Seal Coating Practice in Saskatchewan

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Surface treatments utilizing seal coats is a relatively inexpensive method of maintaining a highway pavement surface. Saskatchewan policy requires that seal coats be applied to all pavement surfaces at intervals to delay the need for structural rehabilitation. Seals are used to prevent moisture penetration, arrest fatigue block deterioration, restore friction resistance, and stop ravel. The primary sealing materials used are graded aggregates and high float emulsified asphalts. Some chip sealing with rapid-setting cationic or rubber-modified asphalts have also been used. Performance and defect levels of seals are mainly related to construction quality and are a function of distributor condition, type of asphalt and aggregate, application rates, surface preparation, and construction of joints and the climatic conditions in which they are applied. Seal coats have served Saskatchewan well by deferring the need for more costly rehabilitation by increasing the life of pavement surfaces maintained and easing demands on cash flow.

Saskatchewan has approximately 23 400 km of highway in the provincial highway system, 10 000 km of which consist of cold mixes on subgrade and 4600 km of which are graveled. The remainder, which carries 70 percent of the traffic, consists of varying depths of pavement structure the depth of which increases with average daily traffic. The structure types used, the highway department designation, and their typical construction and maintenance costs are shown in Figure 1.

The highway system is administered by six districts of the highways and transportation department in Saskatchewan. The current department policy is to seal all surface types at intervals in order to extend pavement life, defer structural strengthening, and reduce routine maintenance. Each district is allocated, on an annual basis, sufficient funds to construct seals. The annual allocation is determined by a formula that depends on the length of each surface type in the district.

The formula consists of adding 5 percent of A surfaces, 8 percent of staged A surfaces, 11 percent of staged B pavements, and 15 percent of 40-mm thick cold mixes. Typically, the length of sealing arrived at for these surfaces is 830 km annually. For 20-mm thick cold mixes that comprise 8800 km, the allocation is approximately 18 percent annually or 1580 km of sealing.

Oil treatment sealing is administered directly by the districts. Seals on the higher type surfaces are administered jointly by the head office and the districts as part of an overall pavement management system.

REASONS FOR SEALING

Cold mixes are relatively porous and allow surface moisture to penetrate to the clay subgrade. Moisture softens and lowers subgrade support, causing premature failure of the surface. Sealing the surface keeps the subgrade drier. Compaction by traffic ensures that the subgrade below the cold mix remains strong enough to carry the volumes of traffic to which it is subject. Cold mixes also show reflective fatigue blocking in the spring as the hard subgrade crust fatigues when surface deflections are high. If the mix is not bonded well to the subgrade, the mix fatigue blocks will kick out under traffic. A seal coat will help arrest this problem by tying the blocks together.

On higher quality surfaces, seal coats are applied to arrest fatigue blocking deterioration. They are required on occasion to prevent pavement ravel and restore skid resistance of pavements the skid number of which falls below 40. Most graded aggregate seals have been tested to give skid numbers of between 55 and 65, based on ASTM standards E249 and E274.

AGGREGATES USED

Most aggregates in Saskatchewan come from post-glacial gravel deposits. Aggregate gradations used in hot mixes and base courses closely follow the natural gradations. Experience with seal coats using similar gradations on low-volume roads has led to chip aggregate seals' being displaced by graded aggregate for seals on most highways of the provincial system. However, one-sized aggregate seals were still required for use with rubber asphalt.

The success of a graded aggregate seal depends on stone content (i.e., plus 5 mm), percentage clay, and moisture content. Sufficient stone content is required to provide a wearing course after the seal coat is swept. If the clay content is too high, asphalt is prevented from adhering to the stone. The high surface area of the clay particles reduces the asphalt film thickness available to coat the stone. A certain amount of moisture is desirable to act as a carrier of the asphalt through the aggregate matrix and onto the stone particles. Too much moisture is undersirable because it robs heat from the asphalt, acts as a mechanical barrier to adhesion of the asphalt, and inhibits curing of emulsified asphalts.

Table 1 gives the current seal coat aggregate gradations. Types 94 and 95 are further processed by washing before use as chips. Types 117 and 119 are typically used with high float asphalts, and Type 118 can be used with rubber asphalt.

ASPHALTS USED

For graded aggregates, primarily high float emulsified asphalts are used. Saskatchewan's experience has indicated that these asphalts do an excellent job of coping with the clay content in the aggregate and wetting the stone. High float asphalts contain large solvent quantities, which are needed to soak into the clay particles, but their high float property reduces the risk of bleeding. Although the emulsifying agent is supposed to impart

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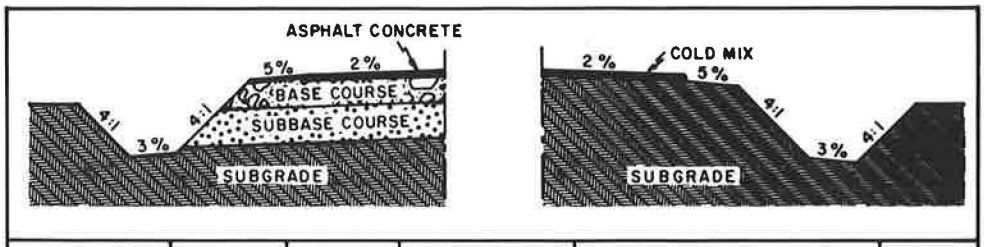

DEPARTMENT DESIGNATION	AVERAGE DAILY TRAFFIC (ADT)	WIDTH DR.L. m	WIDTH SH. m	TYPICAL LANE THICKNESS A.C. mm	TYPICAL LANE THICKNESS B.C. mm	TYPICAL LANE THICKNESS SB.C. mm	ESTIMATED 1985 AVERAGE COST GRADE STRUCT. $/km	ESTIMATED 1985 AVERAGE COST SURFACE STRUCT. $/km	ESTIMATED 1985 AVERAGE COST TOTAL COST $/km	AVERAGE ANNUAL SURFACE MAINT'CE. COST $/km
PAVEMENT 'A'	1800 +	7.4	3	80	130	180	155,000	195,000	350,000	1,020
STAGED PAVEMENT 'A'	750-1800	7.4	2	0**	130	200	113,000	97,000	210,000	1,140
STAGED PAVEMENT 'B'	400- 750	7.4	2	0**	100	130	105,000	75,000	180,000	1,630
STAGED PAVEMENT 'C'	150- 400	8.0	1.5	40***	0	0	79,000	38,000	117,000	2,030
STAGED* PAVEMENT 'D'	50- 250	7.0	2	20***	0	0	79,000	16,000	95,000	3,450
NON-DESIGNATED (GRAVEL)	< 50	8.6	0	0	0	0	45,000	2,650	47,000	2,040

* NO LONGER CONSTRUCTED
** SEALED SURFACE
*** COLD MIX

DR.L. - DRIVING LANE
SH. - SHOULDER
A.C. - ASPHALT CONCRETE

B.C. - BASE COURSE
SB.C. - SUBBASE COURSE
STRUCT. - STRUCTURE

FIGURE 1 Pavement standards used in Saskatchewan.

antistripping properties, high float asphalts occasionally strip off the aggregate if heavy rain occurs shortly after placement.

From 1978 to 1982, rubberized asphalt constructed by government crews was used for seal coats because experience locally and elsewhere indicated that it could keep fatigue blocking and severe map cracking well sealed for several years *(1)*. The rubberized asphalt used was produced by heating ground tire crumb rubber and Saskatchewan 300–400 penetration asphalt cement at about 175°C for 80 min before spraying *(2)*. Rubber asphalt seals were found to be four times as expensive as high float seals *(3)*. They were introduced to determine whether they were cost-effective by sufficiently

TABLE 1 SEAL COAT AGGREGATE GRADATIONS USED IN SASKATCHEWAN

Nominal Sieve Opening	Percent by Weight Passing Canadian Metric Sieve Series — Type 94	95	117	118	119
16.0 mm					100
12.5 mm	100		100	100	
9.0 mm		100			
5.0 mm	0-40	0-40	45-70	45-65	45-70
2.0 mm	0-25	0-25	25-55	25-45	25-55
71 µm	0-5	0-5	0-10	0-6	0-10
Minimum Sand Equivalent (Test 9010)			45	45	45

TABLE 2 RECOMMENDED APPLICATION RATE RANGES FOR ASPHALT AND AGGREGATE USED IN SEAL COATS

Surface Type	Traffic Volume (avg daily traffic)	Asphalt Type[a]	Minimum Air Temperature	Aggregate Top Size (mm)	Asphalt Rate at 15°C (L/m^2)	Aggregate Rate (kg/m^2)
Earth subgrade	<400	RA[b,c]	15°C	16	2.50–2.77	24–27
				12.5	2.34–2.50	20–23
		HF350S[d]	5°C	16	2.17–2.45	27–33
	All	HF250S[e]	5°C	16	1.36–1.63	16–22
Cold mix on subgrade	<600	HF250S	5°C	16	1.36–1.63	16–22
				12.5	1.20–1.41	14–19
				9	1.08–1.20	11–16
Granular pavements A and B	600–1,500	HF150S[f]	5°C	16	1.58–1.79	16–22
				12.5	1.36–1.58	14–19
		RA[g]	15°C	16	2.88–3.00	20–24
				12.5	2.50–2.61	16–20
Asphalt concrete surfaces	1,500+	HF100S	5°C	16	1.58–1.79	16–22
				12.5	1.36–1.58	14–19
		RA[h]	15°C	16	2.88–3.00	20–24
				12.5	2.50–2.61	16–20
	2,000+	RS2K[i]	15°C	12.5	1.63–1.90	14–19
Shoulders	All	HF250S	5°C	16	1.63–2.17	16–22
				12.5	1.41–1.96	14–19

[a]Choice of asphalt type will be determined by economics and policy.
[b]RA = rubberized asphalt.
[c]Usually in lieu of cold mix on subgrade.
[d]Usually in lieu of cold mix on subgrade.
[e]Temporary construction dust treatment.
[f]Double seal on primed base.
[g]Single seal on primed base; can be used with graded or one-sized aggregate.
[h]Can be used with graded or one-sized aggregate.
[i]Use with one-sized aggregate.

delaying the need for major rehabilitation. Some of them exhibited continued stone loss, resulting in numerous damage claims. The use of rubber asphalt was discontinued in 1983.

The high float emulsified asphalt used meets Canadian General Standards Board CAN2-16.5-M84. Softer grades are used on low-traffic cold mixes, and the harder grades on higher traffic main pavements.

For chip seals that do not use rubberized asphalts, RS2K, a cationic emulsified asphalt meeting Canadian General Standards Board CAN 2-16.4-M77, is used. The stone chips form a layer of uniform stones and do not have the same stability of interlock that occurs in graded aggregate; they are therefore susceptible to displacement and overturning by traffic. Thus, an asphalt should be used that sets rapidly in order to lock the aggregate in place. High float emulsified asphalts are much slower to set than cationic ones, and therefore require longer rolling and traffic control periods.

APPLICATION RATES

Application rates are most critical for RS2K and stone chips. In this case a near single layer of stone is applied, and no excess surface area is required to be coated with asphalt. Existing surface condition plays a large factor in the asphalt application rate, depending on whether it is flushing or dry and porous. To remove the judgment factor required by surface condition, it is advisable to apply an initial fog coat to the dry surfaces and not attempt to adjust the designed rate except in response to a check of the embedment of stones after rolling.

Stone application rates should be adjusted to the point at which there is no free asphalt pumping through to the surface under the spreader wheels.

Within a range, rubber asphalt is relatively insensitive to its application rate. The membrane is usually much thicker than that required to fill the voids between the stones that will float in the viscous material. The stone application rate is critical because an application that is too heavy will impede the rollers' ability to press the stones into the surface while the rubber asphalt is still fluid, and will make it more difficult to disperse moisture from the lower stone layer. Minimum rates are governed by the amount of asphalt pickup on the tires of the rollers and spreaders.

Rates for high float emulsified asphalts are not as critical for RS2K and chip aggregates because a matrix of aggregate and asphalt is built up in the seal because of the finer sizes' being completely embedded. Rates are best adjusted by observation of the roll of asphalt, which occurs ahead of the aggregate application. The roll should not exceed 25 mm in width because the aggregate will tend to overrun it and create a fat spot. If this occurs at regular intervals, a washboard-type pattern will be created. Table 2 gives typical recommended application rates.

COMMON DEFECTS IN SEAL COAT APPLICATION

Construction of good seal coats is affected by several factors, including the following:

- Aggregate,
- Asphalt,
- Condition of surface,
- Atmospheric conditions,
- Construction method, and
- Equipment used.

Insufficient attention to the requirements of any one of these factors can create defects in the sealed surface; problems can range from comparatively minor unsightly ones to a complete loss of seal.

Typical defects that occur in seal coats are as follows:

- Streaked appearance,
- Bleeding and flushing,
- Loss of aggregate,
- Surface breaks and poor adhesion to road surface,
- Washboarding, and
- Transverse and longitudinal joint defects.

Each of these defects will be discussed further.

Streaked Appearance

The condition of the distributor and the adjustment of its nozzles is the main factor in causing a streaked appearance. If the spray fan from each nozzle does not overlap adjacent fans by a uniform amount across the bar, a varying asphalt film thickness will occur. There are several reasons why the asphalt film thickness will vary, the most common reasons being (a) clogged or partially clogged nozzles, (b) misalignment of nozzles, and (c) incorrect spray bar height.

Nozzles are usually set at an angle to the spray bar to prevent the fans from interfering with each other. However, if the nozzle angles vary, the width of road affected by each nozzle will vary, and it will be impossible to make each fan width overlap adjacent fan widths by an equal amount. Figure 2

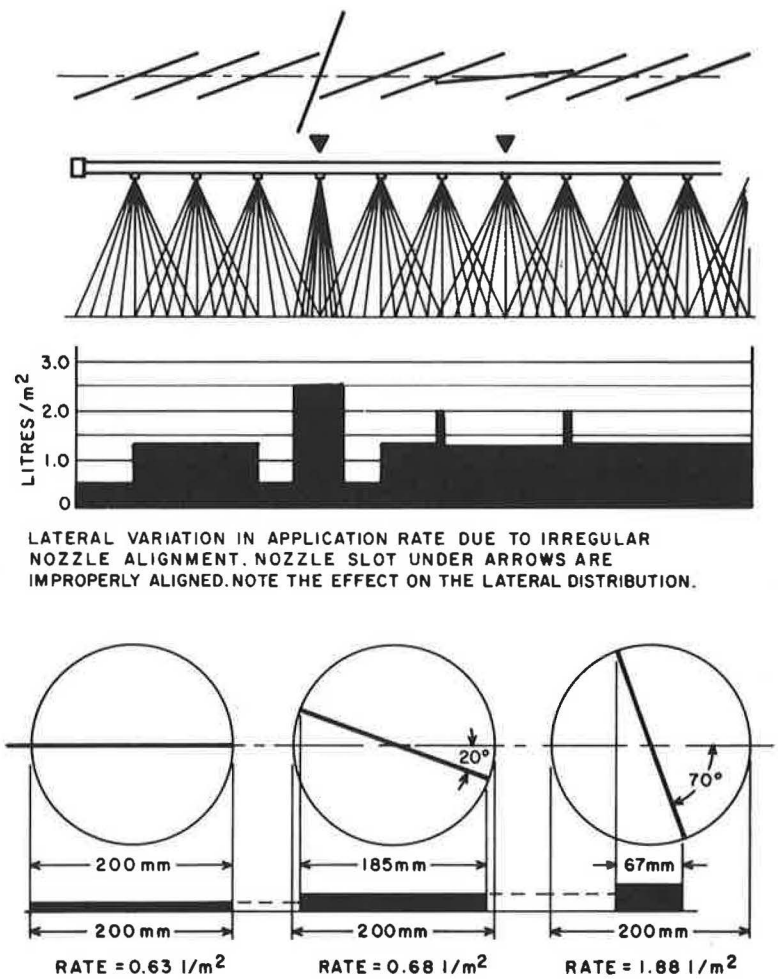

FIGURE 2 Effects of varying nozzle angle.

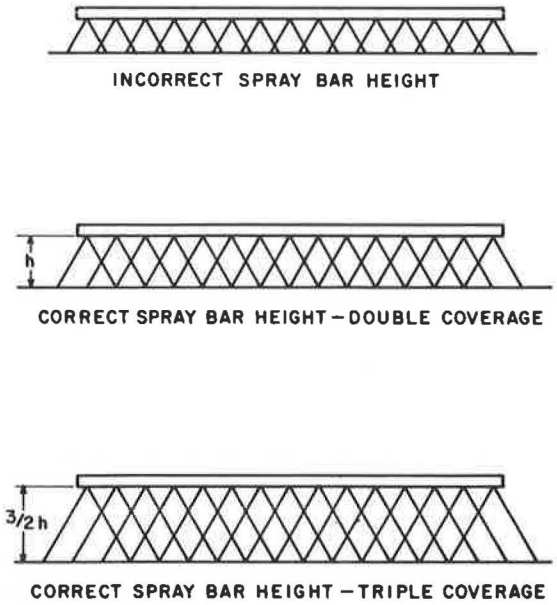

FIGURE 3 Influence of spray bar height.

shows the effect of nozzles set at different angles and the varying rate of application per unit area with each angle setting.

Figure 3 shows the influence of bar height on the overlap of fan widths. If the bar is set too low, the fans will not fully overlap. This will result in under-asphalting where the overlap does not occur as well as stone loss. If the bar is too high, there will be partial triple lap leading to over-asphalting and bleeding.

Although triple coverage should lead to a more uniform spread rate, windy conditions will affect the spray. Tilting the bar to direct the spray away from the distributor will also contribute to unequal spread rates across the bar.

Streaked appearance can also be caused by asphalt viscosity. The viscosity of emulsified asphalts is usually low enough not to be a problem for distributor pumps. However, asphalt cement and rubber asphalt can be too viscous for the distributor pumps unless the temperature is raised sufficiently. The viscosities of rubber asphalts can be 150 times as viscous as emulsions, even at 175°C.

High viscosities require large increases in pumping pressures to enable sufficient spray rates at the end of the bars. A viscosity that is too high or a pumping pressure that is too low will lead to a pressure drop at the bar ends. This will reduce the fan widths and create gaps between fan applications.

Aggregate spread rate can contribute to a streaked appearance. If the rate is too low, the wheel under the aggregate dump truck can displace material sufficient to expose the asphalt. Blockages in the aggregate spreader hopper due to oversize or other foreign matter will leave streaks of exposed asphalt. Dirty aggregate increases the tendency to streak because it more readily strips or loses stones, particularly in the under-asphalted areas.

Bleeding and Flushing

An asphalt application rate that is too high, or an asphalt grade that is too soft for the level of traffic, will create a bleeding condition by asphalt squeezing to the surface under traffic compaction. Alternatively, an asphalt rate that is too low will result in excessive aggregate loss, leading to a black or apparently bleeding surface. Insufficient aggregate applied will also lead to a black-looking surface because of free asphalt left uncovered or not being absorbed by the stone cover.

Fresh maintenance patches are a potential source of rich spots in a new seal. Seal or cold mix patches should not be placed less than 4 months ahead of the main seal. Fatty spots should be burned off and asphalt application rates reduced slightly over asphalt-rich surfaces. In reducing application rates, care must be taken to ensure minimum embedment of stones.

For very viscous asphalt such as rubber asphalts, it is possible to use higher rates of application without risk of bleeding. It is necessary to use the higher rate to improve stone retention because it is difficult to pump up sufficient asphalt around the stone during construction.

Loss of Aggregate

Insufficient asphalt application rate, or insufficient compaction, is a main cause of stone loss. Compaction should occur as close as possible to the aggregate spreader while the asphalt is in its most fluid state. This is particularly important for rubber asphalts the viscosity of which increases rapidly as it cools.

Emulsified asphalt seals require three 12-tonne rubber-tired rollers. Rubber asphalt seals require four to six of them, or two vibratory rubber-covered steel drum rollers. Steel-wheel rollers without rubber covering cannot be used due to uneven contact with rutted and uneven surfaces. They also break the aggregate because of high-pressure contact.

Rolling speed should not exceed 5 km/hr to ensure that stones are forced through the matrix of sand and asphalt. Aggregate application rate should be slow enough to enable at least three full coverages for emulsified asphalts and four for rubber asphalts.

Traffic will aid compaction, provided that it is controlled to maintain a uniform speed without sudden turns. A pilot vehicle is required to achieve this for higher traffic volumes. Gravel trucks can also aid in the compaction process and should be directed to traverse the seal in a random manner. Truck drivers should be cautioned against turning on a new seal or making sudden starts and stops. Graded aggregate is more stable than one-sized chips, which turn over easily until the asphalt sets. Therefore, it is more important to control traffic on chip seals.

If graded aggregate is applied too heavily, it will impede stone penetration during compaction. Moreover, the emulsified asphalt may not set due to lack of water evaporation, and traffic will rapidly abraid the surface. Damp, cool weather or rain on fresh seal will compound the problem and can lead to total loss of cover. In the event that the emulsion is slow to break, the rolling should be prolonged and traffic controlled until it has set.

Dirty aggregates with clay coatings will not adhere to the asphalt even when well embedded. High float emulsions will cope with this problem to some extent because the moisture and solvent will lower the surface tension sufficiently to allow the asphalt to work through the coating onto the stone. Rubber asphalts will lose considerable stone if it is clay contaminated.

Brooming should be delayed as much as possible to allow the asphalt to harden and reduce the risk of sweeping out embedded stones. Controlled traffic will gradually kick aside loose aggregate while compacting the lower embedded layer. Graded aggregate on low-volume roads need not be broomed the day the seal is applied because there is some benefit in traffic compaction. On higher volume roads, flying stones cause too much damage to vehicles, and light brooming should be started as soon as possible. Usually this can be done within 4 hr, depending on temperature and humidity. This is particularly true for chip seals, which are more open than graded aggregate seals and allow faster evaporation of moisture. Chip seals with rubber asphalt can usually be broomed in 4 hr with no danger of stone loss.

Surface Breaks and Poor Adhesion to Road Surface

Surface breaks can be minor, such as broom scars or aggregate deficiencies from blocked spreader openings, or they can be major, such as joints that do not abut or subsurface problems. Both types of surface breaks can cause potholes.

Loose aggregate at poorly swept longitudinal joints prevents newly sprayed asphalt from bonding to the underlying surface, and the seal above breaks out. If this occurs on primed base or subgrade, potholes can develop at these spots.

In poorly graded primed base courses, potholes will tend to occur because of instability in the aggregate. Potholes will also occur in sealed subgrade surfaces if they are constructed with shallow compaction planes, which develop alligator blocking.

Washboarding

Washboarding in seals is mainly a construction problem caused by an asphalt emulsion application rate that is too high. A large wave builds up in front of the aggregate application and overrides the wave at regular intervals, as the wave increases in size and slows in forward movement.

Transverse and Longitudinal Joint Defects

Despite adequate documentation for transverse joint construction techniques, these joints tend to be poorly constructed due to double asphalt or seal application or lack of compaction *(4)*.

Double asphalt and seal application occurs as a result of not using tar paper for squaring off the seal and for starting off the next spray. Lack of compaction occurs while the spreader sits over freshly applied aggregate while there is a delay in asphalt supply. This is most critical should RS2K or rubber asphalt be used due to their rapid increase in viscosity.

Longitudinal joints should be constructed by lightly brooming the centerline edge of the previously laid seal to remove all loose stones and sand. The distributor bar is then set to overlap the joint by approximately one-half the outside nozzle fan. Any aggregate sticking to the asphalt on top of the existing seal will tend to break away under traffic because its asphalt rate will be too low for proper adherence.

Before applying the asphalt, the longitudinal joint should be inspected to ensure that all loose aggregate is broomed away. Occasionally, if the aggregate is high in moisture, it will cake to the surface without there being any asphalt below. A seal applied over the caked material will break away because of lack of bond.

SEAL COAT PERFORMANCE

Properly constructed seals on asphalt concrete wear well and last as long as the structure below it, or until a second seal is placed. Preventing moisture intrusion and keying fatigue blocks together ensures that the existing pavement maintains its structural support.

Seals on granular bases will also perform well and last the life of the structure, provided that there is good initial bond to and stability in the material below. Where this does not occur, potholing will occur both in granular bases and subgrades. Double seals applied to primed granular bases are effective in minimizing the occurrence of potholes. The time interval between the first and second seal is used for making repairs to the surface and restoring rideability.

Frost action in subgrades causes high deflections and will affect seal performance by causing fatigue blocking and shearing in sealed cold mix surfaces and sealed base courses. Timely maintenance with seal patches on sealed cold mixes will usually contain the spread of fatigue blocking sufficiently to last a season after pavement surface deflections are reduced. Shear failures on granular bases are repaired and seal patched unless the condition is extensive and persistent, in which case the structure is strengthened by scarifying, adding additional base, and resealing.

CONCLUSIONS

The seal coat policy of Saskatchewan Highways and Transportation has served well to defer the need for more costly rehabilitation by increasing the life of the various pavement surfaces maintained and thereby easing demands on cash flow.

The use of high float emulsified asphalts in particular has allowed successful use of marginal and moist aggregates that have lower processing costs. The combination of graded aggregates and emulsified asphalts has allowed considerable variation in spread rates and has resulted in acceptable seal coats with minimum design and supervision.

Sufficient grades of high float emulsified asphalts has allowed their use over large traffic ranges. They are also less susceptible to bleeding than cutback asphalts. Their low viscosity and compatibility with moisture has resulted in more successful sealing in the cool fall weather.

On higher class roads, rubber asphalt was found to be more beneficial than high float emulsified asphalts in keeping fatigue cracking sealed and in providing a higher quality surface by the use of one-sized aggregate. However, other economic and technical problems have curtailed its continued use in Saskatchewan.

Stone loss from newly constructed seals is still a concern on higher class roads. In response to this concern, alternatives to

seal are actively being investigated by Saskatchewan Highways and Transportation.

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The contents of this paper reflect the views of the author and do not necessarily represent the official views of policy of Saskatchewan Highways and Transportation.

Publication of this paper sponsored by Committee on Characteristics of Bituminous-Aggregate Combinations to Meet Surface Requirements.

Asphalt Composition Tests: Their Application and Relation to Field Performance

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The application of chemical analysis to specific questions about asphalt and other tests to determine asphalt quality are discussed. Asphalt chemistry is complex; even with the analytical tools available, it would be almost impossible to identify and quantify all the components of even a single asphalt. Asphalt has commonly been analyzed by separating it into fractions on the basis of solubility, absorption, or molecular size. The fractions obtained are operationally or procedurally defined. The chemistry of the fractions has been only broadly defined. These fractional separation tests may be useful in fingerprinting an asphalt or in following changes that may occur during the manufacture, hot-mix processing, or in-use life cycle of a single asphalt. They do not, however, unravel the chemical composition of asphalt. Compositional tests based on fractional separation have not correlated reliably with field performance, nor have ratios based on the fractions. Physical and rheological tests have been shown to correlate with road performance on numerous test roads. These performance-related tests remain the most reliable guide to asphalt quality. Construction practices play a significant role in asphalt durability. High air void content has been shown to override any differences between asphalts. Asphalts from many sources perform well in roads. With this in mind, it appears unlikely that functional specifications based on composition could be devised. The performance-related thin film ovens and viscometers, and possibly new performance-related physical tests, will continue to provide a reasonable way of describing asphalt quality without directly confronting the almost impossible task of describing a most complex chemical material.

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Crude oils are the remains of organisms that once inhabited the inland seas and coastal basins. They were buried in sediments before they were consumed by microorganisms and were transformed into crude oil by a process not yet understood (*1*). Because crude oil is derived from living organisms, the composition of oil is complex. If the number of isomers of the noncyclic alkanes is calculated, for instance, the number of possible compounds is enormous (Table 1).

The molecular weight range of asphalt is about 300 to 2,000; that would include molecules with about 24 to 150 carbons. Asphalt, of course, contains many classes of compounds, not just noncyclic alkanes. Each class of compound exists in asphalt in an immense number of possible isomers. Still, some useful asphalt chemistry is known, as shown by the following details:

- Asphalt has a significant heteroatom content. This includes nitrogen, oxygen, sulfur, vanadium, nickel, and iron.
- Heteroatoms play an important role in the physical properties of an asphalt. The polar heteroatom-containing compounds