12-Year Performance Review of Bloomington Road (York Region Road 40) Rehabilitation using Cold In-Place Recycling and a 6.7 mm Fine Stone Mastic Asphalt

Trevor Moore, P.Eng., GSC
Corporate Technical Director
Miller Paving Limited
Stouffville, Ontario

Mehran Kafi Farashah, M.A.Sc., P.Eng.
Transportation Asset Management Engineer, Transportation Services
The Regional Municipality of York
Sharon, Ontario

Michael Esenwa, P.Eng.
Manager, Technical Services
McAsphalt Industries Limited
Toronto, Ontario

Sina Varamini, Ph.D., P.Eng.
Manager, Research and Development
McAsphalt Industries Limited
Toronto, Ontario

Anton S. Kucharek, P.Eng., C.Chem.
Director, Technical Services
McAsphalt Industries Limited
Toronto, Ontario

© Canadian Technical Asphalt Association 2017

240 12-YEAR PERFORMANCE REVIEW OF BLOOMINGTON ROAD REHABILITATION

ABSTRACT

Bloomington Road, Regional Road 40 in the Regional Municipality of York, serves as a major artery for vehicles accessing Highway 404. The section under review between Kennedy Road and Highway 48 was built in 1969 and rehabilitated with an innovative pavement design in 2005.

Prior to rehabilitation, the asphalt surface was severely oxidized with extensive thermal cracking, however, the longitudinal and transverse profiles of the roadway were in relatively good condition and there was no sign of major structural failures. Rehabilitation of the roadway consisted of Cold In-Place Recycling (CIR), a Heavy-Duty Asphalt Binder Course (HDBC) Hot Mix Asphalt (HMA), and a 6.7 mm rut-resistant fine-graded Stone Mastic Asphalt (SMA).

This paper provides a review of the design and construction details for the pavement lifts, as well as material and process selection details. Special consideration is given to the curing duration of the CIR and the rut resistance of the SMA lift. This paper also presents a long-term field performance evaluation of the rehabilitated pavement section with quantified in-situ performance by means of field observations, laboratory evaluations of retrieved pavement specimens, and semi-automated pavement performance data survey collected by York Region over twelve years of in-service pavement life.

RÉSUMÉ

La route Bloomington, route régionale 40 dans la municipalité régionale de York, sert d'artère majeure pour les véhicules qui accèdent à l'autoroute 404. La section à l'étude entre la route Kennedy et l’autoroute 48 a été construite en 1969 et réhabilitée avec un design de chaussée novateur en 2005.

Avant la réhabilitation, la surface de l'asphalte était fortement oxydée avec une large fissuration thermique, mais les profils longitudinaux et transversaux de la chaussée étaient en relativement bon état et il n'y avait aucun signe de défaillances structurelles majeures. La réhabilitation de la chaussée a consisté en recyclage en place à froid (CIR), un classeur bitume bitumineux (HDBC), un enrobé à chaud (HMA) et un enrobé à matrice de pierre de granulométrie fine résistant à l’orniérage (SMA) de 6,7 mm.

Cet article fournit un aperçu des détails de conception et de construction des chaussées, ainsi que des détails sur la sélection des matériaux et des procédés. Une attention particulière est accordée à la durée de mûrissement du CIR et à la résistance à l'orniérage du SMA. Cet article présente également une évaluation à long terme de la performance de la section de chaussée réhabilitée avec des performances quantitatives in situ au moyen d'observations sur le terrain, des évaluations de laboratoire des spécimens de chaussée récupérés et des sondages semi-automatisés sur les performances des chaussées recueillies par la région de York pendant douze ans de vie de service de la chaussée.

© Canadian Technical Asphalt Association 2017

1.0 INTRODUCTION

York Region, located in the Greater Toronto and Hamilton Area (GTHA), is the sixth largest municipality in Canada with a population of 1.14 million in 2014, representing a 16 percent share of 2014 GTHA population. The Region's population is expected to grow to 1.8 million by 2041. York Region prides itself as a progressive municipality, committed to sustainable and cost-effective pavement technologies. Rehabilitation of Bloomington Road is a prime example of the innovations employed by York Region in pursuing sustainable and cost-effective technologies.

Bloomington Road is a two-lane rural road located in the heart of York Region, carrying over 15,000 Annual Average Daily Traffic (AADT) with approximately 6 percent heavy commercial vehicles. It serves as a main thoroughfare between the limestone aggregate quarries and sand and gravel pits to the Greater Toronto Area.

In 2003, a four-kilometre section of Bloomington Road between Kennedy Road and Highway 48 required pavement rehabilitation due to significant signs of distress evidenced by various types of severe cracking. The section did not include the intersection of Bloomington Road and McCowan Road. York Region engaged the expertise of a geotechnical consultant to conduct an investigation of the existing roadway for rehabilitation design. Based on the recommendations of the consultant, York Region tendered the work in 2004 for construction in 2005.

Following the award of the contract to Miller Paving Limited (MPL), discussions between technical services staff from both York Region and MPL resulted in the decision to move forward with an innovative pavement rehabilitation process.

After twelve years of service, the pavement is performing extremely well with very few distresses exhibited in localized areas, primarily at construction joints.

2.0 GEOTECHNICAL INVESTIGATION

2.1 Overview

York Region retained the services of a geotechnical consultant in March of 2003 as part of its annual road-resurfacing program to investigate the existing roadway and provide pavement rehabilitation recommendations.

The extensive geotechnical report [1] included:

- A visual pavement condition survey identifying pavement surface distresses and roadway drainage characteristics;
- Non-destructive Falling Weight Deflectometer (FWD) load deflection testing to evaluate the structural condition of the pavement;
- Field geotechnical investigations including pavement coring and shallow probeholes to determine the thickness and condition of individual pavement layers, and assess the type and moisture content of the subgrade;

© Canadian Technical Asphalt Association 2017

- Laboratory testing including examination of pavement cores and testing of selected samples of granular base, sub base and subgrade materials; and
- Pavement rehabilitation recommendations based on their findings.

2.2 Pavement Condition Survey

The pavement condition survey summary performed by the consultant indicated varying densities and severities of map, longitudinal, transverse, edge, construction joint, and alligator cracking, which resulted in an overall pavement condition rating of Poor. Analysis of the surface HMA indicated the presence of slag aggregate, which explained the map cracking observed. In addition to the road surface rating, shoulders were mainly classified as good, with some sections rated as fair, and the ditches rated as fair, where cleanout was suggested. Figure 1 illustrates the typical pavement and shoulder condition prior to recycling.

Figure 1. Typical Pavement and Shoulder Condition Prior to Recycling

2.3 Structural Evaluation

The FWD analysis carried out by the consultant revealed varied pavement modulus along the project length. The section between McCowan Road and Highway 48 possessed a higher modulus than the section between Kennedy Road and McCowan Road. Upon further review of the report, the difference in modulus was attributed to the increased HMA thickness in the higher modulus section.

2.4 Original Pavement Structure

According to the borehole analysis performed by the consultant, the original pavement structure was comprised of approximately 165 mm of HMA and 915 mm of granular base. The HMA and granular base depths were however different for the two sections of the roadway as illustrated in Table 1.

© Canadian Technical Asphalt Association 2017

Table 1. Original Hot Mix Asphalt and Granular Base Depths for Each Roadway Section

Road Section	Original HMA Depth (mm)	Original Granular Base Depth (mm)
McCowan Road to Highway 48	205	1024
Kennedy Road to McCowan Road	155	839

2.5 Laboratory Testing

Granular base materials were found to be generally dry sandy gravel while the granular sub base was a mixture of sands, gravel, and silts. In comparison to the OPSS gradations, base and sub base aggregates were found to be finer than Granular A but were within the Granular B gradation band [2].

The sub grade materials were identified as clay silt and sandy silt with moisture content varying between five and 21 percent; identifying them as materials with high frost susceptibility.

2.6 Pavement Rehabilitation Recommendations

The two main pavement rehabilitation techniques presented by the consultant included milling and overlay and recycling and overlay with CIR or Full Depth Reclamation with Expanded Asphalt Material (FDREAM).

To achieve a 20-year design life with the traffic input and expected growth, the following designs were suggested:

- Section one from McCowan Road to Highway 48: a minimum cold milling depth of 40 mm (to remove the slag) followed by two 40 mm lifts of high stability HL8 and a 40 mm lift of HL1. After cold milling, it was recommended that the milled surface was checked to determine if crack repair was necessary.

- Section two from Kennedy Road to McCowan Road: a minimum cold milling depth of 40 mm (to remove the slag), followed by 150 mm of FDREAM covered with two 40 mm lifts of high stability HL8 and a 40 mm lift of HL1.

3.0 INNOVATIVE CHANGE IN REHABILITATION STRATEGY

3.1 Post Tender Change Proposal

York Region Transportation Services Department tendered the contract in November of 2004 under contract number T-04-11 for Foam Stabilization and Asphalt Paving [3] which specified 150 mm of FDREAM, 50 mm of heavy duty binder course, and a 50 mm HL1 overlay for both sections. However, York Region worked with MPL to modify the selected strategy to include a 100 mm CIR application followed by a 65 mm lift of heavy duty dense-graded HMA and 35 mm of a 6.7 mm premium SMA as a surfacing wearing course [4].

© Canadian Technical Asphalt Association 2017

The FDREAM process was replaced with a rapid-curing application of CIR to achieve accelerated cohesion in the recycled material. Development of these mixes and CIR treatment are explained in the following sections.

3.2 CIR Treatment

3.2.1 CIR vs. FDREAM

The CIR treatment was deemed to be a more appropriate rehabilitation strategy compared to FDREAM due to the existing roadway profile and HMA depths. Since the longitudinal and transverse profiles of the existing roadway were considered good, this meant that a surface rehabilitation technique such as CIR was adequate as the profiles could essentially be left unaltered.

CIR is typically performed when the existing HMA depths are in excess of 150 mm while FDREAM is generally performed when the existing HMA depths are less than 150 mm. In this case, CIR would eliminate the removal of material and avoid excessively deep pulverization into the pavement structure. Alternatively, FDREAM is most appropriate on roadways where profile adjustment is required to address distortions. The process typically involves two stages including the pulverization of existing pavement and injection of the EAM into the reclaimed material. The first stage of pulverization allows the existing pavement materials to be crushed in-place and graded to the proper cross fall, thereby providing the opportunity to add corrective aggregate to the roadway for profile adjustments or mix design requirements. The second stage follows the pulverized mat profile while injecting the binder into the reclaimed material. A pulverizer fitted with an injection system or an in-place recycling train fitted with a grinder, crusher, and mechanical paver is used to inject binder into the reclaimed material. The processed materials are then compacted to the required density with rollers.

Implementation of CIR would also help mitigate any reflective cracking that would be a cause for concern if milling and overlay was utilized. Construction of a 100 mm lift of rapid curing partial depth CIR with emulsified asphalt was suggested to accelerate the build-up of cohesion of the recycled material and minimize any risk exposure related to a high volume of truck traffic riding on the surface prior to HMA overlay. While the use of emulsified asphalt for CIR in 2005 was common practice in Ontario, the use of a rapid curing system was not. The technology however was popular outside of the province in Quebec, across the United States of America (USA), and Europe with a long-standing positive performance record. An enhanced binder system was recommended due to the attributes of the subject location, which consisted of a Cationic Emulsified Asphalt and Portland cement.

3.2.2 Rapid Curing System

In-house laboratory analysis by the McAsphalt Industries Research Laboratory determined the strength gain of cationic emulsions would allow the mix to gain cohesion of the mix more quickly than the commonly used anionic emulsions of the time. A slow-setting cationic emulsion classified as CSS-1 would enable sufficient coating of the RAP to ensure that the moisture sensitivity of the mix was optimized. Slower breaking allows the new emulsion to form a continuous film on the RAP and allows for complete coating of all fine aggregate. Complete curing is achieved when all of the water in the system is evaporated, leaving a film of binder on the surface of the RAP particles. This phase is dependent on the temperature and humidity of the air after placement of the material; hot and dry weather allows the material to cure quickly while wet and humid weather will delay the full cure. The addition of Portland cement further improves the rate of strength gain as it provides a pH shift, which allows the positively charged emulsion to chemically break to

© Canadian Technical Asphalt Association 2017

the negatively charged cement-coated RAP. This system improves short-term moisture resistance to protect the completed mat from weather and traffic prior to HMA paving and long-term resistance to optimize pavement performance. Figure 2 illustrates the higher early strength obtained with the CSS-1 plus cement system as compared to the CSS-1 without cement and the HF-150M system within the first 50 hours.

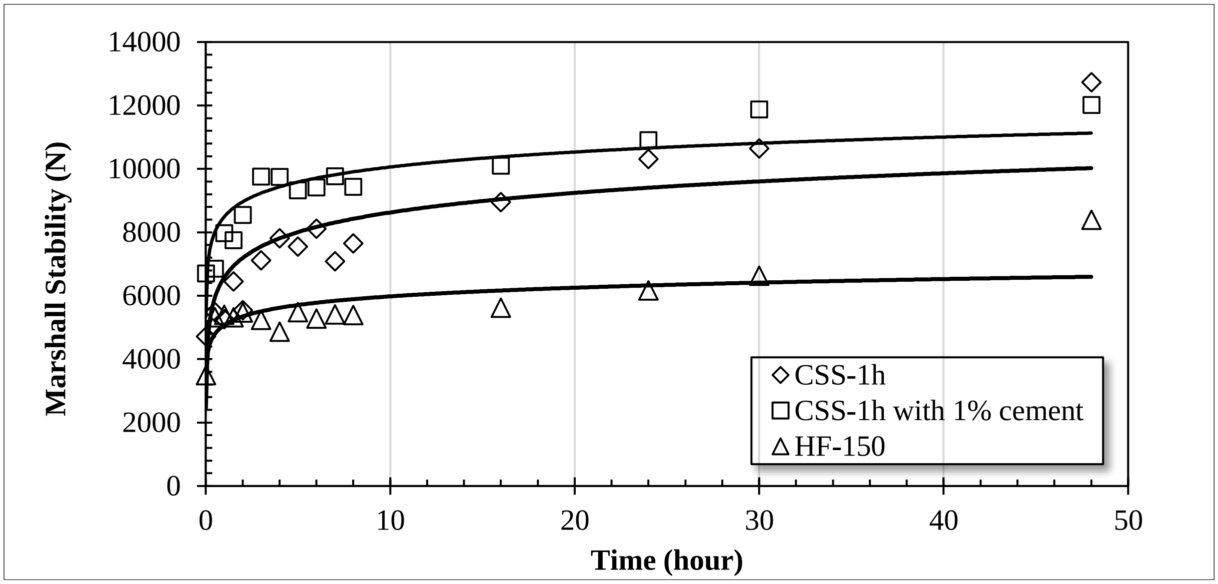


Figure 2. Cohesion Rate of Emulsion Systems Utilized in Ontario

This rapid curing binder system was an important measure at a time where the use of CIR on a high-volume roadway was unique and even more so for high volume to be combined with high truck traffic for a municipal arterial roadway vital to the northeastern GTHA.

3.2.3 CIR Equipment

An in-place recycling train was proposed consisting of:

- a milling machine to mill and reclaim the existing pavement providing the first stage of crushing the in-place HMA;
- a crushing unit to reduce the size of any oversize RAP;
- a mechanical paver integrated with a pugmill and spray bar to add emulsified asphalt; and
- a series of rollers to compact the mix to the required density.

3.3 Premium SMA and Heavy Duty Binder Course

The HMA lifts were chosen to combat rutting due to the high volume of truck traffic. Typically, when designing rut resistance mixes, engineers consider the impact of aggregate as being the most important factor. However, the asphalt cement is also a key factor to design the asphalt pavement properly to ensure post compaction consolidation does not occur. Therefore, for this project both the aggregate and asphalt cement were judiciously considered.

© Canadian Technical Asphalt Association 2017

The inherent consideration to improve rutting performance is to reduce the asphalt cement in the mix but MPL was careful not to follow this approach in an effort to ensure long-term performance of the mix through careful consideration of the AC type and optimization of the AC content. More recently in the pavement industry, this approach is currently known as the balanced mix design approach [5].

In addition to the material characteristics, it was also important to consider the total HMA structure as well as the individual HMA layers to ensure the traffic did not deform the pavement over time. This meant that both the base and surface HMA layers needed to be designed with rut prevention in mind. Building upon the successful application of a Heavy Duty Binder Course (HDBC) base layer, designed and constructed at several heavily trafficked intersections in Markham, Ontario, MPL proposed the use of a similar mix on Bloomington Road. The mix consisted predominantly of crushed aggregates and Performance Graded (PG) 70-28P, designed according to traffic category E with the exception of a small amount of natural sand.

The surface course also needed to account for the heavy truck traffic on Bloomington Road and therefore a SMA was proposed. Although SMA mixes were not extensively used in Ontario at that time, the technology was well developed in Europe and was the pinnacle mix to control rutting. SMA allowed York Region to employ a mix designed to combat rutting due to its stone-on-stone contact and long-term performance due to rich AC content. Initially, a 9.5 SMA mix was selected for Bloomington Road. However, finding an aggregate source in Ontario to meet the narrow gradation band shown in Figure 3 was challenging. Instead, for the first time in Canada, a single-sized 6.7 mm crushed aggregate from a meta-gabbro quarry with gradation shown in Figure 3 was designed to provide a high stability aggregate skeleton filled with rich polymer modified asphalt binder mastic. The PG 70-28P modified asphalt cement selected for this mix was engineered to maintain stone-to-stone skeleton under traffic and environmental loadings.

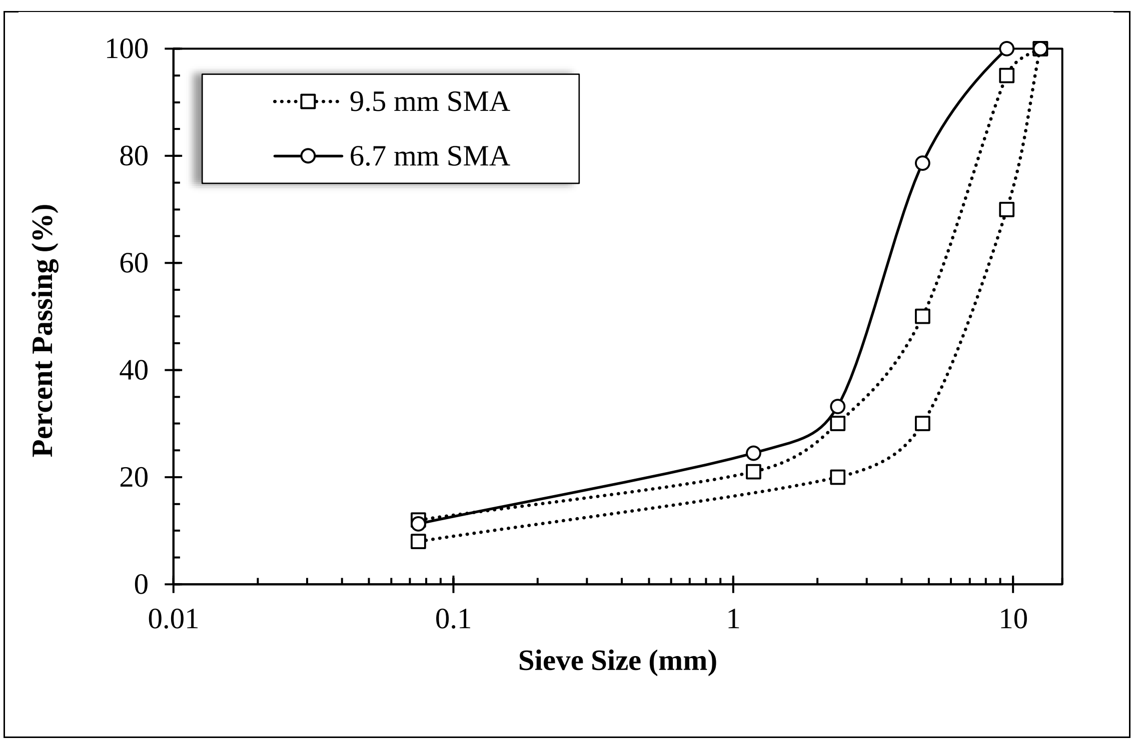


Figure 3. Comparison of Ontario 9.5 mm Stone Mastic Asphalt (SMA) with 6.7 mm SMA Used for Surfacing a Section of Bloomington Road

© Canadian Technical Asphalt Association 2017

The SMA mixture was selected as an alternative to the HL1 surface mixture prescribed in the tender. This change was made to provide a surface course that demonstrated a higher level of rutting resistance and improved fatigue endurance under heavy traffic compared to the HL1 dense graded surface course.

The 6.7 mm SMA was designed by using a Superpave Gyratory Compactor to achieve volumetric properties listed in Table 2. Stability of the mix was evaluated using a French rutting tester at 60°C for 3,000 cycles. As listed in Table 2, the final gradation of the SMA mixture met the 9.5 mm SMA gradation band, except for divergence at the 4.75 and 2.36 mm sieves. The Region accepted the submitted fine-graded SMA mix design.

The HDBC was designed by using crushed stone and a small amount of natural sand combined with a polymer modified PG 70-28P. Modified asphalt binder was used in lieu of unmodified PG 58-28 asphalt binder, which was commonly used at the time in Southern Ontario. Similar to SMA, stability of the HDBC was evaluated by using a French rutting tester with percent deformation listed in Table 3. Volumetric properties of the HDBC mix are also listed in Table 3.

4.0 CONSTRUCTION

4.1 CIR Mix Design

The mix design was developed according to the Ministry of Transportation of Ontario (MTO) Laboratory Testing Manual procedure for CIR with emulsified asphalt, LS-300 [6]. Table 4 shows the properties of the existing RAP, Table 5 shows components of the mix and their respective proportions, while Table 6 summarizes the physical properties of the mix selected.

Physical properties measured for this mix were higher than what was generally achieved with HF-150M, which provided additional assurance the mix would perform well in the field. Typically, CIR mats are covered with HMA within two or three weeks of placement, however, in the case of Bloomington Road, HMA paving did not commence until two months after installation. Prior to the placement of HMA, a field evaluation of the CIR mat indicated no pavement defects even after one of the hottest periods on record within the Region. This positive short-term performance provided a good indication of the mix's resilience to rutting early in its life.

4.2 CIR Construction

The work was constructed according to the contract documents and the agreed proposal. Since the existing pavement was wider than the milling machine used on the CIR train, a small milling machine was used to mill the shoulder and windrow the material in front of the CIR train so that it could be incorporated into the mix as shown in Figure 4(A). Illustration of the full CIR train utilized is shown in Figure 4(B), while Figure 4(C) depicts the completed CIR mat prior to HMA paving in the left lane and the train approaching on the existing, unprocessed pavement in the right lane.

© Canadian Technical Asphalt Association 2017

Table 2. Stone Mastic Asphalt Physical Properties

Property		OPSS Requirement SMA 9.5 mm	6.7 mm SMA
	Sieve Size (mm)		
Gradation (% Passing)	12.5	100	100.0
	9.5	70-95	100.0
	6.7	-	98.6
	4.75	30-50	78.6
	2.36	20-30	33.2
	1.18	-	24.5
	0.600	-	20.3
	0.300	-	17.5
	0.150	-	14.1
	0.075	8-12	11.3
Cellulose Fibres (%)		0.3	0.3
N_{des} (% G_{mm})		80	80
N_{ini} (% G_{mm})		≤ 89.0	85.5
N_{max} (% G_{mm})		≤ 98.0	97.6
Air Voids (%) at N_{des}		4 – 7	5.50
Voids in Mineral Aggregate, VMA (% minimum)		≥ 16.0	17.0
Asphalt Binder Performance Grade		-	PG 70-28P
Tensile Strength Ratio, TSR (%)		≥ 70	92.8
Asphalt Film Thickness (μm)		-	10.8
Asphalt Cement Content (%)		≥ 5.8	5.80
Rutting by French Rutting Tester at 60°C, 1,000 cycles (%)		-	4.50
Rutting by French Rutting Tester at 60°C, 3,000 cycles (%)		-	5.20

Note: SMA means Stone Mastic Asphalt, P means polymer modified asphalt binder, selected values are slightly larger than specified limits to promote finer gradation, colour tone, and texture as recommended to the Region. OPSS is Ontario Provincial Standard Specification, N_{des}, N_{ini}, N_{max} are number of gyrations at different compaction levels (design, initial, and maximum), and G_{mm} is theoretical maximum specific gravity.

© Canadian Technical Asphalt Association 2017

Table 3. Heavy Duty Binder Course Mix Physical Properties

Property		OPSS Requirement	HDBC
	Sieve Size (mm)		
Gradation (% Passing)	25.0	100	100.0
	19.0	94 – 100	95.0
	16.0	77 – 95	80.0
	13.2	65 – 90	70.0
	9.5	48 – 78	68.0
	6.7	-	59.0
	4.75	35 – 52	47.0
	2.36	21 – 54	41.0
	1.18	12 – 49	30.0
	0.600	6 – 38	21.0
	0.300	3 – 22	9.0
	0.150	1 – 9	4.0
	0.075	0 – 6	3.0
N_{des} (% G_{mm})		100	100
N_{ini} (% G_{mm})		≤ 89.0	89.0
N_{max} (% G_{mm})		≤ 98.0	96.4
Air Voids (%) at N_{des}		3.5 – 4.5	4.5
Voids in Mineral Aggregate, VMA (% minimum)		13.5	15.6
Asphalt Binder Performance Grade		-	PG 70-28P
Asphalt Film Thickness (µm)		-	9.3
Asphalt Cement Content (%)		≥ 4.9	4.90
Rutting by French Rut Tester at 60°C, 30,000 cycles (%)		-	4.10

Note: HDBC mean Heavy Duty Binder Course, P means polymer modified asphalt binder, selected values are slightly larger than specified limits to promote finer gradation, colour tone, and texture as recommended to the Region. OPSS is Ontario Provincial Standard Specification, N_{des}, N_{ini}, N_{max} are number of gyrations at different compaction levels (design, initial, and maximum), and G_{mm} is theoretical maximum specific gravity. OPSS requirement for 4.75 mm sieve is by volume.

© Canadian Technical Asphalt Association 2017

Table 4. Properties of Existing Reclaimed Asphalt Pavement (RAP)

Property	Result
Asphalt Binder content (%)	5.37
Recovered penetration (dmm)	23
Aggregate passing 4.75 mm sieve[1] (%)	63.4
Aggregate passing 75um sieve[1] (%)	7.3

Note: [1]gradation after the Asphalt Cement was extracted from the Reclaimed Asphalt Pavement.

Table 5. Cold-In Place Recycling Mix Summary

Material	Mix Percentage (%)
Reclaimed Asphalt Pavement	97.8
Portland Cement	0.5
CSS-1	1.7
Added Water	2.8
Total	102.8

Note: CSS-1 is Cationic Slow Setting Asphalt Emulsion

Table 6. Physical Properties of Cold-In Place Recycled Material

Physical Property	Result
Total Residual Asphalt in Mix (%)	6.32
Dry Stability at 22°C (N)	30,350
Dry Flow Index (0.25mm)	13.2
Wet Stability at 22°C (N)	23,000
Wet Flow Index (0.25mm)	16.8
Retained Stability (%)	75.8
Bulk Relative Density, BRD (tonne/m^3)	2.275
Maximum Relative Density, MRD (tonne/m^3)	2.556
Air Voids (%)	11.0

© Canadian Technical Asphalt Association 2017

Figure 4. (A) A Section Milled by Small Milling Machine and Resultant Windrow, (B) Illustration of Cold-In Place Recycling Train, and (C) Completed CIR mat prior to Hot Mix Asphalt Paving

4.3 HMA Construction

The HMA was constructed with conventional placement and paving equipment with the addition of a shuttle buggy. The construction equipment and typical surface of the 6.7 mm SMA mix is illustrated in Figure 5. The initial texture of the SMA surface appears open in nature and rich due to the relatively high binder content, which is common for these mixes. The stone-on-stone contact is evident due to the coarser aggregate fraction being more predominant in the mix.

© Canadian Technical Asphalt Association 2017

Figure 5. (A) Equipment Used in Construction of Stone Mastic Asphalt, (B) Completed SMA Surface, and (C) Finished SMA Texture

4.4 Quality of the CIR Mix

CIR mat quality was maintained from the time of placement until HMA overlay was applied. There were no signs of any distress despite the high summer temperatures and extended traffic exposure time. The Quality Assurance (QA) test results indicate 120 compaction measurements were taken after the placement of CIR, as summarized in Table 7.

Table 7. Summary of Quality Assurance Compaction Results

Property	Result
Average Dry Density (tonne/m^3)	2.137
Target Density (tonne/m^3)	2.172
Average Compaction (%)	98.4
Minimum Compaction (%)	97.0
Maximum Compaction (%)	100.4
Standard Deviation (%)	0.572

© Canadian Technical Asphalt Association 2017

The Quality Control (QC) records indicate that the average moisture measured for the project was 1.8 percent with a maximum value of 2.2 percent according to MTO Laboratory Testing Procedure LS-291 [7]. These results adhered to the project requirements, stipulating a maximum mean of 2.0 percent per lot with no individual result exceeding 2.5 percent. Achieving this moisture specification is often difficult when wet weather is experienced. Hot and dry weather throughout the construction of Bloomington Road enabled MPL to meet the contract moisture specification.

5.0 FOUR-YEAR PERFORMANCE REVIEW

As part of routine monitoring of pavement innovations constructed by MPL, a condition assessment of the pavement surface, coring, and analysis was conducted in 2009.

5.1 Pavement Condition Survey

The pavement condition was conducted according to the Manual for Condition Rating of Flexible Pavements, SP-024 [8]. The survey indicated an excellent Pavement Condition Rating (PCR) of 95 and Ride Condition Rating (RCR) was assessed to be 9.5. From a visual perspective, there was no evidence of cracking within the traveled lanes, no coarse aggregate loss or raveling, no rippling or shoving, no distortion, and no rutting as exhibited in Figure 6.

5.2 Coring and Laboratory Analysis

Extraction of the CIR layer was performed using a six-inch drill bit to determine the physical properties of the recycled layer after four-years of service. All cores were extracted fully intact with each lift of bituminous pavement bonded together demonstrating a monolithic structure. The cores were delivered to the MPL Materials Research Laboratory, cut to proper length, and tested according to the MTO Laboratory Testing Manual procedure LS-300 [6]. Table 8 summarizes the results of the testing.

Figure 6. Typical Four-Year Condition of Bloomington Road

© Canadian Technical Asphalt Association 2017

Table 8. Summary of CIR Core Results after Four-Years of Performance

Parameter	McCowan Road to Highway 48		Kennedy Road to McCowan Road		Job Mix Formula Results	
	Dry	Wet	Dry	Wet	Dry	Wet
BRD (tonne/m^3)	2.222		2.234		2.275	
Average Stability (N)	35,733	29,933	39,300	32,067	30,350	23,000
Retained Stability (%)	83.4		81.6		75.8	
Flow (0.25mm)	30.7	30.0	33.5	28.0	13.2	16.8

The results indicate that the BRD is slightly less than the mix design for both locations while the stability, retained stability, and flow all exceed the mix design JMF. The recommended minimum stability for an emulsion mix is 2,224 N at 22°C [9]. It is evident that both the coring locations indicate far higher strengths than the minimum suggested which is suspected to be due to the rapid curing binder system utilized and the presence of slag aggregate. Typical dry stabilities of emulsion mixes achieved in Ontario lie in the 10,000-15,000 N range with nominal retained stabilities exceeding 70 percent. As a result of the increased stability, one is led to expect an excellent resistance to rutting. The flow however is much higher than the design value, which would indicate a susceptibility to post construction consolidation as typical maximum flow values for recycled mixes are in the vicinity of 20 (at 0.25 mm). However, the performance of the roadway at the time did not raise any additional concerns.

6.0 12-YEAR PERFORMANCE REVIEW

Similarly to the four year review, a 12-year performance review was conducted which consisted of a visual pavement evaluation, coring of the pavement layers, and testing of the extracted materials.

6.1 Pavement Evaluation

To identify pavement maintenance and rehabilitation needs, particularly preventive maintenance needs, York Region conducts pavement condition surveys on all Regional roads using automated survey vehicles as shown in Figure 7.

Figure 7. Vehicle Used to Collect Pavement Performance Data for York Region

© Canadian Technical Asphalt Association 2017

Collected data includes International Roughness Index (IRI), rut depth, pavement surface distresses, and high definition digital images of the right-of-way. Collected data are incorporated into York Region's Pavement Management System (PMS) to assess pavement condition as a Pavement Condition Index (PCI) ranging from zero to 100 corresponding to those conditions listed in Table 9.

Table 9. York Region's Pavement Condition Index Ratings

Condition Category	PCI	
	Upper Limit	Lower Limit
Very Good	100	90
Good	89	80
Fair	79	60
Poor	59	50
Very Poor	49	0

Note: PCI means Pavement Condition Index.

Based on the 2016 pavement survey data collection, the PCI for both road sections (Kennedy Road to McCowan Road and McCowan Road to Highway 48) are rated in Good condition. The observed pavement survey data indicated few low to moderate severity levels of longitudinal, transverse, and edge cracks and low severity levels of rutting as depicted in Figure 8. The results indicate the pavement treatment has been very effective as the roads are in good condition after 12-years of service.

Figure 8. Condition of Bloomington Road in April 2017

6.2 Pavement Coring and Laboratory Analysis

6.2.1 Overview

Coring was performed in March 2017 to evaluate the road performance after 12-years of service. A total of 20 cores were taken from the outer wheel path in the east and west directions. Cores were received at the

© Canadian Technical Asphalt Association 2017

McAsphalt Industries Research Laboratory, visually inspected, and then cut and separated into SMA, HDBC, and CIR layers prior to extraction and binder recovery.

All cores were extracted from the pavement intact and all layers were well-bound. An example is shown in Figure 9. Asphalt layers were extracted with Trichloroethylene solvent and asphalt cement was recovered using the Abson recovery method. Extraction and recovery were performed in accordance with LS-282 and LS-284, respectively [10, 11].

Figure 9. (A) Coring Operation for a 12-year Old Section of Bloomington Road (Highway 40) in Ontario, Located Between Kennedy Road and Highway 48, and (B) A Well-bound Core Extracted From Bloomington Road

6.2.2 Recovered Binder Analysis

Field-aged recovered binders were performance graded in accordance with AASHTO M320 [12]. As listed in Table 10, all binders recovered from the SMA surface course and HDBC binder met the required high and low PG temperatures after 12-years of service.

Furthermore, AASHTO M332 [13] was used to grade field-aged recovered binders at a 7-day max pavement temperature of 58°C using the Multiple Stress Creep Recovery (MSCR) test as listed in Table 10. The non-recoverable creep compliance (Jnr) values measured at the 3.2 kPa stress level indicate that recovered binders meet the requirements of the extreme high traffic level, grade "E", meaning the binder is still suitable for a traffic level greater than 30 million Equivalent Standard Axle Loads (ESAL) and standing traffic with speed slower than 20 km/hr.

Also, the average MSCR Recovery was in the low 60 percent range for both recovered asphalts, meeting the MSCR criteria for an elastic binder. This is an important observation and it proves that modified asphalts retain their elastic behaviour many years into their service life. Even after 12-years of field-aging the PG 70-28P shows a robust and functional Styrene Butadiene Styrene (SBS) polymer network capable of meeting the most stringent elastic recovery criteria.

© Canadian Technical Asphalt Association 2017

Table 10. Properties of Recovered Binder After 12-years of Field-Aging

Property	AASHTO Test Method	HDBC		SMA	
		Eastbound	Westbound	Eastbound	Westbound
$J_{nr3.2}$ (kPa^{-1}) at 58°C	T 350	0.134	0.343	0.072	0.098
Average $R_{3.2}$ (%) at 58°C		72.87	49.09	63.68	60.16
Continuous PG Grade	M 320	74.1-41.1	71.3-35.3	82.9-30.4	81.1-31.7

Note: Jnr3.2 is non-recoverable creep compliance (Jnr) values measured at 3.2 kPa stress level, R3.2 is the Average Percent Recovery measured at 3.2 kPa stress level, SMA is Stone Mastic Asphalt, and HDBC is Heavy Duty Binder Course.

A Fourier Transform Infrared Spectroscopy (FTIR) analysis was conducted on the recovered binder to: (1) ensure that the solvent has been completely removed during the recovery, (2) evaluate the amount of polymer still present in the recovered binders, and (3) quantify the degree of aging of the recovered PG binder. Figure 10 shows an example of FTIR spectrum showing the absorbance peaks specific to carbonyl (1698 cm^{-1}), poly-styrene block (699 cm^{-1}), poly-butadiene block (966 cm^{-1}) and the reference peaks specific to the methyl groups (1455 and 1376 cm^{-1}).

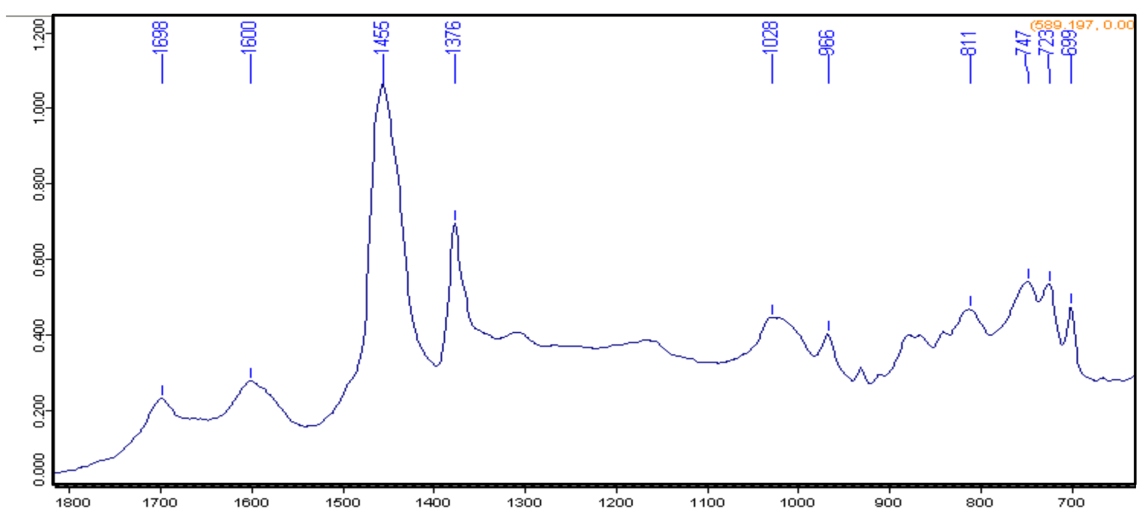


Figure 10. FTIR Spectrum of Modified Binder Recovered from SMA Surface Layer After 12-Years

Trichloroethylene (TCE) has two specific FTIR absorbance peaks at 928 and 836 cm-1. These peaks are not present in any types of asphalt cements and therefore, they are routinely used for verification of complete solvent removal for recovered asphalts from samples extracted using TCE [14]. All samples extracted and recovered from the Bloomington Road pavement sections were tested by FTIR and the complete TCE removal was verified prior to any subsequent testing.

© Canadian Technical Asphalt Association 2017

To quantify the amount of polymer present in the binder, Equations 1 and 2 were used to determine FTIR indices on recovered binders by integrating the area under the absorbance peaks specific for the polystyrene and polybutadiene segments, and then normalizing to the area under the methyl (CH_3). The Carbonyl Index (I_C) is defined by Equation 3.

$$I_S = \frac{\sum A_{685-710}}{\sum A_{1325-1500}} \quad (1)$$

$$I_B = \frac{\sum A_{950-980}}{\sum A_{1325-1500}} \quad (2)$$

$$I_C = \frac{\sum A_{1650-1750}}{\sum A_{1325-1500}} \quad (3)$$

Where: I_S is the styrene index;
I_B is the butadiene index;
I_C is the carbonyl index;
$A_{685-710}$ is the area under the styrene-specific absorbance peak (685 to 710 cm^{-1});
$A_{950-980}$ is the area under the butadiene-specific absorbance (950 to 980 cm^{-1});
$A_{1325-1500}$ is the area under the methyl deformation peaks (1325 to 1500 cm^{-1}); and
$A_{1650-1750}$ is the area under the carbonyl absorbance (1650-1750 cm^{-1}).

As listed in Table 11, these indices were then compared to an unaged tank sample with the same grade and quantity of polymer, as well as a PAV residue of the similar PG sample.

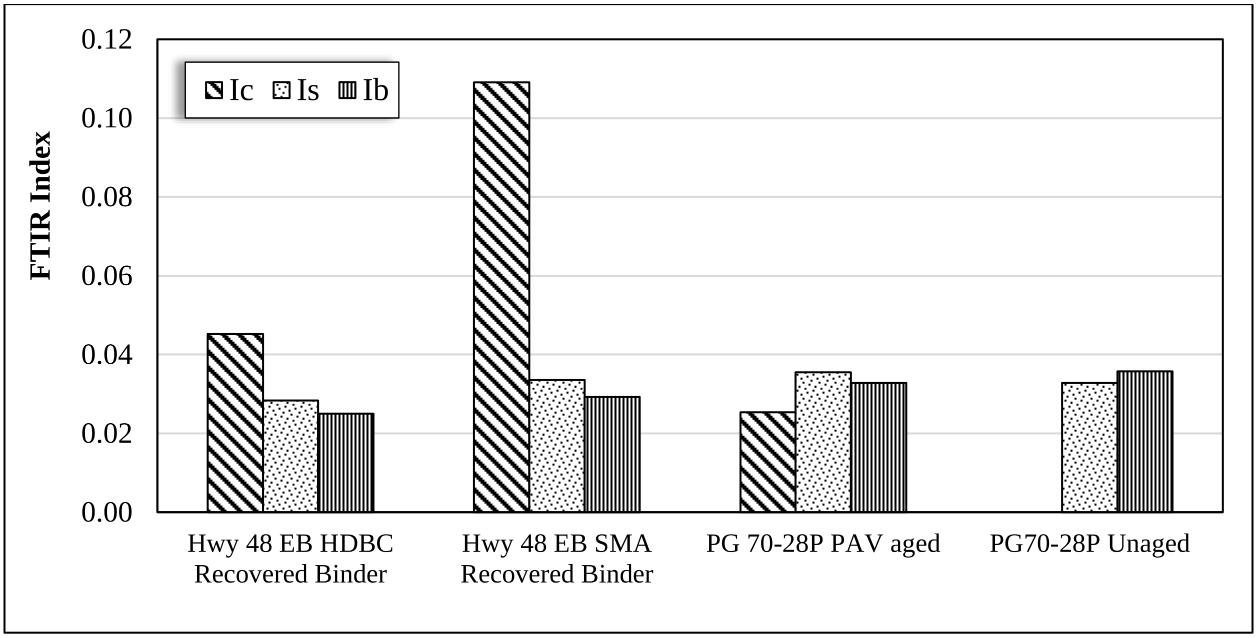
Table 11. FTIR Indices for Recovered Binders from Bloomington Road and Laboratory Aged

Sample	PG 70-28P Recovered SMA	PG 70-28P Recovered HDBC	PG 70-28P PAV Aged	PG 70-28P Unaged
Styrene Index (I_S)	0.033	0.028	0.035	0.042
Butadiene Index (I_B)	0.029	0.025	0.033	0.042
Carbonyl Index (Ic)	0.109	0.045	0.025	0

Note: PG is Performance Grade, SMA is Stone Mastic Asphalt, HDBC is Heavy Duty Binder Course, PAV is Pressure Aging Vessel, and P means Polymer.

Butadiene and styrene segment indices listed in Table 11 and shown in Figure 11 indicate that field-aged binders recovered from SMA and HDBC retain approximately the same amount of SBS modifier as a PAV residue of the modified binder. Both PAV and field aging show a more pronounced drop in the butadiene segment compared to the styrene, as butadiene is the molecular species more susceptible to oxidation. The lower level of polymer presence in the HDBC recovered binder exists due to the dilution of the Polymer Modified Asphalt (PMA) with the RAP fraction binder.

© Canadian Technical Asphalt Association 2017



Note: I_C is Carbonyl Index, I_S is Styrene Index, I_B is Butadiene Index, EB is Eastbound, HDBC is Heavy Duty Binder Course, SMA is Stone Mastic Asphalt, PG is Performance Grade, P means Polymer, and PAV is Pressure Aging Vessel.

Figure 11. FTIR Indices for Recovered Binders from Bloomington Road and Laboratory Aged

By contrast, the Carbonyl Index (I_C) shows that the field-aged binders have oxidized more than the laboratory sample after one PAV cycle, with the SMA binder being more aged than the HDBC. This is expected, as the SMA is subjected to UV exposure and to higher diffusion from the atmospheric oxygen. However, the field and the PAV aging mechanisms must be somewhat different, as the higher I_C of the field-aged samples do not correlate well with the SBS degradation rates or with the rheological properties measured. The PG and MSCR results of the field-aged samples are noticeably better than expected after an aging period that is more severe than a PAV cycle. Our belief is that the better than expected properties of the field aged asphalts could be related to the high Asphalt Film Thickness and VMA values for the SMA and HDBC mixes, as can be observed in Tables 2 and Table 3, respectively.

6.2.3 Mix Analysis

The CIR, HDBC, and 6.7 mm SMA layers were separated for individual mix analysis and the results of which are presented in Table 12.

Notwithstanding the inter-laboratory variability between the MPL Materials Research Laboratory and the McAsphalt Industries Research Centre, the average BRD of the CIR material has increased since the 2009 laboratory analysis for both the east and west samples. Note the samples for the four-year review and 12-year review were taken at the same location. The increase in density suggests that the CIR has continued to densify over time, which would normally translate to an increase in stability. However, this anticipated increase in stability was not measured by the McAsphalt laboratory. Similarly to the four-year review, the 12-year review cores revealed an increase in flow and retained stability to approximately the same magnitude compared to the mix design JMF values. These results reveal that the CIR material continues to maintain strength over the review period.

© Canadian Technical Asphalt Association 2017

Table 12. Mix Analysis of Cold In-Place Recycled Material, Heavy Duty Binder Course, and Stone Mastic Asphalt

Property	CIR JMF	CIR W	CIR E	HDBC JMF	HDBC E	HDBC W	SMA JMF	SMA E	SMA W
MRD (kg/cm^3)	2.556	2.690	2.640	-	2.501	2.532	2.848	2.614	2.628
Average BRD (kg/cm^3)	2.275	2.325	2.320	-	2.455	2.378	2.504	2.441	2.475
Compaction (%)	-				98.1	93.9	-	93.6	94.2
Tensile Strength Ratio (TSR) (%)	-				94.5	90.1	92.8	88.4	89.5
Dry Marshall Stability (N)	30,350	27,899	31,878	-					
Dry Marshall Flow (0.25mm)	13.2	25.7	26.0	-					
Wet Marshall Stability (N)	23,000	24,909	27,282	-					
Wet Marshall Flow (0.25mm)	16.8	31.0	30.3	-					
Retained Stability (%)	75.8	89.3	85.6	-					
Sieve Size(mm)	**Extracted Average Gradation (% Passing)**								
19.0	100.0	100.0	100.0	95.0	98.5	100.0	100.0	100.0	100.0
16.0	99.6	100.0	100.0	80.0	89.3	93.5	100.0	100.0	100.0
13.2	96.8	98.1	99.0	70.0	83.2	86.8	100.0	100.0	100.0
9.50	86.8	91.5	92.1	59.0	70.8	73.1	100.0	100.0	100.0
4.75	63.4	67.1	67.1	47.0	53.2	55.6	78.0	88.2	85.1
1.18	38.0	34.4	41.7	30.0	32.1	33.8	-	24.0	24.2
0.075	7.3	8.3	7.2	3.0	3.9	2.3	11.0	9.7	9.7
Asphalt Cement Content (%)	5.37	5.54	5.44	4.90	4.78	4.90	5.80	5.62	5.31
Recovered Penetration (dmm)	23	16	15	-	54	45	-	48	52

Note: JMF is Job Mix Formula, CIR is cold in place recycled material, HDBC is heavy duty binder course, SMA is stone mastic asphalt, and the recovered penetration of the CIR-Job Mix Formula was from the original HMA prior to CIR construction.

As listed in Table 12, the SMA and HDBC field cores resistance to moisture damage was evaluated as the percentage of indirect tensile strength retained after conditioning as per AASHTO T 283 [15] procedure. The TSR values obtained on both hot mixes indicate that, on average, these mixes still maintain a high level of moisture resistance even after 12-years of service. Such a good level of resistance to moisture damage could be a result of higher film thickness and presence of active polymer in the system as explained previously.

© Canadian Technical Asphalt Association 2017

Higher film thickness was noticeable in the field, as the SMA still maintained a rich appearance as shown in Figure 12A with the aggregate well-coated even after 12-years compared to a picture of an adjacent Dense Graded Friction Course (DGFC) mix placed two-years previously (Figure 12B). The difference in coating and the aggregate size is evident by comparing the SMA and DGFC mixes.

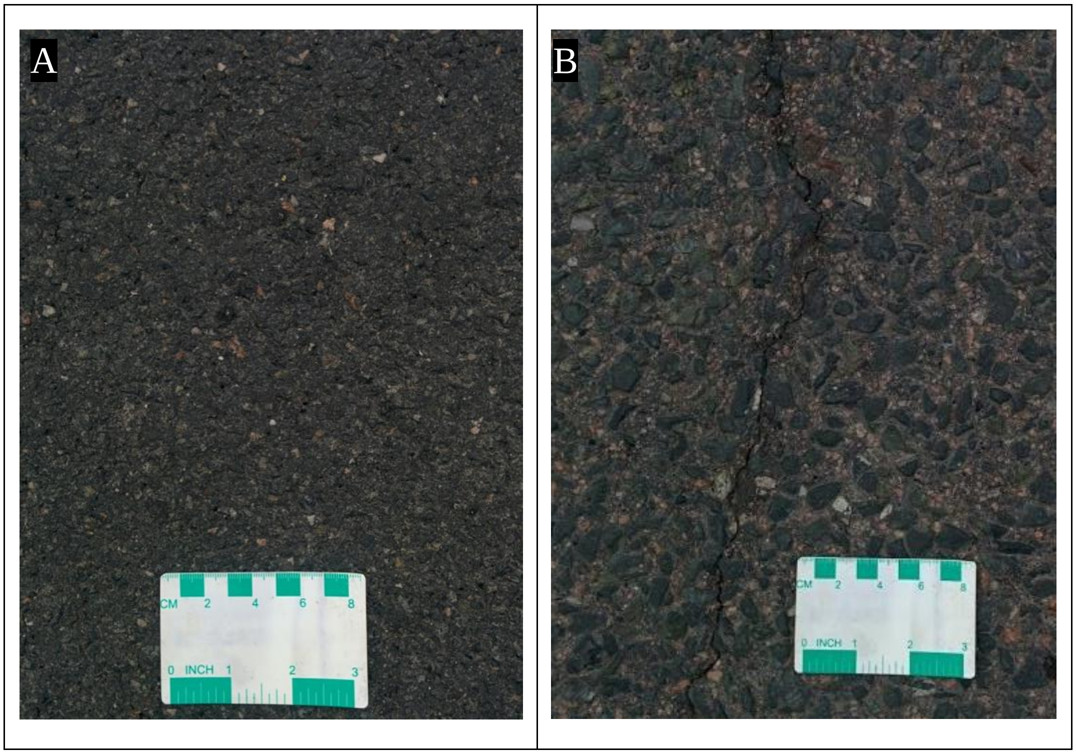


Figure 12. (A) Rich Appearance of 6.7 mm SMA with the Aggregate Well Coated After 12-Years of Service and (B) Lean Appearance of DGFC Adjacent Pavement on Bloomington Road

7.0 FUTURE CONSIDERATIONS FOR MAINTENANCE

The Bloomington Road remains in good condition after 12-years of service, despite ongoing high volume of traffic. During the manual performance assessment, we observed isolated areas of shoulder pavement deterioration as shown in Figure 13.

The observed shoulder deterioration is due to heavy traffic by agricultural equipment from neighbouring farms and tractor trailers utilizing entrances along the length of the roadway. The strength of the shoulder directly impacts the long-term performance of the pavement edge and additional shoulder gravel may be required to increase shoulder elevation to ultimately offer additional support.

York Region has filled some of the cracks on Bloomington Road, including sealing of the centreline joint in 2009. Additional cracks have since surfaced that are very slight to slight in severity but will deteriorate further with weather and traffic. In order to preserve the asset, a preservation technique such as micro surfacing or chip seal would seal the minor cracks, prevent further oxidation, and prolong the pavement life. These preservation treatments have been successfully used in York Region for many years.

© Canadian Technical Asphalt Association 2017

Figure 13. Typical Shoulder Condition of Bloomington Road

8.0 COMPARISON TO OTHER YORK REGION ROADS

The section of Bloomington Road currently under study was compared to an adjacent section between Warden Avenue to Kennedy Road (Figure 14), with similar traffic volume and truck percentages. Stretching approximately two-kilometres, this road section was rehabilitated in 2003 by constructing 40 mm of DGFC and 50 mm of HDBC underlain by 100 mm of CIR.

Figure 14. Comparison of the study section to an adjacent section that exhibited more distresses for nearly the same service life.

© Canadian Technical Asphalt Association 2017

The 2016 condition assessment results indicated poor road condition for this section, with moderate to high transverse cracking severity levels, low to moderate longitudinal, alligator, and edge cracking and rutting. Indeed, the Warden Avenue to Kennedy Road section has more observed pavement distresses with higher severity levels than the 6.7 mm SMA section, as depicted in Figure 14. It is specifically noted that the SMA section possesses higher rutting resistance than the adjacent section. Therefore, one may conclude that the adjacent treatment is not as effective as the treatment in this study despite the two years difference in lifespan.

9.0 CONCLUSION

This paper summarizes an innovative approach made to a York Region contract on Bloomington Road in 2005 whereby a contractor proposal of CIR, HDBC, and a 6.7 mm SMA was implemented. At periods of four and 12-years, pavement evaluations, coring, and laboratory analysis on the extracted materials were performed to determine the attributes of the pavement layers in service.

Our analysis indicates that the pavement is performing very well considering traffic levels on the roadway. Low severity distresses are evident, however, in a low density along the four-kilometre section. The mix attributes measured at both the four and 12-year review confirm the high level of performance with measures consistent, and often exceeding, the mix design properties.

Overall, we believe the high performance shown and especially the very low level of cracking seen on this road section are directly related to the innovative pavement design selection of rapid curing CIR, HDBC, and 6.7 mm SMA. The performance enhancement is observed by comparing the innovative pavement section to the adjacent conventional pavement design utilizing HDFC, which exhibits both higher severity and higher density of distresses. Through comparison of these two adjacent pavement sections, the difference in aggregate size, mastic quality, and overall HMA appearance is dramatic. The innovative pavement design including a 6.7 mm SMA as observed at the surface is clearly performing better.

The use of CSS-1 with cement allowed the CIR to remain exposed to traffic and weather for several weeks during one of the hottest summers on record with no signs of distress. The PMA used for both the surface and binder HMA courses, combined with the high VMA, and high theoretical asphalt film thickness vastly contributed to the overwhelming success and performance of the pavement section as predicted, in part, by the French rutting test conducted during the mix design stage.

Given the high level of performance of the CIR, HDBC, and 6.7 mm SMA pavement over 12-years, the innovative asphalt treatment has proven to be a cost-effective solution to road rehabilitation challenges faced by municipalities across the GTHA. Similar to all flexible pavements, preservation should be considered to ensure the value of investment is maintained and to prolong pavement life.

REFERENCES

[1] Millis T, Uzarowski L. "2003 Road Resurfacing Program – Various Roadway Sections" Report No. John Emery Geotechnical Engineers Limited (JEGEL) 102219, Regional Municipality of York, Newmarket, Ontario (2003).

© Canadian Technical Asphalt Association 2017

[2] Ontario Provincial Standard Specifications. "Material Specifications for Aggregates – Base, Subbase, Select Subgrade, and Backfill Material" Report No. OPSS.MUNI 1010, Ontario Provincial Standard Specification, Newmarket, Ontario (2013).

[3] Regional Municipality of York. "Foam Stabilization and Asphalt Paving" Contract No. T-04-11, Regional Municipality of York, Newmarket, Ontario (2004).

[4] Croteau JM, Hanasoge N. "Road Rehabilitation of York Region Road 40 (Bloomington Rd.) Using a 6.7mm SMA and Other Innovative Hot and Cold Mix Products" Canadian Asphalt Technical Association, 51, 387-406 (2006).

[5] Cambridge Systematics Inc. "Guide to Incorporating Reliability Performance Measures into the Transportation Planning and Programming Processes", SHRP 2 Report No. S2-L05-RR-2, Strategic Highway Research Program (SHRP), Transportation Research Board, National Research Council, National Academies, Washington, D.C. (2014).

[6] Ministry of Transportation (MTO) LS-300. "Method of Test for Preparation of Marshall Specimens for Cold In-Place Recycled Mixtures", Ministry of Transportation, Toronto, Ontario (2015).

[7] Ministry of Transportation (MTO) LS-291. "Method of Test for Quantitative Extraction of Asphalt Cement and Mechanical Analysis of Extracted Aggregate from Bituminous Paving Mixtures", Ministry of Transportation, Toronto, Ontario (1999).

[8] Ministry of Transportation (MTO) SP-024. "Manual for Condition Rating of Flexible Pavements - Distress Manifestations", Ministry of Transportation, Toronto, Ontario (2015).

[9] Asphalt Institute (AI). A Basic Asphalt Emulsion Manual, Series No. 19, Second Edition (1979).

[10] Ministry of Transportation of Ontario (MTO) LS-282. "Quantitative Extraction of Asphalt Cement and Analysis of Extracted Aggregate from Bituminous Paving Mixtures", Ministry of Transportation of Ontario Provincial Standard Specification, Toronto, Ontario (2012).

[11] Ministry of Transportation of Ontario (MTO) LS-284. "Recovery of Asphalt from Solution by Abson Method or Rotavapor", Ministry of Transportation of Ontario Provincial Standard Specification, Toronto, Ontario (2012).

[12] American Association of State and Highway Transportation Officials (AASHTO) M320. "Standard Specification for Performance-Graded Asphalt Binder". Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 1B. Washington, D.C. (2010).

[13] American Association of State and Highway Transportation Officials (AASHTO) M332. "Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test". Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 1B. Washington, D.C. (2014).

[14] Arnold T, Shastry A, Needham S "Use of FTIR in Extraction/Recovery of Asphalt Binders", Petersen Asphalt Conference and P3 Symposium, Laramie, Wyoming (2010).

© Canadian Technical Asphalt Association 2017

[15] American Association of State Highway and Transportation Officials (AASHTO) T283. "Standard Method of Test for Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage", Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2B, Washington, D.C. (2011).

© Canadian Technical Asphalt Association 2017