Fine-graded Stone Mastic Asphalt – Pavement Rehabilitation of Bloomington Road (York Region Road 40)

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ABSTRACT

Bloomington Road is a two-lane roadway that carries more than 10,000 AADT with approximately 10 % heavy commercial vehicle mostly hauling aggregate to the Greater Toronto Area. Prior to rehabilitation, the pavement was severely oxidized and thermal cracking was extensive. The pavement design included an in-place recycling technique to mitigate reflective cracking and 100 mm of new surfacing HMA. The partial depth recycling process was selected using a rapid curing recycling system to accelerate the build up of cohesion of the recycled material. A heavy duty dense graded HMA was selected as a binder course, while a fine-graded SMA was selected as a thin surfacing course. Both HMA mixes were tested for rutting using a European rut testing device to ensure rut resistance performance. Both mixes were produced using polymer-modified bitumen to mitigate both thermal cracking and permanent deformation.

The current concept of Stone Mastic Asphalt (SMA) or "Splittmasticasphalt" was developed in Germany in the mid-sixties and introduced in Canada in 1991. Stone Mastic Asphalt is a gap graded bituminous mixture with a high content of chippings which constitute an interlocking mineral skeleton to resist permanent deformation. The space within the chippings skeleton is filled to a large extent by a mortar rich in bitumen-filler mastic to provide durability. Fine-graded SMAs is a specific category of SMA produced using single-size chippings no greater than 6.7 mm. The resulting mixture provides an aggressive but fine macro-texture conducive to surface drainage and good frictional properties. The rolling noise reduction has been reported to be as much as 3dB(A) compared to dense graded surfacing mixes.

This paper presents the Bloomington Rd. project including details related to the roadway characteristics, the pavement design, the material and process selection and the field construction. Finally, the paper provides performance information of the various techniques with an emphasis on the surface characteristics of fine-graded SMA, including skid resistance and noise reduction.

1.0 THE BLOOMINGTON ROAD REHABILITATION PROJECT

Bloomington Road is a two-lane rural roadway located in the heart of York Region. Bloomington Road is a major York Region arterial road that runs between the York-Durham region boundary line and Bathurst Street. The existing roadway was built to its present standard in 1969.

The 2005 rehabilitation project was located between Hwy 48 and Kennedy Road. The length of the project was the equivalent of two concessions, which equates to approximately 4.0 km. The total roadway surface area to be rehabilitated was 30,000 m^2. The rehabilitation project did not include the roadway area at the intersection of Bloomington Road and McCowan Road located in the middle of the stretch of roadway between Hwy 48 and Kennedy Road. This section of Bloomington Road carries more than 10,000 AADT with approximately 10 % heavy commercial vehicle mostly hauling aggregate to the Greater Toronto Area. The volume of traffic is not only high but it is also considered very aggressive.

Prior to the 2005 roadway rehabilitation, the bituminous surface was severely oxidized and thermal cracking was extensive (Photo 1). Yet, the longitudinal & transverse profiles of the roadway were still in relatively good condition and there was no sign of major structural failures. The geotechnical consultant recommendation for the rehabilitation of the roadway included an in-place partial depth recycling technique to mitigate reflective cracking and 100 mm of new surfacing HMA.

Photo 1 – Roadway condition prior to rehabilitation

The Region elected to select roadway rehabilitation techniques that were compatible with the recommended rehabilitation strategy proposed by the consultant, but could also provide additional safe guards to the Region with respect to constructability and long term performance. The recommended in-place cold recycling process was replaced with a rapid curing partial depth cold recycling process to accelerate the build up of cohesion of the recycled material. The traditional binder course HMA was replaced with a heavy duty dense graded HMA specifically design to resist rutting. Finally, the recommended dense graded HMA surfacing was replaced with an SMA for durability and rut resistance reasons. Both HMA mixes were tested for rutting using a European rut testing device to ensure rut resistance performance and both mixes were produced using polymer-modified bitumen to mitigate thermal cracking and permanent deformation.

This paper presents the Bloomington Rd. project including details related to the engineering of the material selected to comply with the geotechnical consultant roadway structural design recommendation. Performance information of the various techniques is provided with additional details on the surface characteristics of fine-graded SMA, including skid resistance, surface drainage and noise reduction.

2.0 RAPID CURING PARTIAL DEPTH COLD RECYCLING PROCESS

The process of in-place cold recycling of bituminous roadway is well established in Canada. Many Canadian road agencies including York Region use in-place recycling as a standard pavement rehabilitation method. The main technical benefits of in-place recycling relates to the ability of the recycled layer to mitigate reflective cracking, which implicitly provides added life to roadways rehabilitated using this approach.

The roadway evaluation of Bloomington Road quickly led to the selection of the partial depth in-place recycling process. The existing surfacing HMA was severely cracked and oxidized, yet the roadway was not significantly deformed nor was there any sign of major structural weaknesses. Thus, the primary objective of the treatment was to mitigate reflective cracking. The other factor that influenced the selection of the partial depth process vs. the full depth process was the constructability challenges associated with the rehabilitation of Bloomington Road. The one-stage partial depth process was conducive to minimize the potential traffic disruption.

2.1 Engineering of recycled materials

The long term performance of any roadway materials is related to its mechanical properties such as: stiffness, fatigue resistance, reflective cracking mitigation, durability, rutting resistance and thermal cracking mitigation. Whereas constructability performance of recycling work is associated with the: workability, minimization of raveling, ease of compaction, increase smoothness, absence of post compaction and rapidity of the recycled material to build-up of cohesion.

The engineering of recycled material is a rational process by which optimal solutions are selected to maximize the performance of the recycling work. The engineering work for the recycling work on Bloomington Road was carried out in three stages including a detailed analysis of the bituminous aggregate, the selection of the recycling system and the laboratory work. Site specific considerations such as the expected weather during the work and the traffic characteristics were also taken into account.

2.1.1 Bituminous aggregate analysis

Mineral aggregate: The mineral aggregate gradation of the reclaimed materials has a direct influence on the mechanical properties of the recycled mixture. Coarse gradations tend to ravel and the build up of cohesion is limited, while sandy gradations tend to produce tender mixes often susceptible to permanent deformations. The mineral gradation of the blend of existing bituminous surfacing materials was suitable for recycling as is, thus, no corrective aggregate needed to be added to the mixture to meet the requirements for this type of recycling work.

Properties of aged binder: The properties of the aged bitumen contained in the bituminous aggregate were assessed to determine the type of recycling binder needed to optimize the performance of the recycling mixture. The visual inspection of the existing roadway clearly indicated extensive oxidation, thus, binder hardening. The standard penetration test performed at 25°C offers a rapid assessment of the binder hardening and the potential of the cold recycled mixture to resist permanent deformation. Furthermore, the penetration number provides information on the capability of the aged binder to contribute to the cohesion or the recycled mixture. Penetration number of the existing surfacing HMA on Bloomington Road was 23, which was considered relatively hard.

Bitumen aggregate binder content: The binder content is the third important characteristic to assess in the engineering of recycled material. The binder content gives information on the space occupied by the aged binder within the bitumen aggregate, thus, providing an indication on the amount of recycling binder that may be added to the mixture. The binder content of existing surfacing materials on Bloomington Road before recycling was 5.37 %, which may be considered relatively high and can lead to mixture tenderness. However, the low penetration number of the existing binder provided a safe guard with respect to potential tenderness of the recycled mixture. Thus, it was elected not to use any corrective aggregate, unless the laboratory mixture properties would be unfavourable.

2.1.2 Selection of recycling binder system

Recycling mixtures are produced using a very small amount of new recycling binder. Thus, it is imperative to understand how the aged binder and the recycling binder interact with one another to select an optimized system. Recycled mixtures may be produced with the addition of only 0.8 % added residual bitumen. Thus, it is accepted that the aged binder contained in the bituminous aggregate contributes to the build up of cohesion of the new recycled mixture.

Recycling work using cationic slow setting emulsions is becoming more and more prevalent in Canada. The coating characteristics of cationic slow setting emulsion are significantly different than those of the traditional high float emulsion used for many years in recycling in Ontario. The thickness of the coating is thinner than the coating obtained with high float emulsions, but a larger portion of the smaller fraction of the bituminous aggregate is coated at an equivalent emulsion dosage. As the added bitumen fluxes through the aged bitumen, a mortar like paste is created. Cationic emulsions allow the usage of a small amount of cement or lime to accelerate the build up of cohesion of the materials recycled. Due to the field conditions associated with Bloomington Road project, this added feature of the cationic emulsion vs. the traditional high float emulsion turned out to be a deciding factor.

2.1.3 Recycling mixture design procedure

Recycling mixture design procedure is a process by which field conditions are simulated in the laboratory to evaluate the long term and the constructability performance of the recycled mixture. Trial specimens were produced in the laboratory using a modified version of the Marshall method of compaction and a laboratory curing procedure to simulate both the compaction and curing of the recycled mixture occurring in the field. Laboratory testing was performed to determine performance-related parameters that are used to confirm the adequacy of the recycling system and to establish an optimal job-mix formula.

Air voids: The air voids of the laboratory specimen are used to assess the ability of the recycled mixture to be compacted and to provide information on the potential risk of permanent deformation of the recycled mixture. The target laboratory air voids are between 9 and 11% for the Ontario laboratory curing and compaction procedure. Voids below 9% are a sign of mixture tenderness, while voids above 11% are a sign of mixture harshness. Nonetheless, a harsher mixture was preferred for the Bloomington Road recycling work due to the heavy traffic and the favouable weather conditions anticipated for the work. The selected rate of recycling binder was 1.7 % of a standard CSS-1 emulsion.

Moisture resistance: Air voids of recycled mixtures are relatively high compared to dense graded hot bituminous mixture. Furthermore, the coating of the recycling binder tends to be selective. Consequently, recycled mixtures are less cohesive than dense graded hot bituminous mixtures. The adhesion of the recycling binder to the bituminous aggregate is critical, particularly at an early age. If adhesion is poor, rain may have a negative effect on the mixture, which may lead to excessive ravelling. The evaluation of the moisture sensitivity of the recycled mixture was carried out and the retained stability of the mixture was 76 %, which was above the 70 % target.

2.2 Curing of the recycled mat

The build up of cohesion of recycled mixture occurs over two phases. The initial phase corresponds to the time period necessary for the recycling binder to form a continuous film of bitumen. The end of the first phase also corresponds to the beginning of the formation of the new effective binder, which is essentially associated with the second phase of the curing. For constructability reasons, the first phase of curing in the case of Bloomington needed to be as short as possible.

Bituminous aggregate is a unique material with respect to its reactivity with recycling binders. The aged bitumen electrically insulates the surface of the mineral aggregate, which virtually prevents any type of aggregate-binder interaction that may destabilize and break emulsions. Thus, the initial phase of build up of cohesion which is associated with the breaking of the emulsion becomes highly dependent on the evacuation of water.

The evacuation water and, accordingly, the build up of cohesion of the recycled mixture are strongly influenced by the ambient temperature and the atmospheric relative humidity. Warm and dry weather shortens the first phase of curing, while damp and cold weather has the opposite effect. Even though the recycling work was planned for the warmer months of the construction season, a small amount of cement was used as a catalyst to help the breaking of a cationic emulsion. Cement is an alkaline product (pH ~12) and the surface area offered for a small quantity of product is extremely high. The alkalinity of the cement destabilizes the acidic emulsions causing them to break even in the presence of water, thus, helping the recycling mixture to build up cohesion rapidly and relatively independently from the evacuation of water. The rate of cement added to the recycled mixture was 0.5 %.

2.2 Field work

The field work was carried as planned in the early part of June 2005. The bituminous aggregate properties and the job mix formula are summarized in Table 1 and the recycled mixture properties are included in Table 2. The work was performed using a conventional recycling train (Photo 2). It should be mentioned that the recycled mixture was exposed to heavy traffic for a period of two months during one of the warmest summer in the region on record. Yet, the recycling work did not show any signs of tenderness leading to post compaction or permanent deformation (Photo 3).

Bituminous aggregate	
Binder content	5.37 %
Recovered penetration	23
Passing 4.75 mm sieve	63.4 %
Job Mix Formula	
Bituminous aggregate	97.8 %
Cationic emulsion	1.7 %
Cement	0.5 %

Table 1 – Bituminous aggregate properties and job mix formula

Recycled mixture properties	Results	Typical values
Total residual binder content	6.32 %	< 6.5 %
Marshall stability - dry	30,350 N	
Marshall stability - wet	23,000 N	
Retained stability	75.8 %	> 70 %
Air voids	10.99 %	9.0 to 11.0 %

Table 2 – Recycled mixture properties

Photo 2 – Cold In-place recycling train

Photo 3 – Cured cold recycled mat

3.0 RUT RESISTANT BINDER COURSE

The second challenge associated with the Bloomington Road project relates to the engineering of the HMA materials and particularly the binder course. Traditional Ontario HMAs are designed using volumetric parameters related to a certain type of compaction energy, Marshall hammer or Superpave Gyratory Compactor (SGC). The specimens are prepared at a mixing temperature that relates to the field production and placement temperature. The North American road agencies/industry relies on volumetric properties of mixes to assess the performance of HMA mixes. In most cases the volumetric properties will relate to the field performance, but there are the cases where volumetric properties of the mixes were met and the field performance is inadequate for rutting and permanent deformation. The North American HMA specifications are performance-related. The performance of the bituminous hot mix is related to factors such as air voids, VMA and others that are indicative of the fundamental engineering properties of the mixture such as resistance to rutting, fatigue resistance, durability, etc.

In 2001 York Region performed trials at various problematic intersections, where rutting was a recurring problem. The low speed, high volume of heavily loaded trucks turning, acceleration and deceleration as well as temperature changes during the summer posed a significant challenge to the engineering of HMA. The traditional heavy duty mixes did not perform as expected. The performance-related HMA specifications used in York Region did not predict rutting at intersections. It was suggested that a performance-based rut test ought to be considered to assess the long term rut resistance of the bituminous mixtures. The design of the mixes was performed using a combination of volumetric parameters and the mixtures were tested using both the “Asphalt Pavement Analyzer” (APA) and the French wheel tracking testing apparatus (Photo 4). The experience gained in 2001 lead to an equivalent approach for the 2005 Bloomington Road rehabilitation work.

Photo 4 – French wheel tracking testing apparatus

The Bloomington Road work needed specific attention with respect to rutting due to the high volume of traffic but also because of the type of heavy truck using this roadway. The Region requested that engineering of the HMA be performed using the same approach as the 2001 for the intersection work to confirm the ability of the mixture to resist rutting. Rut testing was therefore requested to insure that the rutting potential of the proposed HMA mixture would be mitigate and minimized.

3.1 Engineering of the binder course HMA material

The Quebec specification for HMA strongly influenced the development of the specifications for the binder course HMA material in the 2001 intersection contract. All through the 90' the Ministry of Transportation of Quebec developed and tested an original and unique HMA mix-design procedure that combines some of the principles related to the Superpave method and the French "Laboratoire Central des Ponts et Chaussées" (LCPC). The Quebec mixes are closely related to the Superpave mixes with the exception of the binder content which tends to be higher. The Quebec HMA design approach tends to be more performance-based rather than performance-related.

The Quebec principle of fixing the volume of binder within the mix and adjusting the voids by optimizing the gradation of the mixture is related to the LCPC method, whereas the volumetric parameters calculation is directly related to the Superpave method. There are other particularities of the Quebec method that are strongly inspired from the LCPC method. The voids at N_{design} are be related to the voids expected in the field i.e. 4.0 to 7.0 % not the Superpave single value of 4.0 %. Furthermore, N_{design} is related to the thickness of the mat not the traffic. And, whenever the traffic reaches a certain threshold rut testing is required in the Quebec method, which is a procedure not carried out with the Superpave method.

The principle of fixing the volume of bitumen in the mixture provides the assurance that it will not be lean, which indirectly influences the durability of the mixture. The volume of binder is expressed in volume of effective binder in the Quebec specification and the volume increases whenever the mixture is placed close to the surface. The volume of binder for the York Region contract was not as well defined as the Quebec specification as it didn't relate to the effective volume of the binder but a minimum percentage in relation to the aggregate. The percentage of bitumen specified in the York region specification was 4.9 %, which is related to a typical binder course used in Quebec.

The voids of a mixture compacted at N_{design} provide information on the aggregate packing characteristics of a HMA material and its workability. The design voids requirements are set at the expected field voids contrary to the Superpave method which set the design voids at 4 % for all the mixture. Whenever the N_{design} value increases to achieve a given field compaction the harsher the mixture becomes. In the Quebec method of mixture design, the N_{design} value relates to the thickness of the mat not the traffic loading. The principle associated with this relation of N_{design} with thickness lies with the cooling rates of thin layers vs. thick layers of HMA. On one hand, thin layers of HMA tend to cool down faster and the time available to knit and compact HMA material is shorter, while the opposite applies to thick layers. Hence, the successful placement and compaction of thin HMA is facilitated with workable mixes, while harsher mixes can still be successfully compacted if they are applied in a thicker lift. The N_{design} value used in the York Region contract 2001 and 2005 for the binder course was 100 gyrations.

The workability and aggregate packing characteristics of a HMA material at the production and placement temperature of 150 ºC may be corrolated to the rutting resistance of an HMA material at 60ºC, but not necessarily in all cases and for any type of mixture. As indicated above, the Superpave method is performance-related with respect to rutting as it assumes that the workability or the harshness of HMA at

Photo 5 – Four-year old rut resistant HMA placed at Woodbine Ave. and John Street in York Region

150 ºC is representative of the rutting resistance of the mixture. The LCPC and the Quebec mix-design methods include a specific rutting test at 60ºC. York Region elected to test rutting in both the 2001/2005 York Region contracts. The usage of both laboratory rutting devices, the “Asphalt Pavement Analyzer” (APA) and the European Wheel Tracking Test was permitted.

3.2 Base course HMA material selection and mixture design

The primary objective of the development of the HMA mixture was to address the concern of rutting. Rutting may be related to mechanical deformation (weak or already rutted sub-strata) or due to inadequacy of HMA to meet with the specified requirements (a sub-standard mix) and/or due to the inability of the mix to withstand high temperature changes resulting in high plastic flow allowing the deformation to occur. The long term performance of the pavement is attributed mainly to the Performance Grade of Asphalt Cement (PGAC) and the mineral aggregate skeleton of HMA.

Gradation			
Sieve size (mm)	JMF	Requirement SP-19	Requirements HDBC
26.5	100		100
25.0	100	100	
19.0	95	90 - 100	94 - 100
16.0	80		77 - 95
13.2	70		65 - 90
12.5	68	< 90	
9.5	59		48 - 78
4.75	47		42 - 52
2.36	41	23 - 49	21 - 54
1.18	30		12 - 49
0.600	21		6 - 38
0.300	9		3 - 22
0.150	4		1 - 9
0.075	3	2 - 8	0 - 6

Bitumen content		
Criteria	JMF	Requirements
PG70-28P	4.9 %	> 4.9 %
Volumetric properties		
Criteria	JMF	Requirements
N_{ini} *(10 Gyrations)*	11.0 %	≥ 11.0 %
N_{des} *(100 Gyrations)*	5.4 %	4.0 to 7.0 %
N_{max} *(200 Gyrations)*	3.6 %	≥ 2.0 %
VMA	15.45 %	-
VFA	68.4 %	-
Rutting		
Criteria	JMF	Requirements
30,000 cycle @ 60ºC	4.1 %	< 10 %

Table 3 – Binder course job mix formula details

Binder (PGAC) selection: The selection of binder was crucial for the pavement performance. The asphalt cement binder also plays a significant role in resisting rutting of asphalt pavement. The traditional PG58-28 binder would normally be used in southern Ontario. However, research and experience is now suggesting that the bitumen grading should be bumped by two grades on the high temperature for intersection work. The PG70-28 binder was used in the intersection contract of 2001 and the performance after four years is excellent (Photo 5). The polymer modification of the binder was also preferred. The long term performance of polymer-modified binder vs. non-polymer-modified binders at an equivalent "performance grading" is being debated. Based on the 2001 intersection work and the field observations it was decided to select the PG70-28 polymer-modified binder for the Bloomington Road work.

Aggregate selection: The mineral aggregate skeleton was made up of mostly crushed aggregates. A small amount of natural sand was added to the mixture to create the space needed to meet the 4.9 % binder requirement. In an equivalent Superpave mixture the usage of natural sand would not have been permitted. An equivalent Superpave mixture produced with the same aggregate would have had lower binder content from 0.4 to 0.6 % compared to this York Region mixture. The rut testing device used to assess the rutting resistance of the mixture provided the assurance that the usage of the small amount of natural sand would not be detrimental to the performance of the base course mixture.

Mixture design: The mixture was designed using a SGC and the volumetric properties of the mixture met the York Region specified requirements. Rut testing with the designed mixture was conducted using the French Rut Tester. The job mix formula is summarized in Table 3.

3.3 Field work

The placement of the binder course was carried in August 2005. The work was performed using conventional paving equipment, including a shuttle buggy to avoid mix and temperature segregation.

4.0 SURFACE COURSE – FINE-GRADED SMA

The usage of SMA type mixtures is still relatively new in Ontario even though one of the first North American SMA trials was placed in Ontario in December 1990. It is a well established technology in Europe and many of the states in the USA. Stone Mastic Asphalt mixes are primarily used for high volume roads where the requirements for the resistance to rutting are high. It is also well established that SMAs are more durable than traditional dense-graded mixes due to the high binder content.

Region of York elected to use a surfacing technology that provided both rutting mitigation and additional roadway service life. Thus, the selection of the SMA technology in lieu of the traditional dense-graded HMA became a logical choice to achieve the performance objectives set by the Region for the rehabilitation of Bloomington Rd.

Stone Mastic Asphalt mixtures have a high content of crushed chippings, which interlock to provide a strong mineral skeleton. In order to satisfy the SMA requirements the chippings have to meet rigorous requirements on toughness and shape. The space created within the chipping matrix is filled with a mortar rich in filler-bitumen mastic. Consequently, SMAs are binder rich mixes which necessitate the usage of fibres to avoid drain down of the binder during transportation and placement. The uniqueness of the SMA technology used in York Region lies with the fact that the SMA mixture placed on Bloomington Road was the first fine-graded type SMA mixture (Nominal Maximum Aggregate Size < 6.7 mm) placed on a Canadian roadway.

4.1 Engineering of the fine-graded SMA material

Similar to the binder course, the development of the project specification for the surfacing course was strongly influenced by the Quebec performance-based approach with respect to rutting and mix field compaction. Consequently, in addition to the traditional gradation and volumetric criteria traditionally found in HMA material specification, the York Region project specification included pass/fail performance-based rut resistance criteria. The gradation specification originally specified in the contract was based on the Ontario 9.5 mm SMA gradation. The SMA mixture volumetric and rutting performance requirements are provided in Table 4. As demonstrated hereafter the mix-design work associated with the SMA mixture lead to the development of a fine-graded SMA mixture that provides not only excellent rut resistant and durability performance but also unique surface characteristics.

4.2 Material selection and mixture design

The methodology used to select of binder for the SMA was identical to the approach used to select the bitumen for the binder course. The polymer-modified PG 70-28 was selected to produce the SMA. The aggregate used to produce the SMA came form a meta-gabbro quarry. The Ministry of Transportation of Ontario has approved the usage of that aggregate on all the high volume roads under their jurisdiction. It is considered a premium aggregate with respect to its physical and shape properties.

The selection of the individual aggregates to produce the SMA mixture was a challenge. The Ontario 9.5 mm SMA has a very narrow gradation band and the commercially available aggregates produced in Ontario are not conducive to meet this gradation band. However, the availability of a 6.7 mm single size

Gradation			
Sieve size (mm)	JMF	9.5 mm SMA	*6.7 mm SMA**
12.5	100	100	
9.5	100	92 -100	*100*
6.7	98		*90 -100*
4.75	78	70 - 76	
2.36	33	30 - 35	*28 - 38*
0.075	11	8 - 12	*8 - 12*

Bitumen content		
Criteria	JMF	Requirements
PG70-28P	5.8 %	-
Volumetric properties		
Criteria	JMF	Requirements
N_{ini} *(10 Gyrations)*	14.5 %	≥ 11.0 %
N_{des} *(80 Gyrations)*	5.5 %	4.0 to 7.0 %
N_{max} *(200 Gyrations)*	2.4 %	≥ 2.0 %
VMA	17.0 %	-
Rutting		
Criteria	JMF	Requirements
1,000 cycle @ 60ºC	4.5 %	< 10 %
3,000 cycle @ 60ºC	5.2 %	< 20 %
30,000 cycle @ 60ºC	7.3 %	-

* Proposed

Table 4 – SMA material specifications and job mix formula details

chip provided the opportunity to consider the usage of a smaller aggregate for the production of the prescribed SMA without significantly changing the gradation requirement of the mixture. Similar to the base course HMA, the primary objective of the development of the SMA mixture was to address the concern of rutting. The field experience related to small Nominal Maximum Aggregate Size (NMAS) type mixture is limited, but the European and the Quebec experience related to rut testing indicates that the size of the NMAS of the mixture does not influence the resistance to rutting. Furthermore, regardless of the gradation and the volumetric characteristics of the proposed mixture, the rut testing was considered the fail/pass deciding factor in this case. Therefore, it was determined that the selection of a small NMAS should not be a deciding factor in the development of the SMA mixture, which subsequently lead to the development of a fine-graded SMA.

The mixture was designed using a Superpave Gyratory Compactor and the volumetric characteristics of the mixture are contained in Table 4. The mixture was tested for rutting using a European rut testing device. The rutting test results are also provided in Table 4. The final gradation of the SMA mixture met the gradation of the 9.5 mm gradation band except for divergence of 2 points at the 4.75 mm sieve. Since the divergence from the 9.5mm gradation was minor and all the other mix requirements were met the Region accepted the submitted fine-graded SMA mix-design.

4.3 Field work

The placement of the fine-graded SMA was carried out in the middle of August 2005 right after the placement of the binder course. The placement was performed using conventional paving equipment including a shuttle buggy to avoid mix and temperature segregation. The compaction was performed as per the current practice for SMA with the exception that an oscillating type vibratory roller was used instead of a conventional vibratory roller.

4.4 Surface characteristics

The surface characteristics of fine-graded SMA are excellent considering that the NMAS is only half the size of a conventional surfacing course dense graded HMA. Many of surface characteristics features reported in various technical briefs related to this type of SMA type mixture were confirmed with the Bloomington Rd. project.

The excellent surface characteristics of the fine-graded SMA are related to the unique macro-texture of the mixture. Field measurements have indicated that the macro-texture depth of the fine-graded SMA is comparable to the macro-texture of a dense-graded HMA produced with a NMAS twice the size. The macro-texture depth was measured using the sand patch method on two sections of Bloomington Rd.: the SMA section and the adjacent dense-graded HMA section. The macro-texture depth for both mixtures, the (6.7 mm NMAS) fine-graded SMA and the 13.2 mm NMAS HMA was 0.54 mm. The difference between the two surface macro-textures is related to the fine cross-section of the mixtures macro-texture. The macro-texture of the fine-graded SMA has a relatively uniformed depth and the distance between the peaks is less than 10 mm, while the depth of the dense-graded HMA is variable and the distance between the peaks is also variable, often greater than 10 mm.

The macro-texture of the fine-graded SMA may be comparable to other SMA type mixture, but the distance between the peaks and the depth of the surface interstice is much smaller than other SMA. This fine-graded but aggressive macro-texture (Photo 6) confers to this type of SMA a multitude of excellent

Photo 6 – Fine-graded SMA surface texture

surface characteristics as a roadway surfacing system including good surface drainage, reduction of glare at night from reflection of lights of oncoming vehicles, excellent frictional characteristics and appreciable reduction in rolling noise.

The surface characteristics of porous asphalt mixes (open graded mixes) are excellent and generally better than any low voids mixtures including fine-graded SMAs. However, in the Canadian context due to the extensive and aggressive winter maintenance porous asphalt mixes tend to clog up and ravel at a relatively young age. Consequently, the durability of this type of asphalt mix is often questioned and the usage of this type of mixture is rare. Even though the surface characteristics of fine-graded SMA is not as good as porous asphalt, in the Canadian context this low void type mixture is an excellent compromise between the traditional large NMAS low void mixes (dense-graded mixes and SMA) and the porous asphalt with respect to surface characteristics.

4.4.1 Skid resistance and surface drainage

The skid resistance was measured using the ASTM Brake Force Trailer procedure. The Skid Number obtained for the Bloomington Road fine-graded SMA is well above the expected minimum for this type of roadway after three months of service. It is suggested that the fine-graded but aggressive macro-texture of this type of SMA provides additional points of contact with the rubber of the tire, while evacuating the surface water efficiently through and within the surface texture of the mixture, consequently providing more friction. The evolution of the skid resistance of SMA and other dense graded mixes is being studied world wide and the information available on this fine-graded SMA is limited, nevertheless the Skid Number obtained on Bloomington Road is very encouraging.

4.4.2 Rolling noise

Roadway traffic rolling noise is an increasingly important environmental issue in most industrialised countries. Generally, whenever the speed of a vehicle reaches 60 km/hr. the rolling noise becomes primary source of traffic noise. Rolling noise is generated by series of phenomena occurring at the tire/roadway interface. Rolling noise has been extensively researched worldwide and it has been demonstrated there are techniques available to produce roadway surfacing materials that will mitigate rolling noise without compromising on safety, durability and cost effectiveness. Fine-graded SMA surfacing system used on Bloomington Rd. is considered in many countries as a quiet surfacing system.

4.4.2.1 Rolling noise generation/enhancement mechanisms

At the tire/roadway interface several mechanisms generate energy which eventually radiates as sound along with other mechanisms that will amplify the sound. The mechanisms that generate energy are:

- tire tread impact with the roadway surface (rubber hammer),
- air pumping at the interface of the tire/roadway (clapping hands),
- slip-stick of tire tread blocks (athletic shoes on gymnasium floor) and,
- the stick-snap of the tread blocks with the roadway (suction cup).

The mechanisms that amplify the sound are numerous and much more complex. As an example, the tire belt/carcass and side wall vibrations will amplify sound generated mechanically.

4.4.2.2 Mitigation of rolling noise

Worldwide experimental findings have demonstrated quieter roadways are obtained whenever the:

- distance between the peaks within the macro-texture is smaller than 10 mm,
- surfacing system is porous,
- surfacing system is elastic, and
- macro-texture is negative rather than positive (Figure 1).

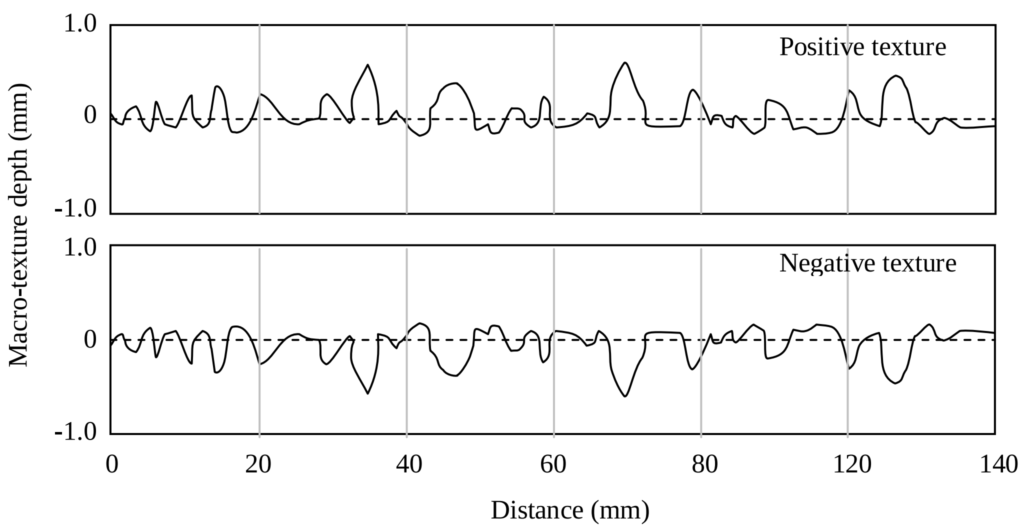

Figure 1- Positive macro-texture vs. negative macro-texture

Short distances between the peaks within the macro-texture and the negative macro-texture reduce the intensity of the tire tread impact/deformation which in turn reduces the tire vibration. This type of uniform and fine-texture (< 10 mm) at the macro-texture level (0.5 to 50 mm) is obtained with the usage of surfacing systems produced with single size small NMAS (10 or 6 mm). The negative macro-texture of surfacing systems is achieved with the usage of smoothing device such a finisher screed.

The porosity of the surfacing system reduces the strength of the air pumping source of rolling noise by preventing and dissipating the air compression underneath the tire. Porous asphalt surfacing systems have that capability and they are well known to be quieter roadway surfaces. Unfortunately, as indicated in a previous section, this type of surfacing system tends to not be as durable as the traditional dense-graded mixes in the Canadian context and they are now rarely used.

Elastic surfacing systems are produced using recycled rubber. The mechanical elasticity of these systems contributes to reduce the intensity of the mechanical sources of sound. Rubber modified mixes have been used on a limited scale for many years. They were originally developed for recycling purposes rather than noise. Nowadays, many US road agencies are using them for rolling noise abatement in urban settings.

4.4.3 Potential noise abatement of fine-graded SMA

Low noise surfacing systems are produce with one or a combination of the above features. Porous asphalt mixes (in-place voids 18-25 %) are the quietest systems followed by the fine-graded, low voids surfacing system (in-place voids 7-9 %) and the rubber modification of the binder. The gain in noise reduction of for certain type of porous asphalt system compared to traditional dense graded HMAs has been reported to be as much as 6 dB(A). The gain for a fine-graded, low voids surfacing system may be as much as 3 dB(A).

Noise abatement in the magnitude of 3 dB(A) in rolling noise is significant. A reduction of 3 dB(A) is correspond to doubling the distance of the noise source or reducing the traffic volume by 50 %. The other point of reference is the traffic speed: noise abatement of 3 dB(A) is equivalent to a reduction of 25 % of the traffic speed.

The fine-graded SMA mixture placed on Bloomington Rd. qualifies as a fine-graded, low voids surfacing system. It is suggested that the multiple points of contact with the rubber of the tire provided by the fine but aggressive macro-texture and the high surface voids of the fine-graded SMA are reducing all the rolling noise mechanisms. Even though the rolling noise was not measured, the field observations over several months of service have clearly indicated that the rolling noise generated by this type of surfacing system is definitely less than that of conventional mixes. The rolling noise difference between the two surfacing system is audible confirming the reported gain in noise reduction for this type of surfacing system.

5.0 SUMMARY

The rehabilitation work undertaken on Bloomington Road in the summer of 2005 was performed using a unique approach. The techniques selected, by their nature and past usage in Ontario, were not new to this market, but the material design approaches used to develop the recycled mixture and the HMA materials were and are still not well established in Ontario. In many respect, the Bloomington Road rehabilitation project has allowed York Region to explore a roadway rehabilitation approach that may be qualified as performance-based rather than performance-related.

Photo 7 – Completed roadway rehabilitation work

The development of the recycled mixture based on an analysis of the bituminous aggregate, the recycling system selection and the laboratory work is different than the conventional recipe type formulation for recycling. Site specific considerations such as the expected weather during the work and the traffic characteristics were also taken into account in the engineering of the recycled work. The conventional approach to recycling would not take those factors into account in the development of the mix-design.

The mixture formulation for the HMA was also a significant departure from the conventional HMA mix-design approach. The HMAs binder course and the surface course were developed and design using the Quebec mix-design approach which may be qualified as performance-based approach rather than performance related formulation system such as the Superpave approach. It was found that the Quebec mix-design approach offered added flexibility on the selection of the aggregates gradation and their characteristics, but having to satisfy a minimum binder requirement which does not exist with the Superpave approach was certainly a challenge.

The development of the fine-graded SMA was strongly inspired by the on going work in the United States and elsewhere in the world where quiet roadways are placed. The usage of a small maximum nominal size aggregate for the production of a surface course bituminous material is not common yet in North America. This is the first time this type of bituminous mixture was placed on a Canadian roadway. The usage of the gyratory compactor to predict the mixture compaction ability and the usage of the wheel tracking device to determine the mixture resistance to rutting were extremely helpful to provide the assurance that this type of mixture once in service will performed as noted in other part of the world. The technical literature review of rolling noise reduction surfacing systems and the field observation with respect to rolling noise generated are conferring the fine-graded SMA placed on Bloomington Road has excellent performance in this regard.

The rehabilitation work was performed as planned and the performance observed after a few months of service is indicative of an excellent long term roadway performance (Photo 7). Nonetheless, additional field investigation work including measurements such as skid resistance, rolling noise, roughness and structural strength would be greatly valuable to quantify and predict the roadway long term performance and to confirm the benefits associated with the approach taken for the engineering of the materials.

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