A Three Year Evaluation of Fibre-Reinforced Chip Seal Systems in Saskatchewan

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ABSTRACT

The Saskatchewan Ministry of Highways and Infrastructure (MHI) relies on graded aggregate seals for the maintenance of the provincial highway network. These types of seals are a good option for a large part of the network, however, their effectiveness is greatly reduced on higher volume roads. MHI was interested in the development of more robust sealing treatments to preserve pavements.

A pilot project of fibre reinforced engineered chip seals was designed and constructed in partnership with ColasCanada Inc. and ACP Applied Products in 2010. The seals were constructed in the Saskatoon and North Battleford maintenance areas, and they included single, racked-in, and sandwich chip seals with and without the use of fibre reinforcement.

To evaluate the performance of the chip seals, graded aggregate seal sections were constructed by MHI immediately adjacent to the chip seals. Test sections were set up for each of the different types of sealing systems used.

This paper provides an overview of the pilot project, including a discussion on the proposed chip sealing selection/design approach used to decide on the various systems, a summary of the placement operations, as well as a three year performance review of the test sections.

RÉSUMÉ

Le ministère des Transports et des Infrastructures de la Saskatchewan (MHI) utilise des scellants à granulométrie donnée pour le maintien du réseau autoroutier. Ces scellants sont une bonne option pour une grande partie du réseau, mais, leur performance est grandement réduite sur les chaussées avec un grand trafic. MHI était intéressé au développement d'un traitement de surface plus robuste pour préserver les chaussées.

Un projet pilote sur la conception et la construction d'un traitement de surface contenant des fibres a été effectué en 2010 en collaboration avec Colas Canada Inc. et ACP Applied Product. Les traitements ont été construits dans la région de Saskatoon et de North Battleford, et ils incluent des traitements monocouches, raclés ou bien en sandwich avec ou sans fibres.

Pour évaluer la performance des traitements de surface, des sections avec le scellant habituel ont été construites juste à côté des sections de traitement de surface. Des sections d'essais ont été préparées pour chaque technique utilisée.

Cet article donne un aperçu du projet pilote, en incluant une discussion sur la sélection et la conception du traitement de surface utilisé, un résumé des opérations de mise en œuvre, et une analyse de leurs performances sur une période de trois ans.

1.0 INTRODUCTION

The Saskatchewan Ministry of Highways and Infrastructure (MHI) relies on "light" maintenance treatments to preserve the provincial pavement road network, and the usage of graded aggregate seals is extensive in this category of treatments. Graded aggregate seals are a good option for a large part of the network, however, their effectiveness is greatly reduced on higher volume roads. Primary reasons for this are flying aggregates that can potentially cause windshield damage, and slow build-up of cohesion during placement of the seal, often resulting in early wheel path bleeding during service life. In addition, high float emulsions used for these graded aggregate seals are sensitive to placement conditions, and therefore their effectiveness greatly depends on favourable weather for construction and curing. In light of these facts, the development of more robust "light" treatments to preserve pavements was identified as a priority.

In 2009, MHI initiated a multi-year Technical Innovation Strategy Program to continually address the challenges facing the province's highway infrastructure. As part of this program, a pilot project of fibre reinforced engineered chip seals was proposed to be constructed in partnership with ColasCanada Inc. and ACP Applied Products. As a result, several chip seal systems were designed for the site-specific road conditions and environmental factors, and applied to select highways as an alternate solution to a portion of MHI's 2010 graded aggregate seal program. These treatments were applied on highways in the Saskatoon and North Battleford maintenance areas, and they included single, racked-in, and sandwich chip seals with and without the use of fibre reinforcement. The materials chosen to construct the chip seals were two types of washed chips with gradations of 6/10mm and 2/6mm, respectively, a polymer modified cationic rapid setting asphalt emulsion, and fibre glass strands.

In order to benchmark the performance of the chip seals in comparison to conventional MHI treatments, graded aggregate seal sections were applied by MHI maintenance crews immediately adjacent to the chip seals to compare the different systems under the same road conditions. Test sections were set up in each of the different types of seals for four of the highways in the program. Where possible, surface defects were documented prior to application of the seals, and surface condition assessments were carried out immediately after construction and annually thereafter.

This paper provides an overview of the chip seal pilot project, and includes a discussion on the proposed chip sealing selection/design approach used to decide on the various systems used, a review of the placement operations, as well as a three year performance review of the test sections.

2.0 SEALING SYSTEMS USED IN THIS STUDY

The systems used in this study included the traditional graded aggregate seals used by MHI, as well as various chip seals. The following subsections describe each of these treatments in more detail.

2.1 Graded Aggregate Seal

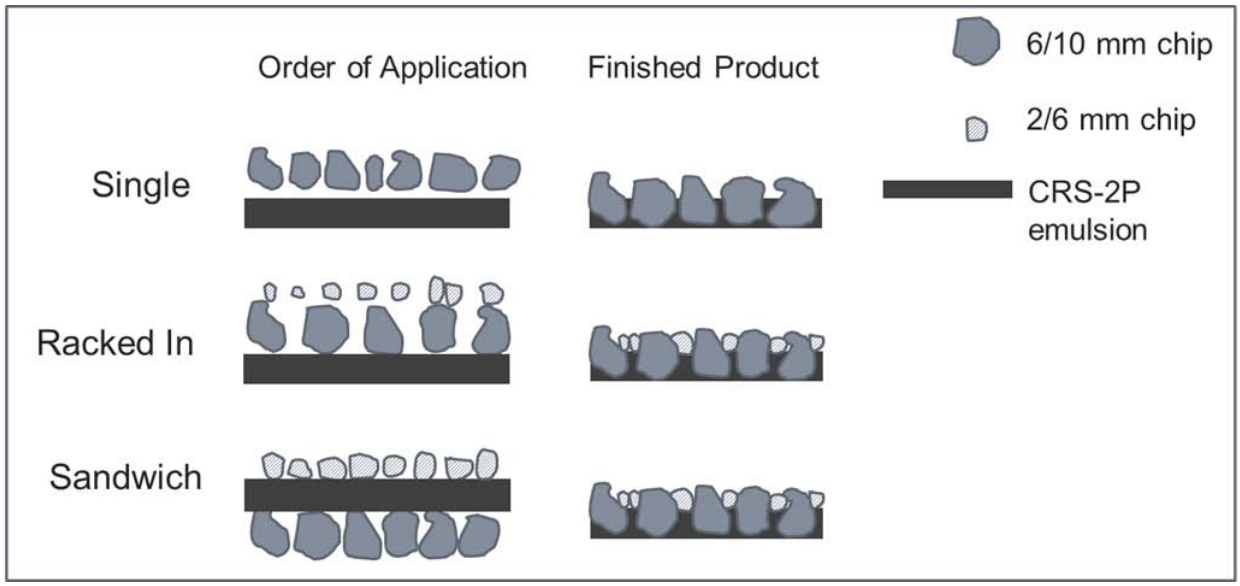
Graded aggregate seals are comprised of well/dense graded aggregate that is embedded into an anionic high float asphalt emulsion. They are constructed by first applying a specified amount of the high float emulsion, and then covering the surface with manufactured dense graded aggregate, and compacting it and pressing it into the emulsion. Saskatchewan's aggregate production utilizes glacial gravel deposits, which

are generally well graded and siliceous in nature. These glacial sources lend themselves well to the production of aggregate for graded aggregate seals.

MHI has had good experience with graded aggregate seals, whether they are carried out by internal maintenance crews, or through provincial/regional sealing contracts. They have proven well-suited for roads with lower traffic volumes, where minor fatigue cracking, longitudinal cracking, and surface conditions such as ravelling require attention. MHI maintenance crews are equipped to efficiently and effectively construct spot seals and full seals, which comprise a large part of their planned preservation work each season.

2.2 Chip Sealing Systems

Chip seal technology has proven effective even under high traffic volume situations, and design methodologies have been developed over time to assist in selecting proper treatments for the site specific conditions [1, 2]. Figure 1 demonstrates cross sections of the chip seal systems that were utilized in this study.



Note: CRS is Cationic Rapid Setting and P is Polymer.

Figure 1. Typical Cross Sections of Chip Seal Systems Used in this Project

2.2.1 Single Chip Seal

Single chip seals are the most common type of chip seal utilized for pavement preservation. This type of chip seal is built upon a single binder thickness followed by an application of a single sized chip. A single chip seal utilizes the least amount of materials, providing a cost effective treatment solution. Single chip seals demonstrate improved skid resistance, can have long service life, and are easily constructed. However they do have some potential performance issues which can include vehicle damage, tire noise, and roughness [3].

2.2.2 Racked-In Chip Seal

Racked-in chip seal systems are well suited for roadways where traffic is heavy and/or fast. In a racked-in chip seal, a layer of asphalt binder is placed initially and is followed by a large chip (6/10mm or 10/12.5mm) typically placed at 75 to 80 percent coverage. This process results in some of the binder left uncovered following the first application of aggregate. The second layer of small chips is then placed on top of the larger chips at 80 percent coverage to act as a cushion. This minimizes the occurrence of larger flying chips that can cause windshield damage during construction. Along with the mitigation of flying chips, traffic can be brought back to a higher speed upon placement of second layer of chippings, even before sweeping has been accomplished. This type of chip seal also produces a smoother and quieter surface condition. Racked-in chip seals have been used successfully on higher traffic applications in Canada [4, 5].

2.2.3 Sandwich Chip Seal

When a bleeding or binder-rich pavement is present, a sandwich chip seal system is recommended as the optimal treatment based on the guidelines found in Road Note 39 and the National Cooperative Highway Research Program (NCHRP) chip seal best practices [1, 6]. The sandwich seal is composed of two layers of chips and a single application of binder, as illustrated in Figure 1. A sandwich chip seal differs from other chip seals in that the initial stage is not to apply binder but to apply the larger chip directly to the existing binder-rich pavement. Binder is next placed on top of the large chips, with care not to disturb or shift the unbound chips. An application of a smaller chip follows close behind the binder application. The concept behind this type of seal system is to utilize the excess binder present on the pavement surface to act as part of the total binder for the larger chippings, while co-mingling with the new binder placed. Sandwich chip seal systems have been used successfully in many jurisdictions to reduce the reoccurrence of flushing, while restoring the surface texture and remediating the flushed surface condition [7-9].

2.3 Fibre Reinforcement Option

The use of fibre reinforcement in sealing treatments is becoming more widely implemented. Fibre reinforcement option is being utilized in both graded aggregate seals as well as in chip seal applications. The fibre reinforcement system is meant to mitigate reflective cracking and potholing while slowing the pavement cracking and inhibiting the opening of the cracks [4, 11].

Fibre reinforcement is installed using a trailer-mounted unit which is pulled by a distributor truck as seen in Figure 2. The trailer unit has its own computer controlled pumping system and radar to monitor the speed and cycle the pumps. A primary application of polymer modified binder is applied to the substrate. Fibreglass spools which are stored in the main housing of the trailer are fed through tubes on the back of the machine to automatic cutting heads that size the fibre multi strands into lengths of 60 mm. The strands are then blown into a random pattern into the first binder layer at a typical application rate of 75 g/m^2. A secondary spray bar then applies another application of polymer modified binder on top of the fibre strands encapsulating the fibres between the layers. The typical total spray rates for the binder are between 1.4 and 2.4 L/m^2 which are split between the two spray bars by the on-board computer system.

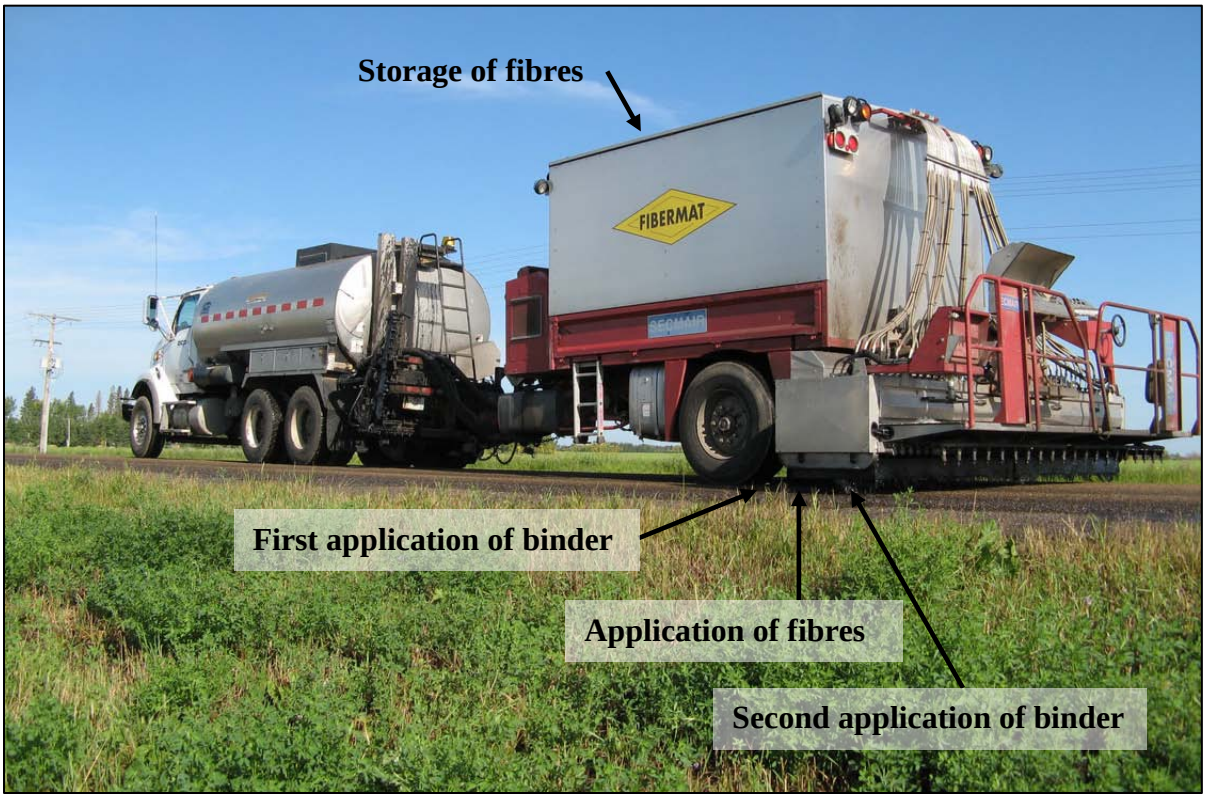


Figure 2. Fibre Reinforcement Trailer Mounted Unit

3.0 TEST SECTION CANDIDATES

As part of this study, 11 different sections of various highways were assessed to determine the most suitable preservation method required. The sections of highway were chosen based on MHI graded aggregate seal program for 2010. Based on field evaluations, seven sections were selected for inclusion in the chip seal pilot. Out of these seven locations, Control Sections (CS) 11-07, 11-08, 40-02, and 312-02 were designed to include test sections to monitor the progression of surface defects throughout the life of the seal coat compared to regular graded aggregate seals. The following subsections briefly describe the conditions of each of these segments prior to construction.

3.1 Control Section 11-07 (Highway 11 South of Dundurn)

Highway 11 (Figure 3) is a divided highway linking Saskatoon and Regina, with heavy traffic volume 750 trucks per day, and a posted speed limit of 110 km/hr. The existing structure in the driving lane in the location of the test sections was built in 1970, and consists of 200 mm of granular subbase, 180 mm of granular base course, and 205 mm of asphalt concrete. The main distresses observed in this section of highway consisted of light to moderate fatigue cracking, especially in the outer wheel path of the driving lane, block/map cracking of light to moderate severity, and depressed transverse cracking with moderate severity. The 2010 Falling Weight Deflectometer (FWD) measurements for this section at a 40 kN load ranged from 0.32 to 0.57 mm.

Figure 3. Control Section 11-07 Before Construction

3.2 Control Section 11-08 (Highway 11 North of Dundurn)

Control Section 11-08 (Figure 4) is located on Highway 11 North of Dundurn, and the test sections were placed in the Northbound driving lane. This road was originally constructed in 1968 with 150 mm of granular base course on in-situ sand subgrade, and currently has 150 mm of asphalt concrete as surfacing. Prior to construction this section was observed to have all transverse cracks treated with rubber crack sealant, and a microsurfacing patch to remove the depressions around the cracks. Slight severity flushing was noted in both wheel paths, and the aggregate was slightly polished in the wheel paths. No other surface distresses were noted, and the FWD deflections were measured as ranging from 0.27 to 0.53 mm.

Figure 4. Control Section 11-08 Before Construction

3.3 Control Section 40-02 (Highway 40 West of Blaine Lake)

Control Section 40-02 (Figure 5) is located on highway 40 between Blaine Lake and Hafford, and carries approximately 100 trucks per lane per day. This structure was built in 1987 with 600 mm of granular subbase, 40 mm of granular base course, and 80 mm of asphalt concrete. With no major rehabilitation treatments since initial construction, the pavement is now beginning to show deterioration. Transverse cracks were depressed, spalling and braided, often with fatigue cracking around the crack, and longitudinal cracking near centreline and between wheel paths was of high severity and consistent throughout the test section areas. Moderate severity fatigue cracking was intermittent, and ravelling was also noted. The surface was treated with frequent graded aggregate seal spot patches, some cold mix, and sand sulphur patching around select transverse cracks. Significant rutting and longitudinal/transverse distortions in the road were observed during the field assessment. FWD deflections before construction ranged from 0.37 to 1.08 mm.

Figure 5. Control Section 40-02 Before Construction

3.4 Control Section 312-02 (Highway 312 West of Rosthern)

Control Section 312-02 (Figure 6) is located west of the town of Rosthern, on Highway 312. This road does not have a formally constructed granular structure, rather, it has been built over the years through many applications of graded aggregate seals, resulting in severe surface flushing in the wheel paths, despite the truck volume being low at 50 trucks/lane/day. Despite of the binder richness of the surface, which was resulting rutting deformation of the seal surface due to viscous flow, potholing was also one of the distresses noted. FWD deflection measurements ranged from 1.16 to 1.38 mm.

Figure 6. Control Section 312-02 Before Construction

4.0 MATERIAL SELECTION AND DESIGN

4.1 Graded Aggregate Seals

Table 1 shows the typical seal coat aggregates used in Saskatchewan. For higher volume and busier roads Type 95 aggregate is typically used, while either a Type 117 or 118 is used for lower traffic volume applications. The aggregate gradations utilized for the MHI maintenance seal test sections were the standard types normally used for each of the roads in question. Type 95 aggregate was used for CS 11-07 and CS 11-08, and Type 117 aggregate for CS 40-02 and CS 312-02.

Table 1. Graded Aggregate Seal Coat Gradations in Saskatchewan [10]

Sieve Designation	Percent By Weight Passing Canadian Metric Sieve Series					
	Type 94	Type 95	Type 96	Type 117	Type 118	Type 119
16.0 mm						100
12.5 mm	100			100	100	
9 mm		100	100			
5 mm	0 – 40	0 – 40	20 – 80	35 – 70	25 – 65	45 – 70
2 mm	0 – 25	0 – 25	0 – 50	20 – 55	10 – 45	25 – 55
900 um			0 – 30			
71 um	0 – 5	0 – 5	0 – 10	0 – 10	0 – 6	0 – 10

Anionic high float emulsions work well with graded aggregates since their gel-like properties are designed to work with the large amount of fines in the aggregate. MHI crews can select HF150 or HF250, and polymer-modified HF emulsions are often chosen for high volume roads.

4.2 Chip Seal Systems

Chipping Selection: All chip seal test sections (single, racked-in, and sandwich) used a washed Type 95 aggregate. The washed aggregate was screened to provide the desired chip gradations specified for the chip seal system selected. The actual aggregate gradations are shown in Table 2. The 6/10 mm chip aggregate was used for all the chip seal systems. For the racked-in and sandwich seals a smaller clean chip aggregate (2/6 mm) was also required.

Table 2. Gradation of Aggregates Used in Chip Seals

Sieve Designation	Percent By Weight Passing Canadian Metric Sieve Series	
	2/6 mm Chips	6/10 mm Chips
12.5 mm		100
10 mm	100	99.8
5 mm	95.5	11.6
1.25 mm	5.2	2.2
0.63 mm	2.2	1.7
0.315 mm	1.6	1.6
0.160 mm	1.4	1.4
0.080 mm	1.2	1.3

Binder Selection: For the chip seal trials a polymer modified, cationic rapid setting asphalt emulsion was the binder of choice (CRS-2P). The chemical nature of aggregates causes the emulsion to break and set rapidly gives rise to why most chip seal systems utilize a cationic emulsion. In several of the test sections, snow plow damage was one of the factors considered in the design stage. The other design factor of importance was the use of fibre reinforcement. With the added presence of these two criteria, polymer modified emulsions were selected to enhance the adhesion and cohesion properties of the seals with the fibre. Further, other jurisdictions have had some success with polymer emulsion in counteracting the aggressiveness of snow plows [5, 6].

Fibre Reinforcement: Glass fibre multi-end roving materials were used in the fibre-reinforcing machinery (Figure 7). These materials were a Type "E" Glass with a specific gravity of 2.59 and a nominal diameter of 11 μm (microns).

Figure 7. Fibre Strands in Asphalt Emulsion

Design Process: The selection of a seal coating system depends on several factors that relate to the road condition, traffic volumes, climate condition and local experience. Following a site visit, the initial stage of design was completed. This consisted of identifying optimum seal coating treatments for each segment of roadway identified. The optimum treatment for each segment was determined using the existing roadway condition, traffic conditions such as speed, Average Annual Daily Traffic (AADT) and Average Annual Daily Truck Traffic (AADTT), snow plough activity, and concern for flying chips and typical seal coating materials (i.e., aggregate and binders). A summary of the resulting designs for each section of roadway can be seen in Table 3.

Table 3. Design Starting Points for Roadway Segments Selected

		Spread Rates (kg/m^2)		**Spread Rates (L/m^2)**
Control Section	**Seal Type**	**6/10mm Chips**	**2/6mm Chips**	**Emulsion CRS-2P**
11-07	Single w Fibre	13.5 – 15 (110% coverage)	N/A	2.00
11-08	Racked-In w Fibre	10 – 10.5 (75% coverage)	5.2 – 5.6 (80% coverage)	1.90
40-02	Single w Fibre	13.5 – 15 (110% coverage)	N/A	2.00
312-02	Sandwich w Fibre	10 – 10.5 (80% coverage)	6.5 – 7.9 (110% coverage)	1.80
All locations	Graded Aggregate	16-22 kg/m^2 of Type 95		1.8-2.2 L/m^2 HF

Note: CRS is Cationic Rapid Setting, P is Polymer, and HF is High Float.

In the design stage, all of the previous mentioned factors were taken into account and utilized in a few different design processes, notably Road Note 39, the French Method, and The McLeod Method, to determine the optimal seal types as well as the respective application rates. In conjunction with the design processes sample aggregates were procured and a French standard test method (NF P 98-276-1) for determining the 100 percent rate of coverage for each aggregate selected was performed. These 100 percent coverage rates were utilized to help calculate spread rates for the racked-in and sandwich seal coat designs. The rates in Table 3 represent the starting point for the application process in the field. Field monitoring was still required to ensure that the desired chip seal systems was achieved.

Fibre reinforcement was also recommended for each of the road segments in order to promote tensile strength to the surfacing systems and to mitigate reflective cracking and potholing.

5.0 CONSTRUCTION

The construction of all the seals took place between July 14 and August 10, 2010, with daily temperatures ranging from 16 to 26°C. Initially it was thought ideal if the maintenance seals were placed within the same timeframe as the chip seals for each of the control sections. While this was possible for CS 11-07 and CS 11-08, for the test sections on CS 40-02 and 312-02 maintenance crews placed their seal after the chip sealing operation.

5.1 Chip Seal Placement

Each chip sealing process applied on this project utilized the same equipment, with different processes requiring the equipment application in varying orders, shown in Figure 8. One Etnyre chip spreader computer controlled with variable width for the application of the bottom 6/10mm chip, one Etnyre distributor with computer controlled application, one Secmair computer controlled fibre/emulsion applicator, one manually controlled Rosco chip spreader for the application of the top 2/6mm chip, and two Hamm pneumatic rubber tire rollers were used for this project.

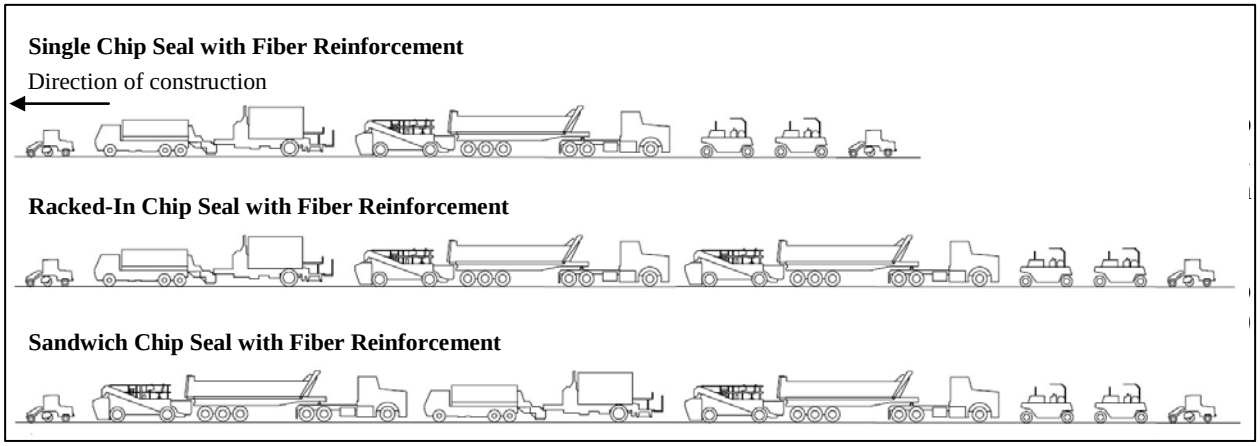


Figure 8. Chip Seal with Fibre-reinforcing Interlayer Process

Figure 9 shows the application of a single chip seal on CS 11-07 and Figure 10 illustrates the finished surface of racked in chip seal on CS 11-08.

Figure 9. Single Chip Seal Construction on Highway 11-07 near Dundurn

Figure 10. Finished Racked-In Chip Seal Surface

Equipment calibration is essential prior to applying chip seals. The binder application is the most crucial element when chip sealing; the target spray rate must be attained to avoid wheel path tracking due to binder over-application or loss of aggregate due to binder under-application. Aggregate application should be adjusted based on the binder application rate, however, due care needs to be taken when applying racked-in and sandwich seals to provide the appropriate coverage. The distributor and fibre machine were calibrated following ASTM D 2995, and the chip spreaders following ASTM D 5624.

The application rates were applied as shown in Table 4. By comparing Table 3 and Table 4 it can be seen that the chip application rates were modified during construction. As the first section of the sandwich chip seal was placed it was observed that the bottom chips were covering more than 80 percent coverage and that the overlaying chips were being applied at less than the desired 110 percent coverage. As a result, the bottom chip application was lowered from 10 to 6.1 kg/m^{2,} while the top chip application rate was increased from 7.9 kg/m^2 to 10.5 kg/m^2 in order to achieve the desired system designed. Other application rates were within the design limits for each section so no in field changes were required.

Due to the chemistry of the cationic emulsion, chip seals are less susceptible to moisture sensitivity as the aggregate charge facilitates the emulsion to break rapidly. This allowed the construction of the chip seals to be applied in a wider range of overcast conditions, thus improving productivity. However, the aggregate application needed to be laid at close proximity to the cationic emulsion as it breaks more rapidly compared to high floats that can take days to cure.

Table 4. Actual Application Rates for Chip Seal Construction

Control Section	Treatment	Chip Application Rate (kg/m^2)		Binder Application Rate (L/m^2)	Fibre Application Rate (g/m^2)
		Bottom 6/10	Top 2/6		
11-07	Single Chip Seal - Fibre	13.6	-	2.0	75
11-08	Racked-In Chip Seal - Fibre	9.5	5.6	1.9	75
40-02	Single Chip Seal - Fibre	14.7	-	2.0	75
312-02	Sandwich Seal - Fibre	6.1	10.5	1.8	75

For CS 11-08, contrary to the other seal coat and chip seal systems, the racked-in chip seal was opened to traffic within a few hours following the rolling of the seal. This is possible since the 2/6mm surface chip does not have enough weight to cause windshield or vehicle damage, thus reducing potential for claims and lowering motorist inconvenience. This also allowed sweeping to be conducted the next day.

5.2 Graded Aggregate Seal Placement

MHI maintenance crews placed single graded aggregate seals adjacent to the chip seals to properly evaluate the performance of each treatment relative to one another. The seals were constructed using the materials and application rates shown in Table 5.

Table 5. Application Rates for Maintenance Graded Aggregate Seals

Control Section	Aggregate Type	Aggregate Application Rate (kg/m^2)	Emulsion Type	Emulsion Application Rate (L/m^2)
11-07	95	20	HF 150P	1.9
11-08	95	18	HF 150P	1.9
40-02	117	20	HF 150	1.9
312-02	117	20	HF 250	1.9

Note: HF is High Float and P is Polymer.

As can be seen in Figure 11, the traditional method of seal construction by MHI maintenance crews involves the use of custom built trucks with hydro-drum bottoms, rather than using an aggregate spreader. This method allows the crews to be versatile and responsive, and allows for easy application of partial or full-lane width seals. The downside of this approach is the lack of tight quantity control of aggregate application. Figure 11 illustrates the construction of a maintenance seal on CS 11-08.

It should be noted that the maintenance seals on CS 11-07 and 11-08 were constructed on the same day, and both experienced bleeding due to a combination of high temperature and heavy traffic. Maintenance crews applied blotter sand, and once the seal cured, no further problems were encountered.

Figure 11. Maintenance Seal Construction on Highway 11-08 near Dundurn

5.3 Excess Aggregate Evaluation

By design, graded aggregate seals require significantly more aggregate than chip seals. Some of the extra aggregate is needed to avoid binder/aggregate pick up by traffic and to protect the seal during early stage of cohesion build up. MHI was interested in determining how much whip-off aggregate is generated during the sealing operation for each process. To that effect, aggregate catchment areas were installed on the Highway 11-07 test sections for the single chip seal, and for the single maintenance-applied graded aggregate seal. Each catchment area was uniform in size, and the collected aggregate was bagged and weighed once the sweeping operations were completed. Figure 12 illustrates one of the catchment areas on CS 11-07 and the aggregate collected.

Figure 12. Excess Aggregate Catchment Area on Highway 11-07

As can be seen in Table 6, there are substantial savings in aggregate when chip seals are used. For the graded aggregate seal the amount of rock swept off was recorded as 32 to 47 percent of total aggregate applied, whereas for the single chip seal only eight to nine percent was swept off. This is partially due to the nature of the graded aggregate seal, and to the construction process. Unlike large contract seal projects where aggregate spreaders are used, MHI maintenance crews utilize hydro drum trucks to apply the seal aggregate. Further, while MHI has specified ranges for aggregate application rates, the application rates are not accurately designed ahead of time, rather, they are determined on site by the sealing crew, based on their expert judgment. All these factors contributed to the single graded aggregate seal resulting in three times the amount of aggregate removed during sweeping when compared to the single chip seal.

Table 6. Highway 11-07 Excess Aggregate Collection Results

Seal Type	Aggregate Applied (kg/m^2)	Aggregate Recovered (kg/m^2)	Aggregate Recovered (%)
Graded Aggregate	20	6.5	32
Graded Aggregate	20	9.3	47
Single Chip With Fibre	13	1.1	8
Single Chip Without Fibre	13	1.1	9
Single Chip Without Fibre	13	1.2	9

6.0 PERFORMANCE TO DATE

Test sections were set up prior to construction to evaluate the different treatments and their effects. Monitoring areas of 150 m in length were photo logged and surface distresses and condition were carefully mapped using the applicable standards set out for Strategic Highway Research Program (SHRP) test section monitoring. Once construction was complete, the test sections were again photo logged and inspected for surface distresses, and this process was repeated annually, with the last monitoring to date carried out in May 2013. The results of the observed behaviour are discussed in the following subsections.

6.1 CS 11-07 – Single Chip Seal

Three test sections were constructed at this location: a single chip seal without fibre, single chip seal with fibre, and a maintenance graded aggregate seal. As discussed in Section 3.1, the main distresses observed in this section were light to moderate fatigue cracking, especially in the outer wheel path of the driving lane, block/map cracking of light to moderate severity, and depressed transverse cracking with moderate severity. Of particular interest was the possibility of fibre inhibiting the progression of fatigue cracking in the outer wheel path. As can be seen in Table 7, it is obvious that the section with fibre has significantly less fatigue cracking reflecting through, with only 16 percent. Further, there is slightly less new fatigue cracking in the fibre section than in the other two sections. It is also interesting to note that the amount of new fatigue cracks is significantly less in the chip seal sections than in the maintenance seal section, regardless of fibre addition.

Table 7. Fatigue Cracking Condition on Control Section 11-07 Test Sections

Fatigue Crack Factor	Single Chip no Fibre	Single Chip with Fibre	Maintenance Seal
Old cracks reflected (%)	34	16	57
Severity improvement	+2	+2	+2
New cracks (m^2)	23	15	70

Transverse cracks have all reflected through on all three sections, however, they remain as very slight (< 5 mm) on the chip seal sections, whereas before construction they were rated as moderate (10 -20 mm), with significant spalling. This is an improvement of two severity levels. As seen in Figure 13, the fibre strands are bridging the cracks and likely assisting in keeping stone and asphalt emulsion in place. Further, no spalling or other crack deterioration was recorded during the 2013 rating on the chip seal sections. The maintenance section has more stone loss around crack edges. The same situation exists with longitudinal and block/map cracks – they have all reflected through, however, the severity level noted in the latest rating was very slight, and the cracks look better on the chip seal sections.

As mentioned in Section 5.2, the graded aggregate maintenance seal bled immediately after construction. While the wheel paths remain darker due to the initial bleeding, overall, the surface condition of the seal is good. Minor stone loss was noted on the maintenance section, whereas both chip seal sections have good stone retention. The surface appearance of the graded aggregate maintenance seal and the single chip seal can be seen in Figure 14.

Figure 13. Fibre Strands Bridging Transverse Crack on CS 11-07

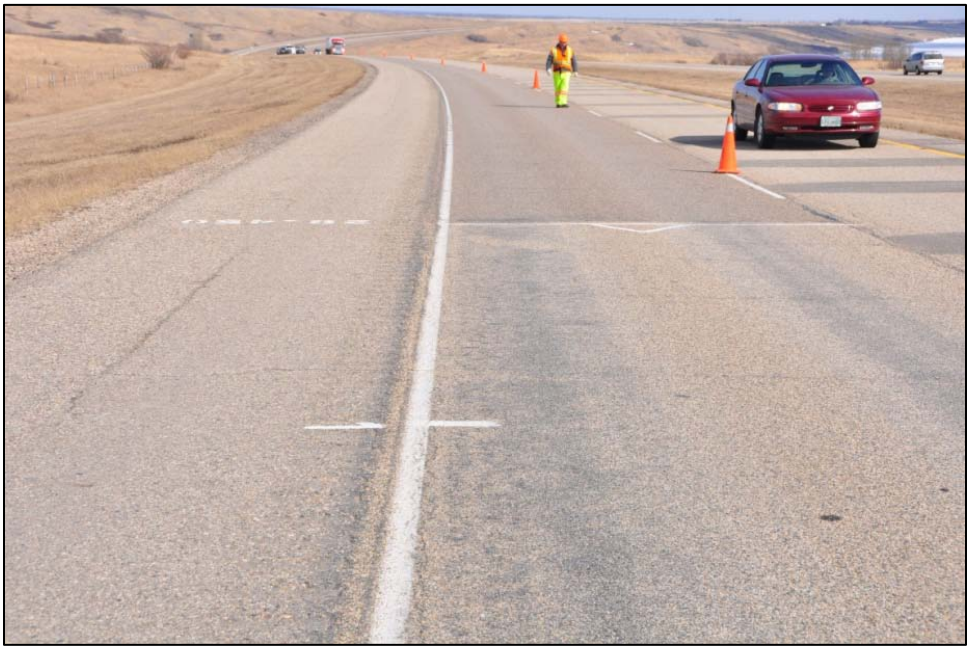


Figure 14. Top: Single Chip Seal, Bottom: Graded Aggregate Seal on CS 11-07

6.2 CS 11-08 – Racked In Chip Seal

As noted in Section 3.2, the main distresses at this location where treated transverse cracks, and minor flushing and polished in wheel paths. Four test sections were constructed here: racked in chip with fibre and a fog seal, racked in chip seal with fibre, racked in chip seal without fibre, and a graded aggregate maintenance seal.

During the 2013 rating it was noted that 75 to 86 percent of pre-existing transverse cracking is currently reflected through the different seal types, with cracks of very slight severity. All test sections are performing similarly, as expected, since the addition of fibre is not thought to be able to prevent transverse cracking. It was also noted that the chip seals were adhering very well to the rubber asphalt crack filling, and that the fibres provided a bridge across the crack openings in many cases. This is illustrated in Figure 15.

The graded aggregate maintenance seal was constructed at the same time as the maintenance seal on CS 11-07, and similarly, it bled immediately after construction and required blotting. As a result, the wheel paths have remained darker, however, the flushing did not worsen in the last three years. This is illustrated in Figure 16.

All sections were noted as having minor stone loss between wheel paths, likely due to ploughing, however, the section with fog seal was performing better in this area.

Figure 15. Racked-In Fibre Chip Seal Adhering Well to Rubber Crack Filling on CS 11-08

Figure 16. Top: Graded Seal, Bottom: Racked-In Chip Seal on CS 11-08

6.3 CS 40-02 – Single Chip Seal

Control Section 40-02 was showing significant distresses prior to construction, as previously noted in Section 3.3. The chip seal test sections were inspected before construction and their surface condition was assessed, however, the maintenance seal was not yet placed at that time, and as a result, the pre-construction rating was not conducted on this section. The maintenance seal test section was first evaluated during the 2011 ratings, since it was still considered valuable to track the comparative performance of these sections, even if baseline data for the maintenance seal was not available.

During the 2010 pre-construction assessment of the two chip seal test sections, the main distresses noted were severely deteriorated transverse cracks with fatigue cracking around the cracks, and longitudinal cracking between wheel paths and near centre line. After three years in service, the chip seals were still providing an improvement in fatigue cracking severity, from moderate prior to construction, to very slight in 2013, which is an improvement by two levels. Further, it was noted that in both chip seal sections about 50 percent of longitudinal cracks had not yet reflected through.

The most concerning issue with all test sections on this control section is the surface condition. With pronounced rutting, distortion of the roadway, and aggressive winter snow removal, significant plough damage is visible in all the sections between wheel paths and along centre line (Figures 17 and 18). While the same amount of plough damage exists in the maintenance seal, the nature of the seal is such that the damage is not readily visible, as all the dust and sand remains embedded in the emulsion leaving a grey finish even though the large stones have been ripped out by the ploughs. With the chip seals, the rock is uniform in size, and the plough removes a lot of the chips, resulting in only the black emulsion remaining.

Figure 17. Single Chip Seal Plough Damage on CS 40-02

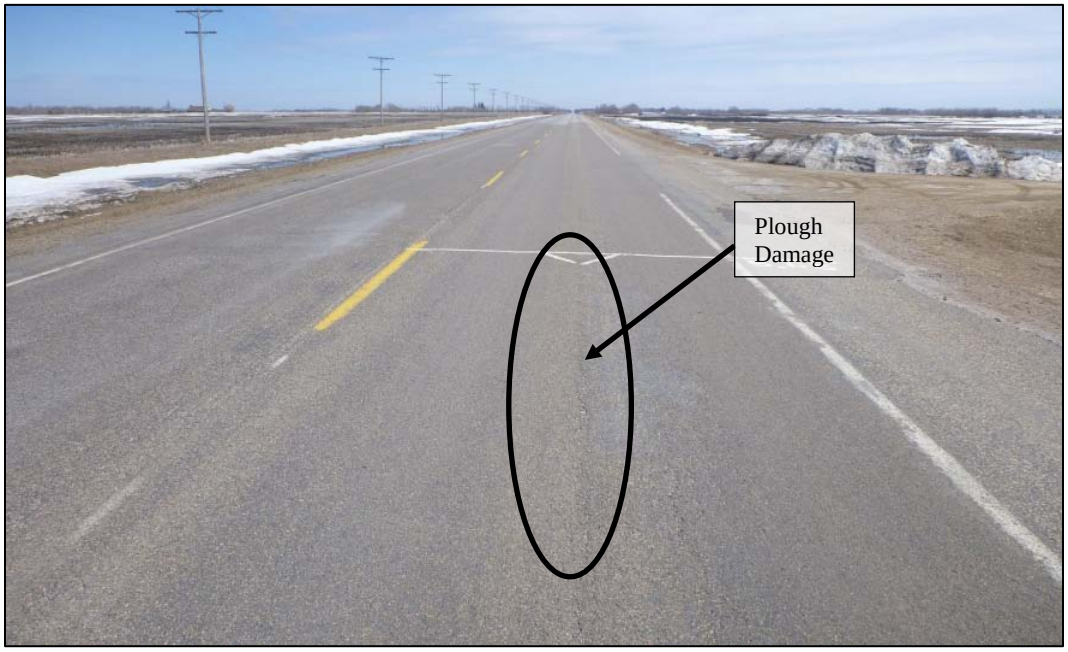


Figure 18. Graded Aggregate Seal Plough Damage between Wheel Paths on CS 40-02

6.4 CS 312-02 – Sandwich Chip Seal

Prior to construction, CS 312-02 was recorded as having excessive binder in wheel paths and severe rutting (12 mm and greater in places). No cracking distresses were recorded. The main purpose of this set of test sections was to compare the effectiveness of the sandwich chip seal with the maintenance seal in terms of effectiveness in treating bleeding. As can be seen in Figure 19, the sandwich chip seal, which is on the right hand side of the image, removed the bleeding and restored good surface texture in the wheel paths, whereas the maintenance seal continues to exhibit binder rich wheel paths.

Figure 19. Left: Maintenance Seal, Right: Sandwich Chip Seal on CS 312-02

7.0 SUMMARY AND OBSERVATIONS

Recognizing the limitations of graded aggregate seals, MHI set out to evaluate the performance of engineered chip seals with and without fibre reinforcement by partnering with ColasCanada Inc. and ACP Applied Products Inc. to design and construct pilot test sections in 2010. The test sections were monitored annually, and the following observations can be made based on the experiences during construction and after three years of in service performance:

- Cationic rapid setting emulsions used with chip seal treatments have allowed faster cohesion build up in comparison to the graded aggregate seals with high float emulsions;
- Racked-in chip seal sections have demonstrated their capacity to reduce the occurrence of flying stones and therefore have allowed accommodating traffic sooner than graded aggregate seals;
- Single graded aggregate seals resulted in as much as 47 percent of total aggregate used being swept off into the ditch, whereas single chip seals only wasted 9 percent of total aggregate;
- Fibre reinforcement has significantly reduced the occurrence of reflective fatigue cracking on the surface, and inhibited the development of new fatigue cracking visible on the surface;

- Where exiting cracks reflected through, both the graded aggregate as well as chip seals have resulted in reduced cracking severity;
- Single chip seals with and without fibre were effective at inhibiting the amount of longitudinal cracking reflecting through;
- Fibre strands have bridged the cracks and are likely assisting in keeping the aggregate and asphalt emulsion in place across the crack;
- All sealing systems have adhered to the rubber asphalt crack filling;
- Plough damage on a single chip seal is unsightly when compared to a graded aggregate seal, which masks plough damage due to the retention of dust and sand in the emulsion; and
- Sandwich chip seal has been effective at eliminating binder rich wheel paths and restoring surface texture, whereas the graded aggregate seal was not successful in this application.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the three-year evaluation of the sealing systems studied in this pilot project, it can be concluded that fibre-reinforced chip seals are effective at mitigating fatigue and longitudinal cracking. Graded aggregate seals, while effective in many instances, do present some limitations for higher volume roads. They result in a large amount of whip-off aggregate, and they are not able to treat fatigue cracking and binder rich wheel paths as effectively as other sealing systems.

As demonstrated in this study, it is important that the right treatment be selected for each road, using an engineering process based on the existing traffic volumes, distresses and environmental conditions. Engineered chip seals can be custom-designed for specific requirements, and are better suited for higher volume roads. Further, they are very precise systems that require knowledge and experience during design and construction. The processes for design and construction of chip seals are well established in other jurisdictions, and should be considered by MHI as additional tools for road preservation.

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