An Overview of the Design of Emulsion Based Seal Coating Systems Available in Canada and Abroad

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ABSTRACT

Seal coat systems have been used in Canada and abroad for many decades. Seal coats are thin wearing courses made of superimposed layers of aggregate and bituminous binder. They may be used to restore the surface characteristics of existing roadways or to waterproof and preserve others.

Seal coats form an impervious thin overlay over an existing bound or unbound material. There are two families of treatments: the *chip seal* and *graded seal*. Chip seals combine the application of a layer of calibrated chips onto a layer of a rapid setting emulsion while the graded seals are systems that combine the application of dense/gap graded aggregate onto a layer of anionic high float emulsion. Each system may be applied as a single or a multiple application.

Parameters such as the traffic and the existing surface conditions must be taken into account in the design of a specific seal coat system for a given roadway. Field conditions such as ambient temperature, the time of the year, the sun/cloud conditions must be taken into account as well.

This paper presents the seal coating technologies and a discussion on the state of the design practices of these surface treatments in Canada and abroad. The paper introduces new concepts related to the selection of seal coating systems, as well as emerging systems now available in North America.

RÉSUMÉ

Les systèmes de couches de scellement ont été utilisés au Canada et ailleurs depuis plusieurs décades. Les couches de scellement sont des couches d'usure minces faites de la superposition de couches de granulats et de liant bitumineux. Elles peuvent être employées pour restaurer les caractéristiques de surface de routes existantes ou pour imperméabiliser et conserver les autres.

Les couches de scellement forment un revêtement mince imperméable sur un matériau lié ou non. Il y a deux familles de traitement : scellement à la pierre et scellement à la grave. Le scellement à la pierre combine l'application d'une couche de pierre calibrée sur une couche d'émulsion à prise rapide alors que le scellement à la grave combine l'application d'une couche de granulats à granulométrie dense ou discontinue sur une couche d'émulsion anionique à flottabilité élevée. Chaque système peut être posé en application simple ou multiple.

On doit tenir compte des paramètres tels que le trafic et les conditions de la surface existante dans la conception d'un système particulier de couche scellement pour une route donnée. Les conditions de terrain comme la température ambiante, la période de l'année, les conditions de soleil et de nuage doivent être prises en compte aussi.

Cet article présente la technique des couches de scellement et une discussion sur l'état des pratiques de conception de ces traitements de surface au Canada et ailleurs. L'article introduit de nouveaux concepts reliés au choix des systèmes de couches de scellement, ainsi que des systèmes émergents maintenant disponibles en Amérique du Nord.

1.0 CONCEPTS

Surface treatments consisting of superimposed layers of bituminous binder and cover aggregate have been used for many decades. For the purpose of this paper, this type of treatment is referred to as "seal coating". The development of seal coating systems is closely associated with the increased usage of the automobile as a means of transportation. Today, this is the most common type of roadway surfacing system in Canada. It is estimated that approximately 40 million square metres of this treatment is placed every year in Canada. The usage of this type of treatment varies greatly from one province to another in Canada. This paper presents an overview of the design practices of seal coating systems available in Canada and abroad.

1.1 Definitions

Unfortunately, there is still no universally accepted nomenclature for this type of treatment of the surface of a roadway. In Canada and the United States (US), it is often referred to as *seal coats, chip seals* or simply *surface treatment*. In the United Kingdom (UK), the term *surface dressing* is used. In Australia, the successive application of bituminous binder and cover aggregate is referred to as *sprayed sealing*. In South Africa, it is called *surfacing seals.* As indicated above, for the purpose of this paper the expression "*seal coating"* is used to designate the different families of processes that may be associated with the superimposed layers of bituminous binder and cover aggregates.

1.2 Reasons for Seal Coating Roadways

This type of treatment may be used for the purpose of restoring the surface characteristics of roadways, mainly texture and friction. It may also be used as a preventive maintenance treatment to stop the ingress of water and the oxidation of bituminous surface. Furthermore, seal coat systems are used as surfacing systems on top of consolidated unbounded base material. However, it should be noted that seal coating systems do not have the ability to correct the profile of a roadway or the ability to strengthen the roadway structure.

1.2.1 Texture and Friction

The texture and the friction properties of surfaces are dependent on the nature of the aggregate mosaic at the surface of the roadway. The aggregate mosaic is a function of both, the micro-texture and macro-texture of the surface of the road. The micro-texture is the texture of the aggregate, while the macro-texture is the overall texture of the surface. The micro-texture provides friction at all speeds, while the macro-texture provides surface drainage and it contributes to friction at higher speeds. Seal coating systems using a carefully selected aggregate can provide both micro-texture and macro-texture.

1.2.2 Ingress of Water

Seal coating systems may be used to cover and protect the existing structure against the damage caused by the atmospheric elements. The membrane like binder can be effective in sealing binder-lean or oxidized surfaces, as well as sealing minor non-active cracks. As for any other preventive maintenance treatment, if applied before the appearance of any major structural deficiencies, seal coating systems will preserve the integrity of the roadway structure, delaying the requirements for major repairs, thus, contributing to prolonging the life of the roadway.

1.2.3 Surfacing System

Seal coating of granular base material is a common practice in Canada. It is a cost effective surfacing system for low volume roads. Low volume roads often consist of layers of granular material placed on top of frost susceptible roadbed soils. Distortion caused by the differential frost heaving actions is common for this type of structure. Seal coating surfacing systems have membrane-like properties, which provide them with the ability to follow moderate distortion induced by differential frost heaving.

2.0 TYPE OF SEAL COATING SYSTEMS

Seal coating systems may be separated into two different families of systems: the one-sized aggregate systems are referred to as "*chip seals*" and the graded-aggregate systems are referred to as "*graded seals*". Within each of these families of systems there are several types of systems that vary according to the number of layers of aggregate and bitumen emulsion. There are the single type systems which consist of a single application of binder and aggregate and there are the multiple systems which consist of one or many applications of binder and aggregate. Table 1 summarizes the type of systems available within each seal coating family.

Table 1 – Type of Seal Coating Systems Available in Canada and Abroad

Type of application	***Seal Coating Systems***	
	Chipping	***Graded-aggregate***
Single application system	- Single chip seal	- Single graded seal
Multiple application systems	- Double chip seal - Triple chip seal - Racked-in chip seal - Sandwich seal - Sandwich seal double chipping - Inverted double chip seal - Cape seal	- Double graded seal
Proprietary application systems	- Fibre/geotextile reinforced seal coating systems	

2.1 Single Seals

The single seal systems consist of a single application of binder followed by a single application of cover aggregate. Most single seals, single chip seals or single graded seals, are placed on existing bound substrate and they are usually sufficiently robust for many situations.

2.2 Double Seals

Double seals have two layers of aggregate and two applications of binder, the second layer of binder is placed between the two layers of aggregate. The double chip seals and the double graded seals are quite different from one another, not only from the aggregate perspective, but also from the binder application and the placement method. Double graded seals may be described as two singles seals applied independently on one another. Double graded seals are mainly applied on consolidated unbound granular material. In the case of the double chip seals, the two layers of binders and aggregates are design as a system. The size of the second layer of chipping is selected to knit the aggregate mosaic of the surface. Consequently, double chip seals produce a lower texture depth than other chip seal and as a result, they are usually quieter and more robust. Double chip seals are usually applied on consolidated bound materials ranging from low to high volume roads.

2.3 Triple Chip Seals

Triple seals have three layers of aggregate and three applications of binder. The triple chip seals are extremely robust and may be used on a wide range of situations. The largest size chipping is applied as a first layer and it determines the thickness of the treatment. The subsequent layers serve to fill the gaps in between the chippings of the first layer. Similar to double chip seals the triple chip seal has a lower texture than other seal coating systems and they are also quieter. Triple seals are used in the US.

2.4 Racked-in Chip Seals

Racked-in chip seals are also referred to as “choke seals”. It consists of one heavy layer of binder followed by two layers of cover aggregate. The second layer of chipping is smaller than the first layer and it fills the gaps within the mosaic of the first layer of aggregate. The smaller chippings lock the larger chipping in position, thereby producing a stable mosaic. It is used in Europe and Australia on roadways where traffic is heavy and/or fast.

2.5 Sandwich - Single Chip Seals

The sandwich - single chip seal system consists of a layer of coarse chippings applied onto the substrate first, then a layer of bituminous emulsion followed by the application of a single fine chipping. Sandwich - single chip seals are mainly used where the existing substrate is binder rich.

2.6 Sandwich - Double Chip Seals

Similar to the traditional sandwich - single chip seals, the sandwich - double chip seal consist of a layer of coarse chippings applied onto the substrate first without any binder followed by the application of a double chip seal with the smaller chipping applied at the top. This type of treatment is used in certain region of France as a treatment for highly heterogeneous substrates.

2.7 Inverted Double Chip Seals

The inverted double chip seal is a type of double chip seal where the layer of small chipping applied at the bottom. This treatment is used in the UK on substrate of variable hardness due to extensive patching.

2.8 Cape Seals

The Cape seal is a system that combines a single chip seal with a fine slurry seal. The slurry seal locks the large chipping in position, thereby producing a stable mosaic. It provides a “knobby” type texture with excellent friction properties. Similar to double chip seals, Cape seal may be applied over a wide range of situations and they are usually quieter and more robust than other types of seal coating systems. Cape seals are commonly used because of their colour and the surfacing characteristics that they provide.

2.9 Fibre/Geotextile Reinforced Seal Coating Systems

This type of seal coating system originated in Europe and it has been recently introduced in the US market. A network of fibre or a geotextile fabric is incorporated within the binder prior to the application of the cover aggregate. This type of seal coating system has enhanced tensile properties, which provides the ability of the system to absorb stresses generated in the roadway surface. It is used on cracked roadways where mitigation of reflective cracking is important. It is often described as a Stress Absorbing Membrane (SAM) system and it may also be used as a Stress Absorbing Membrane Interlayer (SAMI) system.

3.0 PARAMETERS TO CONSIDER IN THE SELECTION OF SEAL COATING SYSTEMS

The selection of an optimized system may be carried out in four basic steps. The first step is related to an evaluation of the parameters related to the environment and the roadway condition. The second step concerns the selection of the type of seal coat system, including the selection of the aggregate and the binder type. The third step consists of determining the binder spray rate in accordance with the aggregate characteristics. Finally, the last step consists of correcting the design binder spray rate in accordance with the localized site conditions and timing of placement.

3.1 Parameters Related to the Existing Roadway and the Environment

The parameters related to the roadway to be seal coated are related to its location, the existing surface conditions, the traffic counts, the traffic speed, the roadway layout, the substrate hardness, and trafficked pathways within the roadway. The parameters related to the environment of the roadway to be seal coated are related to the local climatic conditions, the shade conditions, and the timing of placement of the seal coating system.

3.1.1 Surface Conditions

The evaluation of the surface conditions is critical for the selection of an optimized system. It is an assessment of the dryness/roughness/fatness of the surface and its homogeneity/heterogeneity characteristics. A smooth-rich surface will likely require a different seal coating system or a larger chip compared to a smooth-dry surface. Similarly, the design approach may be different for a smooth-dry surface compared to a rough-dry surface. Moreover, heterogeneous surfaces due to extensive patching may require a different seal coating system compared to homogeneous surfaces.

3.1.2 Road Hardness

The road hardness is the assessment of the potential of the aggregate to indent the existing roadway surface. It is a property influenced by the surfacing material and the local climate. This is a critical property to accurately assess to select the correct size of aggregate. The UK and Australia have developed and standardized hardness probes and methods to measure this property. It should be noted that both the UK and Australia use with success seal coating systems in urban areas and on high volume roads.

Generally, on soft substrate a larger aggregate is used while on a hard substrate a smaller aggregate is used. The binder spray rate is also adjusted accordingly.

3.1.3 Traffic Categories

The evaluation of the volume of traffic per each lane of the roadway is critical for the success of the treatment. The traffic, especially the volume of heavy vehicles, embeds the aggregate into the binder and the substrate. In a certain manner, the traffic itself is part of the method of placement. The determination of the binder spray rate is closely associated with the traffic travelling in the lane. The binder rate may be different from one lane to another on the same roadway. The best example to illustrate this approach is the rate of binder required for a seal coat system applied on the travelling lanes of a four-lane roadway compared to the rate of binder required for the passing lanes.

3.1.4 Traffic Speed

The traffic speed is a factor to consider in the selection of the seal coat system. If the traffic is moving at a high speed, it increases the risk of having aggregate come loose. Multi-layer seal coating systems may be preferable on high speed roadways. For the purpose of the selection of a seal coating system the UK considers roadways as high speed, when the travelling speed is greater than 80 km/hr.

3.1.5 Roadway Layout

Vehicles travelling on a roadway with a steep gradient and tight curves induces stresses in the surfacing differently than the same vehicle travelling on a straight and flat roadway. Similarly, additional stresses are transferred into the surfacing system of the roadway at intersections where traffic is stopping and turning. Considerations ought to be given to these factors in the selection of an optimized seal coating system.

3.1.6 Trafficked Pathways

Roadway surfaces are not trafficked uniformly across their width. The embedment of the aggregate is greater in the wheel path compared to the centre of the roadway or in between the wheel path of a lane. Whenever practical, the usage of a higher binder rate is usually considered for the areas of a roadway that are less trafficked to compensate for the lack of kneading action provided by the traffic to embed the aggregate.

3.1.7 Climate and Timing of Placement

The placement of seal coating system must be carried out in the summer months. Moreover, the success of a seal coating treatment is not only related to favourable climatic conditions during placement, but also, and very importantly, the following weeks after the placement of the system. This is particularly important to ensure the long term stability of the system. As indicated before, the traffic contributes to the embedment of the aggregate into the binder and the substrate. The embedment and the kneading action induced by the traffic, only occur if the temperature of the roadway is warm. If the aggregate of the seal coat system is not properly embedded into the substrate before the onset of the cold weather, snowplough damages can occur during the winter months. If work must be carried out at the end of the season, finer multi-layer type systems may be less at risk than a single seal with coarse aggregate. The usage of a premium binder may also reduce the possibility of snowplough damage. Increasing the binder rate may also be considered as a measure to prevent snowplough damage but it also increases the risk of bleeding the following summer. It is important to carry out the placement of a seal coat system under good weather, yet it is probably just as important that a few weeks of good weather remains after the work is completed to allow the traffic to complete the embedment of the seal coat system.

3.1.8 Shade Conditions

Seal coating systems applied on roadway surfaces constantly shaded by trees or other object tend to remain cooler than the areas exposed to sun. The embedment of the aggregate into the substrate/binder will be less in the shaded areas compared to the areas exposed to the sun. The rate of binder is normally increased in these areas to take into account the lack of warmth of the roadway surface due to shading.

3.2 Selection of the Type of Seal Coat System

The selection of the type of seal coating system for a specific roadway depends on a number of factors. The usage of flow diagrams, catalogues of systems, or decision trees are common. Computer programs have been developed in France and in the UK to help with selection of optimized systems. The local experience is required to develop selection systems that accounts for the local conditions. For example, snow removal and snowplough damage is a very important factor to take into consideration in many parts of Canada and it needs specific attention, while in other counties the variation in the hardness of the substrate requires a more specific evaluation. It is the case in the southern US where the indentation of the aggregate into the substrate will be significant because of the long period of warm weather. Other factors such as reduction of initial aggregate loss or the pressure to open the road to traffic may influence the selection of an optimized system. Moreover, there may be reasons other than those included in standard selection process that may influence the final selection of an optimized system. Noise generation may be a factor to consider in the selection of the system. If noise is a factor the selection of a finer multi-layer system may be preferable, even though a single chip seal may be adequate.

3.3 Parameters Related to the Aggregate

The aggregate parameters necessary for the determination of the binder spray rate in accordance with the aggregate characteristics are related to the “average least dimension” of the aggregate and the “voids in the loose aggregate”. The average least dimension represents the average of the thickness of all individual particles when the particles lie with their least dimension upwards. The aggregate flakiness and gradation are evaluated to determine the average least dimension of the aggregate. The voids in the loose aggregate provide an indication of the space available to fit the binder in between the aggregate particles. The aggregate loose unit weight along with the aggregate specific gravity is used to determine the voids in the loose aggregate.

3.3.1 Flakiness

The flakiness of the aggregate particle is evaluated by determining the percentage of flat particles within the aggregate. The preferred shape of the cover aggregate is cubical rather than flaky. Flaky particles tend to lie on their flat side in the wheel paths and tend to lie randomly in the less trafficked areas. An excessive amount of flaky particles in a seal coating system may cause the system to bleed in the wheel paths and to be more susceptible to snowplough damage and aggregate dislodgment in the less trafficked areas. The flakiness characteristic of the aggregate is determined using different methods; the Flakiness Index is however, widely used. It is defined as the percentage of the aggregate particles having their least dimension less than 60 percent of the average size of the aggregate. The least dimension of an aggregate is defined as the minimum opening of a slot through which the aggregate can be passed. The tolerance limits for the flakiness of the aggregate are modulated in accordance with traffic but generally should be less than 30.

3.3.2 Gradation

Along with the shape, the gradation of the aggregate is assessed to determine the average least dimension of an aggregate. The average least dimension of an aggregate is influenced by the mean size of an aggregate. An aggregate is considered coarse if its gradation is positioned in the lower part of the gradation band; normal if it is positioned in the middle and fine if it is positioned in the upper part. Accordingly, the mean size of the aggregate varies from coarse to fine gradations within the same gradation band. The optimal binder spray rate for a single chip seal system may vary as much as ten percent between a coarse aggregate and a fine aggregate even when both chips comply with the same single-size gradation band. The impact of the aggregate gradation on the binder rate is less for the secondary layers of multi-layer chip seal systems.

3.3.3 Loose Unit Weight

The loose unit weight of an aggregate is used to determine the voids in the loose aggregate parameter. It is used along with the average least dimension parameter to determine the design binder spray rate specific to the aggregate. It is used to calculate the voids expected to remain between the aggregate particles after rolling. The loose unit weight of an aggregate depends on its gradation, shape, and specific gravity. Graded aggregate may range from dense graded to gap graded. They tend to have a greater loose unit weight compared to chippings, thus, they provide less space for the binder. Dense graded aggregate are the least desirable type of aggregates for seal coating as they tend to provide less space for the binder. Consequently, dense graded seals may flush and/or ravel depending on the variation of the aggregate gradation.

3.3.4 Angularity

Even though the angularity of the aggregate is not a factor considered in determining the design binder spray rate, it is important factor to take into account in the overall performance of the seal coating system. Closely knitted mosaics are more difficult to achieve with round particles compared to angular, crushed particles therefore, round particles seal coating systems tend to be more prone to aggregate dislodgement cause by the rolling of the aggregate. Field experience has revealed that round particle chip seal systems tend to perform better than round particle graded seals providing the proper embedment of the chip has been achieved.

3.4 Parameters Related to Localized Site Conditions

As indicated before, the selection of an optimized seal coating system for a specific roadway depends on a number of factors, which may vary within a site. Roadway parameters that influence the selection of an optimized seal coating system may vary within a site longitudinally and/or transversely. A steep gradient may be treated differently in an uphill direction compared to the downhill direction. The shaded areas may require additional binder compared to the non-shaded areas within the same site. A job site may be divided into homogenous sections to account for the factors influencing the selection and the design of optimized systems.

4.0 SELECTION OF AGGREGATE AND BINDER

4.1 Aggregates

4.1.1 Aggregate Type

As indicated in the section describing the various families of seal coating systems, there are two types of seal coating systems, which are differentiated with the type of aggregate used to build them. The one-sized aggregate systems are referred to as chip seals and the graded-aggregate systems are referred to as graded seals.

The one-sized aggregate systems are built using clean chippings. Chippings are defined as one-size aggregate if nearly all the aggregate particles are contained between two consecutive sieves that obey the general rule of $d \geq 0.6D$ where "d" represents the size of the smaller sieve, while "D" represents the size of the larger sieve. The common sizes of the chippings, expressed in d/D, are 2/4 mm, 2/6 mm, 4/6 mm, 6/10 mm, and 10/14 mm. Coarser chippings (14/20 mm) are also used as the primary layer of triple chip seals.

The graded-aggregate may be dense graded or gap graded. They are usually unwashed and the dust content may range between 1 to 8 percent. The nominal maximum size of the aggregate or the D value ranges from 10 to 16 mm. Coarser graded-aggregate such as 20 mm are occasionally used as the first layer of multi-layer systems.

4.1.2 Cleanliness

The cleanliness of the chipping is of the utmost importance for the success of any of the chip sealing systems. The presence of a thin layer of dust on dry chipping will prevent bonding between the chipping and the binder. Chipping is considered cleaned when the proportion of particles passing the 75 µm sieve is 1 percent or less. In some cases, the specified maximum particles passing 75 µm may be as low as 0.3 percent.

The cleanliness requirements for graded-aggregate seal coating systems requirements are not as stringent. The anionic high float type emulsion used with this type of aggregate contains a wetting agent, which allows proper bonding. However, the development of aggregate/binder adhesion and strength may be slow, which limits the usage of this type of seal coating system to lower volume roads.

4.1.3 Aggregate Selection for Primary Layer

The toughness of the primary layer of chippings (or chipping of a single chip seal system) is modulated in accordance with traffic loading. The chippings used for the primary layer are selected in accordance with traffic to provide friction, as well as resistance to crushing and abrasion. For most chip sealing systems the chipping of the primary layer protrude at the surface to provide friction, as well as crushing and abrasion resistance. The thickness of a chip seal system is closely related to size of the chipping used for the primary layer. In the case of an inverted double chip sealing system the objective of the primary layer is different thus, the toughness of the primary layer of chip is not as critical. The first layer smaller chipping is applied to produce a more uniform surfacing of a roadway with variable hardness. Similarly, the first layer of a double graded-aggregate seal provides uniformity and also surface cohesion. In both cases, the inverted double chip seal and the double graded-aggregate seal, the aggregate of the primary layer are not protruding at the surface of the roadway.

4.1.4 Aggregate Selection for Secondary/Tertiary Layer

The role of the secondary/tertiary layer of a multi-layer chip sealing system is to lock the chipping of the primary layer in position. The toughness of the frictional properties of the chipping of the secondary layer is important but not as critical as what is required for the chipping of the primary layer. The chippings are smaller and selected to fit within the interstices left by the chippings of the primary layer and pack around the larger chipping in position.

4.1.5 Aggregate Size Selection

The aggregate sizes for the seal coating systems are selected in accordance with both the traffic and the hardness of the existing roadway. On softer substrate and/or higher volume roads increased embedment is expected thus, multi-layer chip seals with a larger primary layer chip may be required. In contrast, on harder substrate and/or lower volume roads less embedment is expected therefore, small chippings single chip seals or multi-layer chip seals with a smaller primary layer chip may suffice.

4.2 Binder

4.2.1 Binder Types

There are four families of binders that have been used over the years for seal coating: cutback bitumen, tar-bitumen blend binders, hot sprayed bitumen, and bitumen emulsions. However, the implementation of more restraining health and safety regulations has spurred the development and the usage the bitumen emulsions. Bitumen emulsions are the preferred binders for seal coating in many industrial countries. There are mainly two types of emulsions used for seal coating; anionic high floats and cationic emulsions. The emulsions are further classified in accordance with their setting characteristics and their viscosity. Regardless of their type, emulsions may be unmodified or modified with polymer.

Anionic high floats emulsions
The anionic high float emulsions set as water evaporates and they are usually not chemical sensitive to the mineral nature of the aggregate. The build up of cohesion and adhesion of anionic high float seal coating systems may be considered rapid or medium setting. It is possible to include a wetting agent in the manufacturing of high float emulsions to facilitate the coating of large particles even in the presence of dust. Anionic high float emulsions are mainly used with graded-aggregate seal coating systems. The setting and viscosity characteristics of high float emulsions are selected in accordance with the gradation of the aggregate. Slower setting high floats with lower viscosity is preferred for dense graded aggregates while faster setting with higher viscosity high float emulsions is preferred for gap graded aggregates.

Cationic emulsions
Contrary to anionic emulsions, the setting of cationic emulsion is strongly affected by the chemical nature of the aggregate, which destabilizes cationic emulsions causing them to break and set rapidly. Thus, gain in strength of cationic seal coat systems is more rapid than with anionic type systems. Consequently, cationic emulsions seal coating systems are preferred where and when the success of the treatment is highly dependent on the rapid gain of strength of the system. This is essentially associated with the build up cohesion of the systems and the build up of adhesion of the binder with the aggregate. The surface area

of the aggregate influences the setting of cationic emulsions. Therefore, the presence of high surface particles, dust, may cause the emulsion to destabilize in an uncontrolled manner, which may in return, prevent the binder to build up adhesion with large particles. Fast setting and high viscosity cationic emulsions are the preferred binders for dust free chippings used to produce the various types of chip sealing systems.

Modified bitumen emulsions
Bitumen emulsions, anionic or cationic, may be modified by the addition of polymers to enhance their adhesion and cohesion properties. Compared to unmodified emulsions, polymer modified emulsions are not as thermally susceptible. They also provide both, better early adhesion to the aggregate and better long term durability as binder film thickness increases. Polymer modified emulsions are particularly suitable for high volume roads and/or where snowploughing may be considered aggressive.

Binder/aggregate adhesion properties
The initial test in determining the adhesion properties of a binder/aggregate system consists of making sure that the emulsion has the ability to coat the aggregate. A simple coating test is performed to verify the compatibility of the emulsion with the aggregate. The binder/aggregate compatibility test may be performed for both graded seals and chip seals. The Vialit Pendulum test (NF T 66-037) is used in Europe to assess the long term adhesion property of chip sealing systems [2]. The tests replicate the ability of the binder of a chip sealing system to retain chips under different environmental conditioning.

Rate of adhesion/cohesion build up
The rate at which seal coating systems build up strength may also be verified to determine the suitability of the systems for usage on roadways where early return to traffic is important. The recently developed ASTM International (ASTM) D7000-04, Sweep Test provides excellent information in this regard [10]. The test simulates potential aggregate loss caused by the brushing action of a sweeper on the surface of freshly place seal coating system.

5.0 SPREAD RATE OF AGGREGATE AND BINDER

5.1 Rate of Spread of Aggregate

The spread rate of the aggregate is determined using empirical methods based on field trials or by methods based on the aggregate properties such as the average least dimension, the voids in the loose aggregate and the “bulk specific gravity” of the aggregate. The method based on the aggregate properties has been developed specifically for chip seals systems. The aggregate spread rates for graded-aggregate seals are determined by trial and error based on coverage of the binder. The selected coverage varies from one system to another and from one layer to another.

Some cover aggregate gets thrown to the side of the roadway by the traffic. The amount of traffic whip-off varies from one type of system to another and also from one layer to another, plus traffic speed. For the single treatments, the coverage is usually 100 + 5 percent whip-off for the single chip seals to 100 + 10 percent whip-off for the single graded-aggregate seal. The lower layer chips of multi-layer systems are usually applied at coverage equal or less than 100 percent of the surface to provide space to place the smaller upper chips within the chips of the lower layer. The typical coverage is associated with the number of binder applications. For example, the racked-in system has only one layer of binder and two layers of chips; the first layer may be set at 100 - 25 percent and the second layer may be set at 100 - 20 percent. The whip-off aggregate may be relatively high compared to a double chip seal, where the first layer may be set at 100 - 5 percent and the second layer is set at 100 +10 percent. Even though, there is less coverage with the racked-in system compared to the double system, the whip-off aggregate is greater because of the total surface of the binder available.

5.2 Rate of Spray of Binder

The success of a seal coating operation is highly dependent in the approach taken to establish the rate of spray of binder. The spray rate of binder is commonly determined in three stages consisting of: establishing a basic spray rate of binder for the selected system using the information available for the site; then corrections are applied to the basic spray rate based on the aggregate properties; and finally, correction factors are applied to the spray rate of the binder for localised adjustment within the site.

5.2.1 Basic Spray Rate

Basic spray rate is established using the information specific to both the site and the selected seal coating system. The information specific to the site includes: the existing surface conditions; the traffic count; the traffic speed; the roadway layout; the substrate hardness and trafficked pathways within the roadway; local climatic conditions; the shade conditions; and the timing of placement of the seal coating system. The information specific to the selected seal coating system is related to the number of aggregate layers and the size of the aggregate selected. The UK approach and the French approach in establishing binder basic spray are quite similar. Comprehensive tables have been published and even computer software has been developed to determine basic binder spray rates. The North American approach still relies on the experience of the localized agency. The basic spray rate designs are provided in tables but in a much more generalized manner compared to the UK/French approach that specifies the parameters to evaluate so a basic spray rate design can be obtained.

5.2.2 Corrections Related to the Aggregate Shape and Gradation

Once the aggregate becomes available the spray rate of binder may be corrected in accordance with the flakiness of the aggregate and its gradation. The optimum binder spray rate is established in relation to the voids available within the aggregate mosaic. After embedment of the aggregate mosaic, the optimum volume of residual binder should represent approximately 70 percent of the voids available within the mosaic. In the trafficked areas such as the wheel paths, correction factors based on the average least dimension of the aggregate are applied to the basic spread rate. However, in the less trafficked areas of the roadway where aggregate particles may not lay flat or be fully embedded in the binder/substrate a higher binder rate may be considered. This is particularly critical to account for potential of snowplough damage. In the State of Minnesota, correction factors based on an average of the aggregate mean dimension and its average least dimension is applied to the basic spray rate.

5.2.3 Localised Site Corrections

Localised correction factors are applied to specific areas along the site to account for specific conditions, which are mainly shade, sharp curves, steep gradients, intersections, local traffic, and substrate changing conditions. The localized site corrections are either applied ahead of time if the information is available or as the work progresses on site. When more than one layer of binder is applied, the correction factors are usually applied to the last layer of binder except for the substrate changing conditions. In this latter case the correction factors are applied to the first layer of binder.

6.0 SUMMARY

Seal coating systems offers to roadway engineers a quick, efficient and cost effective way of maintaining roadways in regards to surface texture and friction, and to stopping both the ingress of water and the oxidation of the existing bituminous surfaces. As illustrated in this paper, there are many types seal coating systems available to practitioners ranging from the traditional single chip seals to fibre reinforced multi-application type seal coating systems. Therefore, many possibilities are offered to practitioners for a wide the range of roadway conditions. Nevertheless, as indicated in the paper, the success of seal coating work is closely connected to the careful assessment of a certain number of well defined parameters related to the roadway environment and condition. Practitioners commonly use a decision tree approach to select optimized seal coating system. Furthermore, the meticulous selection of the aggregate and the binder has an impact on the outcome and the performance of the seal coating. Strict guidelines are followed to design appropriate spread rates for both, the binder and the aggregate. Although the topic of this paper was related strictly to the design aspect of seal coating systems, it is important to carry out the placement of any type of seal coating in accordance with a set of well defined procedures regarding the site preparation, the equipment characteristics and calibration, the workmanship and the quality control of the components.

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