonal temperature. Weather factors include daily temperature, humidity, rainfall and wind.

Mn/DOT specifications now limit seal coat operations to June 1st through September 15th. Seal coats benefit from as much traffic under warm weather as possible. Seal coats perform better when placed early in the season because the additional embedment makes the seal coat more durable in the harsh winter months. Mean temperatures in Minnesota drop off significantly in September according to the climatological data. It is recommended that Mn/DOT specifications be changed to allow seal coating from May 15th through August 31st with special attention paid to weather after August 15th.

Mn/DOT specifications call for a minimum air temperature of 50°F and a minimum surface temperature of 70°F during daylight hours. Asphalt binder set time and therefore the time to open the road to traffic are shorter with warmer temperatures. These temperatures are very critical for late season work.

Asphalt cements can experience serious adhesion problems with high humidity and moisture. Emulsions, being water based, are much less susceptible to humidity and moisture problems. Mn/DOT specifications call for a dry road surface and less than 75% humidity for seal coat operations. High humidity will slow the cure rate.

Seal coats should not be exposed to rain for at least 24 hours.

High wind speeds can reduce breaking time and distort distributor spray patterns. Also, blowing dust can contaminate the asphalt binder.

Daily weather factors can be primarily responsible for the failure of a seal coat. It is better to postpone a seal coat operation than to place it under adverse conditions.
HIGHLIGHTS AND RECOMMENDATIONS

PLANNING

- A good seal coat program should be integrated into an existing pavement management system or a seal coat programming guide should be established.

- Crack sealing and patching should be completed as soon before the planned seal coat as possible.

- Pavement porosity, hardness, texture and other surface analysis characteristics must be considered when choosing materials and estimating application rates.

- Chip seals should be completed early in the season to allow traffic to increase aggregate embedment during the warm summer months. Contracts should be let accordingly.

- Skilled and experienced contractors and inspectors are key elements to a quality chip seal program. (Provide adequate training up-front).

MATERIALS

- Asphalt emulsions are by far the most commonly used binder in Minnesota because they are more versatile and offer many advantages over cutbacks and asphalt cements.

- Seal coat designs should start with a choice of aggregate. Other parameters of the design must consider the characteristics of the aggregate used.

- The ideal aggregate is a one-sized cubical or pyramidal stone with a rough surface texture. Availability and cost, however, often dictate the use of less desirable aggregates.

- A choke stone course (<1/8 inch) can help lock in single size chips when applied immediately after initial rolling.

- Aggregate cleanliness is crucial to obtaining optimum results. Material passing the # 200 sieve should be limited to 2% or less. Washing the aggregate to meet this provision or precoating should be required.

- When performing chip seals on higher volume roads
(>3000 ADT), crushed aggregates and the use of additives should be considered.

- The main advantages of using additives are early chip retention and more flexibility in establishing optimum asphalt binder rates.

EQUIPMENT

- Good equipment and procedures can, in many instances, overcome marginal or even poor materials to produce a successful seal coat. Conversely, even the best materials cannot surmount poor equipment and construction practices to avoid a failure.

- The need for equipment which is accurate and operates well is essential. Periodic maintenance and calibration checks are crucial for ensuring a successful seal coat. New "state of the art" equipment allows operators to easily make adjustments.

CONSTRUCTION OPERATIONS

- Each project should begin with a short test section bearing in mind that application rates can vary ± 10%.

- Binder application rates should allow for 50% aggregate embedment initially and 70% after one year. Application rate and embedment checks must be performed periodically in the field.

- Aggregate application rates should also be carefully monitored. Excess aggregate is a waste of material and can be detrimental to the performance of a seal coat. The underlying asphalt should be visible after the cover aggregate is applied.

- The cover aggregate should be applied immediately following the binder distribution. The time available before the emulsion breaks can be obtained from the supplier. At least one rolling pass must be performed prior to the emulsion breaking.

- All loose aggregate should be broomed off or picked up as soon as possible. If embedment is low and there are signs of chip loss after brooming or exposure to traffic, a fog seal can be used to increase embedment and reduce winter chip loss.

CLIMATE AND WEATHER

- Mn/DOT specifications should be changed to allow seal
coating May 15th to August 31st. Special attention should be given to seal coats applied after August 15th. Early season seal coats perform much better that those placed in the late season. June and July are usually the best months to place seal coats.

- Temperature, humidity and wind affect seal coat performance. Decisions regarding these factors must be made on a day to day basis by experienced field personnel.
BIBLIOGRAPHY


ACKNOWLEDGEMENTS

The author would like to thank Earl Angell of the Mn/DOT bituminous office, Fred Kovall of Mn/DOT District 8, and Roger Olson and Jerry Teig of the Mn/DOT Physical Research office for their help and contributions to this report.
APPENDIX
## CONSTRUCTION EQUIPMENT CHECKLIST

### Asphalt Distributor

<table>
<thead>
<tr>
<th>Nozzle Sizing</th>
<th>Shoot slightly less binder in the wheel paths</th>
<th>Each Job</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nozzle Positioning</td>
<td>Should be at an angle of 30 degrees with the bar</td>
<td>Daily</td>
</tr>
<tr>
<td>Nozzle Cleanliness</td>
<td>Inspect for clogs or erratic spray patterns</td>
<td>Daily</td>
</tr>
<tr>
<td>Spray Bar Height</td>
<td>Normally 10&quot; above pavement surface. Check fan spray</td>
<td>Daily</td>
</tr>
<tr>
<td>Instrument Calibration</td>
<td>Bitometer, pressure gauge, tachometer, thermometer and dipstick</td>
<td>Yearly</td>
</tr>
</tbody>
</table>

### Chip Spreader

<table>
<thead>
<tr>
<th>Gate Openings</th>
<th>Ensure proper operation</th>
<th>Daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spread Rate</td>
<td>One stone depth of aggregate</td>
<td>Each Job</td>
</tr>
</tbody>
</table>

### Rollers

| Contact Tire Pressures   | Adjust pressures if crushing of soft aggregates is observed | Each Job       |

### Haul Trucks

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Ensure enough trucks and positioning to eliminate lag time</th>
<th>Each Job</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compatibility</td>
<td>Make sure all trucks function properly with chip spreader</td>
<td>Each Job</td>
</tr>
</tbody>
</table>

### Pilot Vehicle

<table>
<thead>
<tr>
<th>Markings</th>
<th>Markings should identify vehicle and purpose</th>
<th>Each Job</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drivers</td>
<td>Understand traffic plan</td>
<td>Each Job</td>
</tr>
</tbody>
</table>

### All Equipment

<p>| Preventative Maintenance | All systems to reduce breakdowns                        | Each Job       |</p>
<table>
<thead>
<tr>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill manholes to max. 50 mph for 24 hours or use addresses</td>
</tr>
<tr>
<td>No traffic until rolling is complete and emulsion has set</td>
</tr>
<tr>
<td>(usually the next morning unless addresses used)</td>
</tr>
<tr>
<td>Sweep loose aggregate as soon as possible</td>
</tr>
<tr>
<td>Install traffic speed advisory signs (25 mph)</td>
</tr>
<tr>
<td>Remove equipment from clear zones</td>
</tr>
<tr>
<td>Equipment should be 50%+</td>
</tr>
<tr>
<td>Initial pass must be completed prior to emulsion break</td>
</tr>
<tr>
<td>Use at least two and preferably 3 pneumatic tire rollers</td>
</tr>
<tr>
<td>Roll a minimum of 2 passes (over rolling is nearly impossible)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rolling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suggested rate (15-25 PSY FA-2, 20-30 FA-3)</td>
</tr>
<tr>
<td>Repair process if necessary</td>
</tr>
<tr>
<td>Adjust application rate as needed</td>
</tr>
<tr>
<td>Observed aggregate coverage (should be one stone depth)</td>
</tr>
<tr>
<td>Run 1000 ft section at predetermined rate</td>
</tr>
<tr>
<td>Suggested rate (0.2-0.3 GSY with FA-2, 0.3-0.4 with FA-3)</td>
</tr>
<tr>
<td>Repair process if necessary</td>
</tr>
<tr>
<td>Adjust application rate as needed</td>
</tr>
<tr>
<td>Check aggregate emulsion after rolling (should be 50%)</td>
</tr>
<tr>
<td>Run 1000 ft section at predetermined rate</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Application Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface preparation</td>
</tr>
<tr>
<td>Project</td>
</tr>
<tr>
<td>Surface analysis</td>
</tr>
<tr>
<td>Preparing sampling and testing requirements; establish allowing (also see 2356 specifications and Blumirius Manual 5-693:600)</td>
</tr>
</tbody>
</table>

CONSTRUCTION OPERATIONS
## CONSTRUCTION EQUIPMENT CHECKLIST

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<th>All Equipment</th>
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<tbody>
<tr>
<td>Preventative Maintenance</td>
<td>All systems to reduce breakdowns</td>
</tr>
<tr>
<td>General</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>Make sure traffic control plan and other safety requirements are followed.</td>
<td></td>
</tr>
<tr>
<td>Maintain maximum 25 mph for 24 hours or use additives.</td>
<td></td>
</tr>
<tr>
<td>No traffic until rolling is complete and emulsion has set.</td>
<td></td>
</tr>
<tr>
<td>Clean up</td>
<td></td>
</tr>
<tr>
<td>Asperapeutic emulsion should be 50%+.</td>
<td></td>
</tr>
<tr>
<td>Initial pass must be completed prior to emulsion break.</td>
<td></td>
</tr>
<tr>
<td>Leave at least two and preferably four nominal lift rolls.</td>
<td></td>
</tr>
<tr>
<td>Roll a minimum of two passes (over rolling is nearly impossible).</td>
<td></td>
</tr>
<tr>
<td>Rolling</td>
<td></td>
</tr>
<tr>
<td>Repeat process if necessary.</td>
<td></td>
</tr>
<tr>
<td>Density, application rate, or emulsion.</td>
<td></td>
</tr>
<tr>
<td>Run 1000 feet section at predetermined rate.</td>
<td></td>
</tr>
<tr>
<td>Application Rate.</td>
<td></td>
</tr>
<tr>
<td>Asphalt Application</td>
<td></td>
</tr>
<tr>
<td>Suggested rate (6.5-14 GY, with FA-2; 6.5-14 GY, with FA-A-3).</td>
<td></td>
</tr>
<tr>
<td>Repeat process if necessary.</td>
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Surface Preparation
- Check repair, pole, patching, patching and sweeping
- Remove asphalt, coarse aggregate, and condition

Planning (Project Specific)
- Preparation

(Also see 2366 Specifications and Bituminous Manual 5-693.600)

CONSTRUCTION OPERATIONS