Optimizing the Effectiveness of High Performance Chip Seals in Ontario

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ABSTRACT

Chip seals have been used in Ontario for preventive maintenance for many years. However their utilization was always limited to secondary roads. The apparent unsuitability for using chip seals on high traffic roadways resided in early stage binder-aggregate adhesion problems, which created loose chip hazards. Other problems existed, such as a lack of resistance to snow ploughing and susceptibility to flushing in the high-stress areas. During the early 2000's, the Ontario Ministry of Transportation (MTO), in cooperation with the industry, started implementing a superior type of chip seals, capable of performing under the high stresses of heavy trafficked roadways. The first Ontario project was designed and executed during 2006, with more being constructed during the following years.

This paper presents the use of high-performance chip seals in Ontario over the last five years. A number of key projects are reviewed, with emphasis on design, construction, and performance, as well as specific discussions on lessons learned, including late season application, repair and re-application of centreline sections damaged by snow ploughs, and repair of flushed areas using water blasting techniques. A summary of the general performance in the field over the five years is assessed, with specific distresses and specific accomplishments.

RÉSUMÉ

Les enduits superficiels ont servi en Ontario pour l'entretien préventif pendant de nombreuses années. Cependant leur utilisation a toujours été limitée aux routes secondaires. L'inaptitude apparente pour l'utilisation des enduits superficiels sur les routes à grande circulation résidait dans les problèmes d'adhérence liant-granulats au stade précoce, ce qui a créé les dangers de granulats lâches. D'autres problèmes existent, comme le manque de résistance au déneigement et la susceptibilité au ressuage dans les zones de contrainte élevée. Au début des années 2000, le Ministère des Transports de l'Ontario (MTO), en collaboration avec l'industrie, a débuté la mise en œuvre d'un type supérieur d'enduits superficiels capables de performer sous les fortes contraintes de routes à trafic lourd. Le premier projet de l'Ontario a été conçu et exécuté au cours de 2006, et d'autres mis en construction lors des années suivantes.

Cet article présente l'utilisation des enduits superficiels à haute performance en Ontario au cours des cinq dernières années. Un certain nombre de projets clés sont passés en revue, en mettant l'accent sur la conception, la construction et la performance, ainsi que sur des discussions spécifiques sur les leçons apprises, y compris l'application en fin de saison, les réparations et la ré-application de la ligne de centre des sections endommagé par les charrues et la réparation des endroits de ressuage à l'aide de techniques de projection de l'eau. Un résumé de la performance générale en chantier sur une période de cinq ans est donné, avec les défauts spécifiques et les réalisations particulières.

1.0 INTRODUCTION

During the last few years, increased emphasis has been placed on pavement preservation in our industry due to four overwhelming benefits. Preservation enables road owners to i) manage their assets more effectively, ii) with processes which perform well, iii) are environmentally beneficial, and iv) can be implemented at a low cost. For a pavement to last for an extended time, routine maintenance is required to seal cracks and prevent water intrusion into the aggregate layers of the pavement structure. The methodology of pavement preservation is similar to other preventive maintenance that is performed on homes and vehicles. More and more agencies have moved away from the “worst first” mentality where the owner waits until the asset fails before planning repair. That mode of pavement management has often led to a downward spiral in pavement network condition, as the necessary funds to support it, are not available. In an era where road repair and construction budgets are shrinking, pavement preservation is the optimum way to keep our roads in good condition, while saving money and reducing pollution.

Many technologies exist that are utilized for pavement maintenance. Among the most widely used are surface treatments, which are thin lifts of bituminous products applied over the surface of the existing pavement. Surface treatments seal the existing pavement from moisture penetration, protect the asphalt from oxidation and aging, repair minor structural defects, and restore surface texture. The benefit list is much longer and we won’t elaborate further on this subject. If we continue breaking down the classification of surface treatments, part of this group are seal coatings, which are also known as chip seals. Chip seals encompass many distinct styles and versions.

In our present summary, we will be talking extensively about “high performance chip seals”. A little clarification of the nomenclature would be welcome, to explain what exactly is described by this term. A large part of the seal coatings done in Canada are of the graded seal type. These applications use graded aggregate and emulsions (mainly high float emulsions) that can handle contact with high quantities of fines. Known in Scandinavia as Otta Seals, they are most commonly referred to in our industry by the generic name of “surface treatments,” or even more archaically (and incorrectly) as “tar and chip.” These graded seals can be applied over many kinds of surfaces and are extensively used over unbound, granular roadways.

A surface treatment where single sized chips are used is usually called a chip seal. These are considered to be suitable to withstand higher traffic volumes and loadings than the graded seals (even though graded seals can also be engineered to have adequate strength). Traditionally, in North America, many chip seals are applied with minimal designs and minimal quality requirements for the materials. As a result, in order to differentiate these “traditional” chip seals from the seals engineered to perform under much higher loading conditions, we have coined the term “High Performance Chip Seals” (HPCS). For a chip seal to qualify as “high performance,” several criteria must be met: premium quality raw materials are used, aggregate emulsion compatibility and the systems’ adhesive and cohesive properties are always measured, an established design methodology is used for determining spray and spread rates, and design corrections are applied along the entire project length. High performance seals have a longer life expectation and a warranty of two years after construction usually applies. They are applied on high volume roads and on roads where high stresses exist (from traffic and from snow removal equipment). A wide variety of seal types can qualify as high performance, if they are engineered accordingly (single, double, multiple, etc.).

In the following paragraphs we will outline the key features of a number of high performance chip seals constructed in Ontario since 2005. The emphasis will be put on lessons learned over the last six years, as the design and construction of these seals is still a learning curve for all stakeholders.

2.0 DESIGN METHODOLOGY

2.1 Overview

Seal coating design methodologies have evolved over the last few decades. The old approach, where the aggregate and binder spread and spray rates were decided strictly based on the operators experience, has all but disappeared. Such a design method was highly empirical and, as a result, the performance of seal coatings was highly variable.

Dr. Norman McLeod developed the first design methodology for seal coatings based on engineering parameters in the 1960's. Even though it has received several updates and refinements since its initial publication, it still remains a widely accepted design methodology. It is primarily known today as the Modified McLeod Method. Several newer design procedures exist today. They are based on semi-empirical engineering principles and utilize algorithms for calculating the final design.

Regardless of the design methodology used, there are a total of four main stages in designing and optimizing a high performance seal coating system [1]: project selection; materials and seal coat type selection; determination of the basic spray and spread rates; and applying design corrections.

2.2 Project Selection

This first stage of the HPCS design process is virtually always done by the Owner or Owners Representative, such as a consultant. In selecting a candidate road section for a chip seal application, a number of parameters specific to the roadway will become important input criteria for the subsequent design steps. The main design parameters that come with the candidate road selection include the following [1]:

- Surface conditions – asphalt, surface treatment, smooth, cracked, flushed, dry, uniformity, etc.
- Substrate hardness
- Traffic type – volume, speed, channelized sections, etc.
- Road layout – grades, curves, shaded areas, etc.
- Time of placement of the seal coating

Each and every one of these parameters will have an impact on the subsequent stages of the project design and execution. Some of the above criteria can, and should, be considered sufficiently important for the entire project to be re-considered, adjusted or even cancelled. For example, if a roadway shows rutting that is too deep for a HPCS application, then a micro surfacing might be the better suited treatment. A HPCS applied on such a road surface has a high chance of failing, or not performing to expectations. If a roadway has traffic levels that are extremely heavy or is travelled at very high speeds, it could be that a chip seal is not the best suited treatment, and that better surface treatment solutions exist. If a seal coating project gets delayed and work would have to be carried out too late in the season, then a responsible decision would be to postpone the remaining work for next year or the risk of failure increases dramatically. Every one of us can think of instances where projects did better than expected, or ended up performing well against initial odds. A design process should not count on such examples, and should instead focus on maximizing the probability of success for a given project.

Input parameters need to be measured or calculated, and specific tests were developed to quantify some of them. For measuring the surface texture of an existing road, the “sand patch” [2] and the “sand circle” [3] test are the traditional methods. More recently, several ways of measuring surface macro texture electronically are being developed. For determining the hardness of the existing pavement, one of the available methods is the Ball Penetration Test, developed in Australia and New Zealand [4]. Figure 1 shows the application of the Sand Circle test and the use of the Ball Penetrometer.

Figure 1. Sand Circle Test and Ball Penetrometer Used in Ontario

2.3 Seal Coat Type and Material Selection

The parameters assessed as part of the project selection stage should be the primary factors for determining the best suited chip seal type for each particular case. Substrate specifics as well as environmental factors will determine if a single chip seal will perform adequately, or the need exists for a different seal type. For example, if the roadway in question is subject to high stresses (aggressive ploughing, steep grades, heavy traffic, etc.) a double seal will be better suited than a single, as it is tougher and more robust. If the existing surface is flushing or bleeding, an inverted seal should be considered. If the substrate is ravelling or has extensively pocked surface texture, a suitable choice might be a sandwich seal. Even if some of the aforementioned seal types have been little used in North America, there is substantial information about these seal types published in the National Cooperative Highway Research Program (NCHRP) Synthesis 342 entitled “Chip Seal Best Practices” [5], as well as in European, Australian and South African documentation.

Seal type selection is directly related to material selection. In some warm parts of the world hot seals are used extensively, but they are virtually non-existent in Canada, due to environmental and safety risks associated with these seals. Cutback binders for chip sealing were discontinued in the 1970’s, because of high cost and a very high environmental impact. Asphalt emulsions are the sole chip sealing binder used today across our country.

The essential requirements for an asphalt emulsion to be successful in chip sealing are the following:

- A carefully controlled viscosity – emulsion should be thick enough to stay on the road, but fluid enough to self-level after being sprayed. Also, the aggregate can bring extra moisture to the system, so the emulsion should be capable to handle this without thinning down too much.

- Fast breaking – the emulsion should de-stabilize and coalesce immediately after contact with the aggregate. This property requires some tuning, depending on some aggregate specifics (chemistry, gradation, etc.). Breaking properties are quantified by the demulsibility test.

- Fast curing – a very important property, which is different from breaking, and not well captured in today's emulsion specifications. This property defines the capability of an emulsion residue to build strength after breaking has occurred. This happens while the water phase is eliminated from the bituminous residue. Ideally, a chip sealing emulsion residue should achieve a viscoelastic modulus that equals the one of the original asphalt cement as soon as possible. Some modern chip sealing emulsions can achieve over 90 percent of the target strength in a little over two hours [6]. This behaviour is strictly an emulsion property, and is important for achieving a robust chip seal short time after construction. This should not be confused with a chip seal achieving its full strength, which can take up to 30 days.

- Specific parameters for the residue – once the water phase has left the system and the asphalt residue is performing its job as a binder, specific values for penetration, ductility, modulus and elasticity will be required.

Historically, mainly high-float emulsions with or without polymers were used for seal coating. High-floats are anionic emulsions that possess two very desirable characteristics for a seal coating emulsion. Firstly, the gel structure provides them with a shear thinning behaviour that makes them easy to spray but won't allow them to flow off the road. Secondly, they have very good wetting characteristics, allowing them to make intimate contact with aggregate surfaces, even if in the presence of dust or fine particulates. The down sides of the high float emulsions are less-than-ideal curing characteristics and poor adhesion to acidic aggregate.

Modern chip sealing emulsions are mostly Cationic Rapid Setting (CRS). These emulsions, like the high floats, may or may not contain polymers as part of their compositions. CRS emulsions generally have very high breaking and curing speeds, but they require washed or at least very clean chips for creating a strong bond. Their compatibility with aggregate is excellent, regardless of aggregate type or surface charge.

The aggregate needed for HPCS is of high quality, and the physical requirements are pretty stringent. The three most important parameters required for chip sealing aggregate are gradation, Average Least Dimension (ALD), and Loose Unit Weight. Aggregate size varies widely when it comes to HPCS, however in general they have to be a clean, "one size" chip. What constitutes a "one size" chip is defined differently across the world but its meaning is that virtually all chips must have very similar sizes. The definition of "clean" most of the time means "washed," with fines content of maximum 1 percent and with no dust adhering to the surface of the chips.

Further requirements for the aggregate physical parameters are shape (described by the Flakiness Index), angularity (described by percent of crushed aggregate), impact resistance (LA abrasion); abrasion resistance (Micro-Deval), freeze-thaw resistance, and polishing characteristics. In a nutshell, the aggregate used for a high performance chip seal must have as good physical properties as a premium Superpave™ aggregate, and in addition have even more stringent shape and gradation requirements.

The ALD is defined as the average thickness of all individual particles when they are positioned on their flattest side. This parameter is a function of both the median aggregate size and the Flakiness Index – a measure of the content of flat and elongated particles in the aggregate. The ALD is an essential input parameter for calculating the binder spray rate.

The loose unit weight of an aggregate, together with its specific gravity, will determine the voids in the loose aggregate, also called the Voids Fraction.

2.4 Basic Spray and Spread Rates Calculation

The ALD and the Voids Fraction are essential input parameters for calculating the basic binder spray rate. The basic binder spray rate is calculated so that the aggregate embedment in bitumen will be 60 to 70 percent of its height, after all the aggregate has been positioned and compacted by traffic into its most stable arrangement. In order to calculate this, precise input is required about the voids fraction of the aggregate and the traffic volume. The substrate conditions also have a major impact on the spray rate calculation, but for the basic rate a smooth road surface is assumed. The actual substrate conditions, such as surface texture and hardness, will be applied as corrections after calculating the basic spray rate.

The aggregate spread rate is determined by semi-empirical methods, using the ALD and the Voids Fraction. For single chip seals, a minimum of 100 percent coverage is needed. Some excess due to wastage is usually allowed for the design, but caution is exercised as too much excess aggregate will lead to loose chips, which will translate into flying stone hazards. For double seals or other seal types, aggregate spread rate becomes more critical. The coverage requirement has to be very precise for double, racked-in and sandwich seals, where the first lift often requires less that 100 percent coverage. Good calculation and good control of aggregate spread rates is very important for such chip seal systems.

2.5 Applying the Design Correction Factors

Once the basic spray and spread rates are established, the final step in completing the design is to apply the necessary corrections required by assessing the remaining input parameters. The corrections apply mostly to the emulsion spray rate.

Aggregate shape and gradation is taken into account when determining the ALD and the Voids Fraction, so these parameters go into the basic spray rate calculation and do not count as corrections. Substrate texture and hardness, on the other hand, are probably the next most important adjustments. The existing surface texture will determine how much additional binder will be needed to account for surface texture, porosity, cracking and pocking, or how much excess binder is there due to flushing or bleeding. Surface hardness will determine how much embedment for the aggregate is predicted, under traffic, for the chip seals life. The surface hardness becomes a very important factor in the performance of HPCS, especially when the existing surface is flushed. In this scenario, the hardness of the pavement will provide an indication of embedment but the designer should also rely heavily on experience with these softer pavements. All these corrections have to be quantified and applied to the spray rate.

Several other project specific parameters require spray rate corrections. Steep grades, curves and intersections affect the seal coating by increasing the stresses and shear loadings. Shaded areas will increase the curing time needed for the emulsion. The same effect can be expected if chip seal construction is done late in the season when temperatures are lower and sunlight is scarce.

Winter related distresses, in particular snow ploughing, require special attention for our Canadian geography and climate. Winter-related distresses are given little or no attention in design methodologies developed in countries such as Australia, South Africa or even the UK. The French chip seal design method does account for winter conditions and does apply a correction for it. In our experience, it is the single biggest risk for a chip seal constructed in Canada and in the northern parts of the United States. Often, applying a spray rate correction is not sufficient to reduce the risks of damage by ploughing, and the need will arise for a tougher chip seal type to be applied instead. For this reason, project selection is critical to the performance of a HPCS as uneven pavements will be more susceptible to snow plough damage.

The chip seal design correction factors have to be applied most of the time by project sections, and the design corrections will vary along the length of a roadway. For a high performance chip seal to be successful, the entire project needs to be carefully assessed and for each specific section the sum of all correction factors needs to be calculated and applied. As a result, a typical project will usually have two, three or even more design conditions per traffic section.

3.0 HIGH PERFORMANCE CHIP SEALING PROJECTS

3.1 Introduction

The high-performance chip sealing program was started in Ontario with a number of relatively small York Region projects. These were the first projects where a formal design methodology was utilized, complete with preliminary project mapping, aggregate and emulsion selection, chip seal type selection as a function of the existing conditions, and design corrections applied by section. The following year, the Ministry of Transportation (MTO), Eastern Region tendered the first project on Highway 127, where the major difference was the use of high quality, non-polishing type aggregate.

The following years brought more projects. York Region continued their program, and so has the MTO, with jobs being called by Eastern, Northeastern and Northwestern regions. The seals were applied on roads having various surface conditions and a wide range of traffic volumes. Table 1 lists the more important HPCS projects and the key design input and output parameters.

3.2 York Region Projects - 2005

The Region of York is a highly populated area just north of Toronto with a very diverse road network. The Region has been employing double surface treatments over granular surfaces to accommodate the northward movement of urban sprawl. Their contracts had typically employed method specifications, in which all roadways were treated similarly. In 2005, The Region of York let a tender, T-05-17 for single surface treatment as a preservation method to eight road sections throughout the Region. These roads were to be treated using a modified cationic rapid set asphalt emulsion and an Ontario Provincial Standard Specification (OPSS) Class 1 stone. Spray and spread rates were stipulated using Provincial guidelines. The roads varied greatly in traffic volumes, surface homogeneity, distress levels and geometry.

Once the project was awarded, Miller Paving approached the owner to apply a recognized seal coat design methodology to each roadway. This modification to the design method helped us understand the best suited chip seal process and the best applicable spray and spread rates for each of these roads. The design procedures included were the Modified McLeod, the French Alogen, and the UK Road Note 39.

Table 1. Summary of Main High Performance Chip Seal Projects in Ontario

Project Location, Year, Owner	Seal Type	AADT (%CV)	Substrate	Aggregate Type	Aggregate Spread Rate, kg/m^2	Emulsion Type	Emulsion Spray Rate, L/m^2
St John Sdrd, 2005, YR	Double		HMA, hard, rough, het.	Limestone L1: 6/10mm L2: 2/6mm	L1: 11-13 L2: 6-8	CRS-2P	2.85 (1.35+1.50)
Ravenshoe Rd., 2005, YR	Single		ST, homog., patched	Limestone L1: 6/10mm	L1: 13	CRS-2P	2.15 *C1: 2.05*
Pine Valley, 2005, YR	Single		Micro, smooth, cracked	Limestone L1: 6/10mm	L1: 13	CRS-2P	1.90 *C1: 1.80*
McCowan Rd., 2005, YR	Double		ST, rich, flushed het.	Limestone L1: 6/10mm L2: 2/6mm	L1: 9-13 L2: 6-8	CRS-2P	2.20 (1.10+1.10)
Kennedy Rd, 2005, YR	Single		ST, rough, oxidized	Limestone L1: 2/6mm	L1: 7-8	CRS-2P	1.50
Teston Rd., 2005, YR	Single		ST, soft, smooth	Limestone L1: 6/10mm	L1: 13	CRS-2P	WP: 1.65 OWP: 1.8
HIGHWAY 127, 2006, MTO	Double	1600 (8.5)	HMA, hard, oxidized	Trap Rock L1: 6/10 mm L2: 2/5 mm	L1 : 10.5 L2: 7	CRS-2P	2.45-2.65 *L1 :1.05-1.15* *L2 : 1.40-1.45*
HIGHWAY 590, 2007, MTO	Double	1100-1450 (11.3)	HMA, hard, oxidized, cracked	Basalt L1: 6/10 mm L2: 2/5 mm	L1: 10.5-11.5 L2: 6.5-7.5	CRS-2P	WP: 1.9-2.1 OWP: 2.5-2.6
Ravenshoe Rd., 2007, YR	Double	4600 (11)	HMA, hard, smooth	Meta Gabbro L1: 6/10 mm L2: 2/5 mm	L1: 10.5-12 L2: 6.5-8	CRS-2P	2.2 *L1 :1.0* *L2 : 1.2*
Park Rd., 2007, YR	Double	870-2700 (5)	HMA, hard, smooth	Meta Gabbro L1: 6/10 mm L2: 2/5 mm	L1: 10.5-12 L2: 6.5-8	CRS-2P	2.3-2.5 *L1 :1.1-1.2* *L2 : 1.2-1.3*
HIGHWAY 28, 2007-2009, MTO	Double	990-1800 (11)	CS, rich, flushed WP, edge cracking	Meta Gabbro L1: 6/10 mm L2: 2/5 mm	L1: 10.5-12.5 L2: 6.5-8	CRS-2P	1.9-2.4 *L1 :0.9-1.2* *L2 : 1.0-1.2*
HIGHWAY 41, 2008, MTO	Double	1200 (5-10)	HMA, oxidized, cracked	Meta Gabbro L1: 6/10 mm L2: 2/5 mm	L1: 10.0-12.0 L2: 5-7	CRS-2P	2.4-2.5 *L1 1.2-1.3* *L2 : 1.2*
Mt. Albert Rd., 2009, YR	Double	8150 (10)	HMA, oxidized, smooth	Meta Gabbro L1: 6/10 mm L2: 2/5 mm	L1: 10.0-12.0 L2: 5-7	CRS-2P	2.3 *L1 1.1* *L2 : 1.2*
Weston Rd., 2009, YR	Double	1500 (2)	HMA, oxidized, smooth	Meta Gabbro L1: 6/10 mm L2: 2/5 mm	L1: 10.0-12.0 L2: 5-7	CRS-2P	2.6 *L1 1.3* *L2 : 1.3*
HIGHWAY 11B, 2009, MTO	Double	1400 (11)	HMA, oxidized, cracked	Gneiss L1: 6/10 mm L2: 2/5 mm	L1: 11.0-13.0 L2: 6-8	CRS-2P	2.45-2.7 *L1 1.2-1.3* *L2 : 1.25-1.4*

Notes: YR is York Region, MTO is Ministry of Transportation Ontario, ST is Surface treatment (graded seal), CS is Chip seal, HMA is Hot Mix Asphalt, L1; L2 is First or Second lift, WP; OWP is Wheel Path; Outside Wheel Path; homog. is homogeneous, het. is heterogeneous.

The design outcomes provided us with a comfort level to designate the seal coat best suited to each road section. The designs were such that three of the eight roadways required single applications, each having unique spray rates along with condition modifications for uphill lanes on steep inclines, while five roadways required double seal coats of which there were three different total binder rates and one binder rate condition modification for an uphill lane on a steep incline. When we disclosed these findings, the Region was interested in a change proposal to adopt these applications to their roads in place of the initially specified single treatments. As stated previously, five of the eight sections were treated utilizing a double seal coat system of CRS-2P asphalt emulsion and alternate layers of a 6/10 mm stone (OPSS 1006 Class 1) and 2/4 mm chip. At this time all but one of these road sections are still in service today after 6 years, although some are showing signs of snow plough damage on the high areas. The only other distress is the loss of surface texture, which is common with the use of limestone aggregate in this region on surface courses. This typical performance is illustrated in Figure 2.

We have gained valuable lessons through our experience with the use of design methods for constructing HPCS; namely that each roadway is unique and that by treating them identically can lead to the common failures associated with chip seals such as premature flushing, broken windshields from flying chips, aggregate whip-off and poor public perception. The use of high quality aggregates has since been added to the specification, which will increase the frictional qualities and lengthen the life of chip seals as they are not as susceptible to polishing from the higher traffic levels and snow clearing equipment. It appears that, when well designed and properly constructed, a chip seals' ultimate failure comes when it no longer possesses the frictional properties required for the safety of the motoring public.

Figure 2. Teston Road Single Chip Seal as it Appears in 2011

Another major contributor to chip seal failure is weather. With this in mind we have examined weather patterns following the application of chip seals on numerous projects over a number of years. With Ontario being a Province that experiences winter weather and the accompanying maintenance, it was important to look not only at the weather in which the chip seals were applied but also the temperatures of the following weeks prior to snow falls. There was found to be a correlation between the amount of damage by snow ploughs and the average temperature of the 30 days preceding the application. More details on this will be presented in Section 4.

3.3 Highway 127 for the Ministry of Transportation Ontario - 2006

Highway 127 was the first HPCS designed and applied in 2006 with excellent performance to date. A detailed description of the design and construction of this project was presented at the CTAA Conference in 2007 [7]. In 2006, shortly after application, the road exhibited an excellent Friction Number (FN) of 56.7, and in the following two years has held steady at 55.4 in 2007 and 54.8 in 2008. When comparing this data to that of previously applied chip seals using unspecified sources for aggregates, we see a major improvement. Skid numbers on Highway 127 north of this section, which did not utilize high quality aggregates, indicated significantly lower, but acceptable friction numbers over time. This data reinforces the benefits of specifying durable aggregates for chip seal applications on high volume roads, in order to maximize service life. Adjusted spray rates applied to Highway 127 were within 0.015 L/m^2 and subsequent plough damage was minimal and confined to areas within the project that were prone to significant frost heaving. The common occurrence of plough damage and reflective cracking also emphasizes that the life cycles of chip seals are directly related to the pavement condition of the roadway being treated. The average temperature following the thirty days after completion of this project was only 11.6 degrees Celsius.

3.4 Highway 590 for the Ministry of Transportation Ontario - 2007

The first HPCS in Northwestern region was called in the spring of 2007. The MTO NW region had had limited but good experience with a single chip seal over existing surface treatment. The project design was not approached with the same scrutiny as for Highway 590. During the design stage for the project, it became obvious that a slightly different construction approach would be needed. The substrate was hard, somewhat pocked, with significant alligator cracking, mainly around the centreline and near the road edges. Measurements of the surface texture by the Sand Circle method produced values of 0.67 mm for the wheel paths and 1.48 mm for the alligator cracked areas at the centreline. This creates the risk for part of the emulsion to be lost in the cracks and to reduce the aggregate embedment. Also it means an increased risk of snow plough damage at the centreline, where little aggregate embedment by traffic occurs. The situation was aggravated by the aggregate selected having a Flakiness Index of about 30. The only solution was to choose to apply a differential spray rate for the emulsion for the wheel paths and outside the wheel paths, respectively. In analyzing the in-service performance of this chip seal today, we believe this was an excellent decision.

The project was about 13 km long and its construction was done in August 2007. Three distributors were used, the first one spraying the excess binder at the centreline, centre lane and road edge and leaving about two feet of space in each wheel path. The second distributor was following immediately behind and was applying a uniform layer across the whole lane. The third distributor was used to spray the second lift of emulsion. Subsequently, the construction was done like any HPCS. The resulting total spray rate varied between the wheel paths and outside the wheel paths by as much as 0.5 to 0.6 L/m^2. This approach allowed the construction of a solid centreline and centre lane that will be resistant to snow ploughing. At the same time, it minimized the risk of flushing in the wheel paths. A picture of the variable application of the emulsion on Highway 590 is shown in Figure 3.

Figure 3. Construction of Highway 590 with the Use of Differential Spray Rate

This section of road is in excellent condition today. Some of the cracking has reflected through, and this was expected by all parties at the construction time. Otherwise, the road texture is excellent, the plough damage is minimal, and the road condition is very good overall. Figure 4 shows the condition of Highway 590 during the spring of 2011.

Figure 4. Typical Road Condition and Road Macrotexture for Highway 590 in 2011

3.5 Highway 28 for the Ministry of Transportation Ontario – 2007 to 2009

The MTO tendered two separate HPCS contracts on Highway 28 totalling more than 35 kilometres between Bancroft and Denbigh in 2008. Both contracts were tendered in late July, awarded mid August, and constructed within the month of September. The construction sequence started at Bancroft and proceeded easterly toward Denbigh. The traffic within these sections varied from 700 to 1800 Average Annual Daily Traffic (AADT) with 11 percent trucks for the entire area. More specifically, from Bancroft to Boulter Road the traffic was 1800 AADT, from Boulter Road to Hardwood Lake the traffic was 1100 AADT and from Hardwood Lake easterly for 1.8 kilometres the traffic was 700 AADT. Also of particular note, the grade also varied with some areas reaching over 9 percent incline.

The pavement was originally constructed with 50 mm of HL-4 HMA in 1992 and was then sealed with a double surface treatment through four separate contracts between 2001 and 2004. Due to the nature of the materials and design method utilized during construction of the double surface treatment at the time, polishing and flushing was evident in many areas in 2008. Figure 5 illustrates the typical condition of the pavement prior to the HPCS application in 2008.

In addition, isolated areas exhibited edge line cracking, deformation, rutting, and inadequate cross slope that were repaired with a scratch overlay of HMA under the contract. Figure 6 illustrates typical areas patched with HMA prior to the application of the HPCS in 2008.

Figure 5. Illustration of Typical Pavement Condition in 2008 Prior to Construction

Figure 6. Illustration of Areas Requiring Hot Mix Asphalt Patching

The HPCS was placed in September producing an excellent surface with no contractual issues. Upon inspection of the completed seal in early October, the mat was typical of other HPCS constructed under the same specification since 2006. Figure 7 illustrates the construction and appearance of the completed surface.

Toward the end of October, the Bancroft area experienced its first snow fall where ploughs were required to remove the snow from the road surface. This occurred within one month of the final day of construction when the mat was still somewhat tender in nature.

An inspection of the roadway was carried out during the first week of December 2008 and revealed that the double seal coat surface had already been adversely affected by the snow plough blades resulting in scarring of the completed seal. Through subsequent visits to the site the frequency and severity of the damage continued to increase to a fair degree.

Figure 7. Illustration of Construction and Completed Double Seal Coat on Highway 28 in 2008

The damage was mostly concentrated at the centreline of the roadway with some damage observed between the wheel paths. Within the west section of the job near Bancroft, the damage was intermittent, however as the inspection proceeded easterly, the frequency and severity of the damage increased. Through our analysis, we have attributed the aggregate loss from snow ploughs to an incomplete cure of the emulsion utilized for the HPCS. This can be confirmed by two main observations. Firstly, the extent of the damage was worse for work done later in the job than earlier thereby concluding that cold weather delayed the curing process of the emulsion. Secondly, upon inspection of the scarred areas, the emulsion still remained on the existing roadway proving that there was strong adhesion but unfortunately the aggregate was dislodged proving that the emulsion did not possess enough cohesion. We feel that adequate cohesion of the emulsion was not obtained prior to being subjected by snow ploughs due to the low air temperatures in the area from the time the seal was placed until the snow ploughs were first used. In fact, during the month of October but prior to the first snow plough, the average air temperature was approximately 7.5°C. Through experience with chip seals utilizing cationic rapid setting emulsion, it is hypothesized that approximately 30 days of hot weather is required to ensure that the emulsion is fully cured and can successfully withstand the abrasive forces of snow plough blades.

Due to the nature and extent of the damage, repairs to the HPCS were required to remediate the roadway to a safe driving condition. During the summer of 2009 the areas to be repaired and the repair method were established by both the owner and contractor. Since the predominant distress was at centreline, we proposed to apply a one metre treatment of seal coat with the original top aggregate only in these areas.

This would cover most of the areas where aggregate was dislodged from the snow ploughs. The aggregate and emulsion aggregate application rates required modification from the original design, however through past experience in performing similar repairs in 2008, significant confidence was felt with our approach. Figure 8 illustrates typical areas of distress with the corresponding repair seal.

It can be readily observed that the one metre repair treatment blended in very well with the lane portion of the seal that was not affected by the snow ploughs.

Although most of the damage was at the centreline, there were areas where full lane widths and full pavement widths required repair. These sections were repaired with both bottom and top aggregates at application rates similar to those of the original construction. Consistent with the centreline repair, the full lane and full pavement width repairs blended well with the original seal coat and have performed very well over the last two years.

Figure 8. Illustration of Centreline Distress before and After Repair

During the summer of 2010, the MTO measured the skid resistance with a brake force trailer, conforming to ASTM E-274 [8] and E-501 [9], as part of their contract monitoring process. As part of the developmental process of moving to contracts with performance measures, this contract had required the surface friction to exceed a value of Friction Number (FN) of 30, at the posted speed. The results of the skid testing revealed that there were areas where the skid resistance fell somewhat below this threshold as a result of flushing. It was determined that due to an excessively hot summer in July and August, the heat and traffic caused the HPCS to flush the joint of the original seal coat and the repaired seal coat which was unfortunately located directly in the wheel paths of the traveling public. Out of interest to maintain a safe roadway, and to meet contractual requirements, the road required repairs to restore the FN to the specified level. The Owner and Contractor again met in early October to determine the most appropriate course of action during early October. The contract stipulated that a lean double seal coat be applied to the areas possessing low friction but due to the time of the year, this was not a feasible option as we would potentially risk subsequent aggregate loss due to inadequate emulsion curing. To avoid any risk, the MTO and Miller Paving decided that water blasting the flushed seal coast surface was the only feasible option. Water blasting has been utilized in Ontario and around the world as an acceptable technique to remove asphalt cement that is on the surface of the pavement on both seal coat and hot mix asphalt surfaces. Therefore, provided the equipment was able to obtain the required pressure to remove the excess asphalt cement we surmised that the technique would be adequate.

At the end of October, the water blasting occurred on Highway 28. It was quickly observed that the equipment was able to remove the excess asphalt cement from the surface and leave the original seal unaffected to withstand the traffic and snow ploughs. Figure 9 illustrates the before, during, after photographs of the water blasting.

To quantify the effect of water blasting to the seal coat surface, the Sand Circle Test was used to measure the macrotexture before and after the asphalt cement was removed. Prior to the water blasting in flushed areas, the macrotexture was found to be approximately 0.5 mm and in normal areas, where no flushing existed, the macrotexture was found to be 1.4 mm. After the water blasting occurred, the macrotexture of the surface was 0.9 mm. Therefore, it was proven immediately on site that the water blasting was effective.

Figure 9. Illustration of Before, During, and After Water Blasting Treatment

In addition to the aforementioned sections treated on Highway 28 in 2008, a section of the road was treated with a HPCS from Hardwood Lake westerly for 5.8 km. The traffic on this section was 990 AADT with 11 percent commercial vehicles and a maximum grade of 4.85 percent. The original pavement was 50 mm of HL-4 HMA and was constructed in 1989 with a subsequent double surface treatment applied in 2001. The actual intersection was not originally included within the contract but through communication between the MTO and Miller Paving, it was agreed by the Contractor to include this area at no cost to the owner for research purposes. This particular corner has been plagued with flushing issues upon completion of the 2001 double surface treatment due to the high volume of logging trucks braking on the intersection approach and turning easterly at the intersection. The MTO did not originally include this intersection within the contract as they felt that it could not be sealed with a HPCS without flushing.

During the design stage of this section, it was determined through hardness and macrotexture measurements of the existing pavement that the emulsion rates needed to be reduced significantly to ensure that flushing did not reoccur. The total binder rate for the remainder of the contract section was 2.1 L/ m^2, but due to the flushing tendency of the intersection the total binder rate was reduced to 1.9 L/m^2.

The rate reduction proved to be adequate as the performance of the seal in the following season was excellent. Subsequent visits to the site have revealed that the surface is somewhat smoother than normal, however it is still providing adequate skid resistance and sealing of the pavement, as shown in Figure 10.

Figure 10. Illustration of the Harwood Lake Intersection after the HPCS Application

3.6 York Region Projects - 2007

York Region let their first HPCS over asphalt surfaces contract in 2007, under Contract T-07-37. The project consisted of two separate roadways with different traffic patterns. The contract required the use of a rapid setting polymer modified asphalt emulsion and aggregate for both layers to come from a source listed on the MTO's designated sources list for premium aggregates. The first roadway, Park Road was a 12 km section that ran north-south and had an AADT of 2670 with 4 percent heavy commercial vehicles. This roadway had both urban and rural sections, as it began in the north as a residential area with a 50 km speed limit over the first 1 km, where it intersected a local arterial leading into the town of Sutton. South of this intersection the roadway was a 80 km rural zone linking Sutton to Highway 48 and Highway 48 southerly to Ravenshoe Sideroad.

Although not specified in the tender document, it was later determined that the AADT was significantly less in the north 1km section requiring a separate design. In total, Park Road required two seal coat designs and five condition modifications for intersection approaches (3), shade (1), and steep inclines (1). The two designs had a total binder rate of 2.5 and 2.7 L/m^2, respectively with condition modifications reducing the binder rate slightly at intersection approaches and steep inclines, and increasing slightly for shaded areas.

The second road of the contract was Ravenshoe Road, which carries significant traffic volumes from Highway 48 observing an AADT of 4600 with 8.2 percent heavy commercial vehicles. The section ran 2 km westerly from Highway 48 and required one HPCS design. The designs for both of these roads incorporated the use of a CRS-2P asphalt emulsion and 6/10 mm and 2/5 mm aggregate layers.

As for the 2007 York Region work on Park and Ravenshoe roads, the average daily temperature of the succeeding 30 days was found to be 19.4 degrees Celsius. Macro texture values measured before construction and after the first year in service showed a substantial increase. It has been learned that the higher the traffic volume, the greater the variance in texture measurements between wheel path and non wheel path macro texture measurements. Park Road had an initial increase of 1.2 mm (from 0.70 mm to 1.9 mm) with an annual decline to the present condition (Spring 2011) of 1.6 mm. Similarly, Ravenshoe

Road with a higher traffic volume had an increase from the pre construction average of 0.27 mm to a post construction average of 1.7 mm, and a decrease to 1.3 mm in 2011 in the wheel paths.

3.7 York Region Projects - 2009

After a review of the 2007 chip seals, The Region of York once again let a tender (09-174) for HPCS over asphalt surfaces on two regional roads. The first was Mt. Albert Road running east-west from the York Durham boundary through the town of Mt. Albert, and connecting to Highway 48. This section had an AADT of 8148 with 10 percent heavy commercial vehicles. The second road was Weston Road running southerly from Highway 9 to Aurora Road with an AADT of 1508 including 2 percent heavy commercial vehicles. Fog coating to reduce the initial macrotexture was included on these projects in order to mitigate noise complaints from the public. A diluted CSS-1H asphalt emulsion was applied to the chip seals at a rate of 0.3 L/m^2 and a light sand blotter was applied to allow for immediate traffic flow. Weston Road had an adjusted spray rate differential of 0.25 L/m^2 and it is performing with no damage from winter maintenance activities (see Figure 11). Mt. Albert Road on the other hand had a spray rate differential of 0.55 L/m^2. This section was affected by the winter maintenance activities, thereby strengthening our theory previously stated concerning large spray rate differentials. As this work was completed in July the average daily temperatures of the succeeding 30 days was over 20 degrees.

Figure 11. York Region Weston Road, Before and After Construction, 2009

3.8 Highway 11B Cobalt for the Ministry of Transportation Ontario

In 2009, the MTO's Northeastern region let their first HPCS project utilizing the contractor design method. The road way designated for this application was Highway 11B running from Highway 11, a major north-south route linking Northern Ontario communities to the South. Highway 11B is a business section link into the Town of Cobalt and runs north to New Liskeard. The section to be treated was designated by the MTO as a "holding strategy" as its condition was well below that of a preservation candidate. The road consisted of many areas of block cracking throughout and exhibited bumps and ruts (Figure 12). The more severe ruts were padded with HMA prior to chip sealing.

Figure 12. Wide-Spread Block Cracking on Highway 11B

The HPCS design utilized a high quality aggregate, as specified, and was a 6/10 mm for the first layer and 2/5mm for the second. The total application rate of CRS-2P asphalt emulsion was 2.6 L/m^2 with two condition modifications: a reduction of 0.15L/m^2 for a steep incline, and an increase of 0.1 L/m^2 for the badly cracked areas.

The differential between adjusted and the unadjusted spray rate was only 0.07 L/m^2 and to this day we have witnessed only damage by winter maintenance equipment on the surface where the pavement was extremely uneven as localized high spots. The average temperature of the succeeding 30 days was 19 degrees Celsius. Figure 13 shows the current condition of Highway 11B.

Figure 13. Highway 11B Typical Condition and Localized Plough Damage in 2011

4.0 CONCLUDING REMARKS

Our experiences with constructing and constant monitoring of these roadways have led us to a number of findings.

Firstly, we learned that public acceptance of chip seals in urban areas is difficult to gain. The initial dramatic increase of texture creates a pavement that is perceived as second rate. After completing the work in York Region in 2007 for example, the public had many complaints about Park Road, as this roadway had sections with many homes. The initial comments were, “why are we not getting pavement.” Ravenshoe Road on the other hand, which is primarily a commuter route, was not an issue. A similar opinion was registered during our first York Region contracts in 2005. Apart from highly residential areas, the reception from the public can be positive, if the public is adequately informed. The best example was Highway 127, where fliers were sent to residents prior to construction by the MTO. These fliers were outlining the basic concepts of pavement preservation and chip sealing, what was to be constructed on the stretch of road and why. As a result of the mailing campaign, public opinion about sealing Highway 127 was generally positive.

Secondly, the greater the design spray rate is decreased due to design parameters, the more susceptible the seal will be to plough damage. This happens mainly outside of the wheel paths, in particular the crowns which by design are exposed to the concentrated force of snow plough blades. These areas are not directly exposed to the traffic they were designed for, like the wheel paths. It takes much longer for the aggregate to reach a similar degree of embedment as the wheel paths, if ever. Ravenshoe Road in York Region experienced some plough damage primarily at centre line, whereas Park Road did not. The spray rate adjustments (for traffic and substrate conditions) for the two designs on Park Road were 0.33 L/m^2 and 0.13 L/m^2 respectively. On Ravenshoe Road, the same adjustments amounted to 0.63 L/m^2. Similar behaviour was described on Mt. Albert Road, which sustained plough damage and had a highly reduced spray rate, because of high traffic levels. By comparison, Weston Road, with higher emulsion spray rates, has experienced no damage.

By monitoring the performance of all the projects, we have concluded that extra binder must be applied to areas outside of the wheelpaths when design parameters reduce the spray rates by more than 10 to 15 percent from the basic, unadjusted spray rate. Projects where differential spray rates were used have had very little snow plough damage, even at the centreline. Spraying the extra binder outside the wheel paths will be utilized on a much wider scale by our group, on future projects.

Our third finding refers to the 30-day curing period after the seal’s construction. It is generally accepted that a period of one month of “good weather” is required for a chip seal to reach its full strength, by a combination of emulsion curing, aggregate embedment and aggregate-binder adhesion enhancement. The monitoring of the HPCS in Ontario over the last few years has helped us gain more insight into this. Table 2 lists a number of projects, their completion dates, the average temperature for the 30 days after construction, precipitation data, and the starting date for snow ploughing.

Based on the data we have collected so far, it seems that a chip seal’s ability to withstand the winter maintenance activity experienced in Ontario is dependent on average daily temperatures being above 10 degrees Celsius for the 30 days following the application. We will, no doubt, refine this threshold as we accumulate more data. This conclusion re-emphasizes the need for a timely tendering and construction of HPCS. We believe that a cut-off date for chip seal construction should be specified and that all stakeholders must be aware that pushing chip seal construction into the fall increases dramatically the risk of failure, or at least plough damage to the surface.

Table 2. Selected Project Completion Date and Subsequent Weather Data

Project	Completion Date	Average Temp for 30 Days After Completion	Precipitations for 30 Days After Completion	Date of First Snow Ploughing	Significant Plough Damage
Highway 127 MTO, 2006	September 5, 2006	11.6 °C	125.6 mm	October 12, 2006	No
Highway 28 MTO, 2007	August 21, 2007	17.3 °C	99.9 mm	November 21, 2007	No
Park Road, 2007	September 10, 2007	19.4 °C	45.8 mm	N/A	No
Ravenshoe Road, 2007	September 10, 2007	19.4 °C	45.8 mm	N/A	Not weather related
Highway 28 MTO, 2008 (Section 1)	September 16, 2008	9.2 °C	65.0 mm	October 28, 2008	Yes
Highway 28 MTO, 2008 (Section 2)	September 24, 2008	7.6 °C	65.0 mm	October 28, 2008	Yes
Highway 11B MTO, 2009	August 19, 2009	19.0 °C	N/A	N/A	No

Note: MTO is the Ontario Ministry of Transportation

In having to execute repairs on some sections, both chip loss and flushed areas were addressed successfully and the integrity and functionality of the chip seal was restored in full. The water blasting technique was used for the first time, as part of a contract for removing excess asphalt present in flushed areas and its effectiveness was very good. If they are constructed correctly, chip seals can be maintained and repaired relatively easily and inexpensively, and their full functionality and aspect can be restored.

To conclude, over the last six years of constructing high performance chip seals in Ontario, many lessons have been learned. We will continue to monitor, observe and refine our performance expectations about these products. Overall, we believe that we were successful so far in raising the bar regarding the design, construction and in-service performance of chip seals, by observing engineering principles and good practices. Quality is essential, as it translates into economic benefits for all stakeholders, good and well maintained roads for the traveling public and reduced impact on the environment.

REFERENCES

[1] Davidson JK, Houston G, Linton P, Croteau JM. “An Overview of the Design of Emulsion Based Seal Coating Systems Available in Canada and Abroad”, Proceedings, Canadian Technical Asphalt Association, 50, 363-377 (2005).

[2] ASTM International (ASTM) E965. “Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique”, Annual Book of ASTM Standards, Road and Paving Materials; Vehicle-Pavement Systems, 04-03, West Conshohocken, Pennsylvania (2010).

[3] TNZ T/3:1981. “Standard Test Procedure for Measurement of Texture by the Sand Circle Method”, Transit New Zealand (1981).

[4] Austroads STD 04:2003. “Ball Penetration Test”, Austroads Sprayed Seal Test (2003).

[5] Gransberg D, James DMB. Chip Seal Best Practices, National Cooperative Highway Research Program (NCHRP) Synthesis 342, Transportation Research Board, National Research Council, National Academies, Washington, D.C. (2005).

[6] Kucharek AS, Davidson JK, Croteau JM. “Chip Sealing Systems: Improving Early Age Chip Retention”, Proceedings of the 10th International Conference on Asphalt Pavements, Quebec City, Quebec (2006).

[7] Kucharek AS, Davidson JK, Linton P, Phillips T. “Resurfacing of Highway 127 in Ontario Using a High Performance Double Chip Seal”, Proceedings, Canadian Technical Asphalt Association, 52, 325-348 (2007).

[8] ASTM International (ASTM) E274. “Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire”, Annual Book of ASTM Standards, Road and Paving Materials; Vehicle-Pavement Systems, 04-03, West Conshohocken, Pennsylvania (2009).

[9] ASTM International (ASTM) E501. “Standard Specification for Standard Rib Tire for Pavement Skid-Resistance Tests”, Annual Book of ASTM Standards, Road and Paving Materials; Vehicle-Pavement Systems, 04-03, West Conshohocken, Pennsylvania (2010).