Development of a Performance-Based Asphalt Mixture Overlay for Usage In A Low-Budget Pavement Management System

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ABSTRACT

An effective pavement management system should include a full range of cost-effective preservation and rehabilitation techniques to ensure that a smooth and durable surface with adequate skid resistance is available to road users. However, insufficient funding or budget cuts at federal, provincial, and municipal levels of government does not help road agencies to maintain their network at the desired level of service. These funding shortfalls often result in severely distressed and deteriorated pavements within the network, requiring costly rehabilitation or reconstruction.

In this paper, an overlay solution is presented that can be used as a reactive type of maintenance. This solution is a performance-based flexible asphalt overlay designed to be placed without the need for milling operations. This paper provides steps employed to develop a performance-based requirement focused on low-temperature flexibility and long-term fatigue behaviour under repetitive stresses that would be expected from low to medium level of traffic coupled with extreme temperatures. Production and paving experience with the flexible overlay are also included in this paper, as well as field performance of a trial section in the province of Quebec.

RÉSUMÉ

Un système efficace de gestion de la chaussée devrait inclure une gamme complète de techniques de conservation et de réhabilitation rentables pour garantir aux usagers de la route une surface lisse, durable et offrant une résistance suffisante au dérapage. Cependant, l'insuffisance des financements ou des coupes budgétaires aux niveaux fédéral, provincial et municipal n'aident pas les agences de voirie à maintenir leur réseau au niveau de service souhaité. Ces déficits de financement se traduisent souvent par des chaussées gravement endommagées et détériorées au sein du réseau, nécessitant des travaux de réhabilitation ou de reconstruction coûteux.

Dans cet article, une solution de revêtement, qui peut être utilisée comme type de maintenance réactif, est présentée. Cette solution est un revêtement de bitume flexible, basé sur les performances, conçu pour être placé sans travaux de fraisage. Ce document fournit les étapes utilisées pour développer une exigence de performance axée sur la flexibilité à basse température et le comportement à la fatigue à long terme sous des contraintes répétitives que l’on pourrait attendre d’un trafic faible à moyen couplé à des températures extrêmes. Le présent document traite également de l’expérience de la production et de la pose de chaussée avec le revêtement flexible, ainsi que des performances sur le terrain d’une section d’essai située dans la province de Québec.

1.0 INTRODUCTION

Exposure to climate conditions coupled with traffic loadings cause cracks to appear on the pavement surface in different forms of distresses, which allow water to infiltrate and further weaken the pavement surface. No matter how adequately designed or well-constructed, over time with usage, these surface distresses can contribute to reducing the serviceability and causing deterioration of the underlain layers to the point that the pavement cannot provide the required structural adequacy for supporting traffic and environmental loadings. A number of techniques can be employed to preserve or rehabilitate the road surfaces and their effectiveness mainly depends on the degree to which the pavement has deteriorated. These techniques are broadly categorized into emergency, routine, reactive, minor and major maintenance, preventive maintenance, corrective maintenance, preservation, restoration, and rehabilitation [1]. The selection of these activities is generally based on the type and classification of the roadway (i.e. rural versus urban), as well agency policies and available funding. The selection is further influenced by the availability of materials, contractor capability and cost effectiveness [1].

An effective Pavement Management System (PMS) should include a range of techniques to ensure that a smooth and durable surface with adequate skid resistance is available to road users. However, chronic insufficient funding or budget cuts at federal, provincial and municipal levels of government does not help road agencies to maintain their network at the desired level of service, especially rural road networks. These funding shortfalls often result in a network that includes a large number of severely distressed and deteriorated roads, requiring costly reconstruction or a reactive solution. The reactive solution has to be cost-effective in increasing the pavement condition to an optimal level of service, while deferring the rehabilitation and reconstruction budget until sufficient funding is available to the owner agency.

When it comes to severely deteriorated rural roads similar to the road section shown in Figure 1, few effective solutions are available. These solutions include either partial or full-depth reclamation of the existing layers and placement of new layers and building a proper drainage system. In addition to the cost of these solutions, they could be disruptive to the economy and social activities of rural communities where the road network is the main means of transporting all goods and services to the communities.

Figure 1. An Example of Road Candidate to Receive Enrobés Flexibles Municipaux (EFM) Overlay

An overlay solution without the need for costly milling operations or rehabilitation could be an ideal tool. However, overlays are generally used to address minor surface distresses that occur within the first 5 to 7 years of pavement life. Overlays are not placed on roads that could be suffering from full-depth cracks, block cracking, deep ruts in the wheel paths or underlying structural problems, such as moisture or differential settlements due to lack of drainage.

It was until around 2008 that an overlay solution known as Enrobés Flexibles Municipaux (EFM) found its way through the paving industry in Quebec. EFM is essentially placed on roads that are not properly maintained over their service life either due to lack of effective PMS or insufficient funding at municipal levels. However, there are challenges in finding scientific or practical documents on the usage of overlays on badly deteriorated roads, as all major suppliers have their own proprietary products. In addition, the usage of such performance-based materials in Canada has been limited and there is no understanding on long-term behaviour and performance. This paper provides development experience with performance and volumetric-based type of mix. Production and paving experience with the flexible overlay are also included in this paper, as well as the field performance of a trial section in the province of Quebec.

2.0 MIXTURE DEVELOPMENT

2.1 Overview

The municipal flexible overlay (EFM, in Quebec) was first introduced to the Quebec paving industry around 2008 as a proprietary overlay solution without the need for costly milling operations or rehabilitation. EFM mix is essentially a reactive type of maintenance to restore rideability, while deferring the rehabilitation cost to at least 5 to 10 years. Since EFM is placed on badly deteriorated roads, the mix has to exhibit strength and flexibility by enduring a series of performance-based type of laboratory testing listed in Table 1. Volumetric-based requirements for EFM are also provided in Table 1 while the requirements for aggregate structure are provided in Table 2.

Table 1. Requirements For Enrobés Flexibles Municipaux (EFM)

Test	MTQ Method	Specification
Marshall Flow (0.25 mm)	LC 26-410	Min. 8.0
Marshall Stability (N)	LC 26-060	Min. 7,200
Resilient Modulus (MPa) +10.0°C 0.00°C -10.0°C	LC 26-700	Max. 1,000 Max. 3,500 Max. 10,000
Rutting Resistance After 10,000 Cycles (%) by FRT	LC 26-410	Max. 5.00
Asphalt Binder Content (%)	-	4.70 ± 0.25
Thermal Strain Restrained Specimen Test (TSRST)	AASHTO TP 10-93	Max. -34°C
Film Thickness (µm)	-	Min. 10.0
Air Voids (%)	LC 26-320	5.0 – 10.0
Recycle Asphalt Pavement (% of aggregate blend)	-	Max. 15.0
Mixing Temperature (°C) Compaction Temperature (°C)		60 – 120 60 – 100

Notes: MTQ is the Ministry of Transportation of Quebec and FRT is the French Rut Tester.

Table 2. Aggregate Gradation for Enrobés Flexibles Municipaux (EFM)

Sieve Size (mm)	Passing (%)
10.0	95 – 100
5.0	45 – 55
2.5	25 – 35
0.08	2.0 – 6.0

The test methods listed in Table 1 are expected to simulate repetitive traffic loading coupled with those temperature ranges expected in summer and winter conditions. The specification for EFM is not the same for all the municipalities in Quebec, and often there are differences in requirements for rutting (as tested by the French Rut Tester, FRT) and thermal cracking (as tested by the Thermal Strain Restrained Specimen Test, TSRST) requirements.

For example, TSRST requirement is often specified as maximum temperature of -28, -34, or -40°C. The maximum rutting can be also specified at 10,000 or 30,000 cycles depending on the level of expected traffic. But the requirements provided in Table 1 are the most commonly used for EFM. Moreover, there are limitations on production and placement temperatures. This is to ensure that the mix could bring major environmental, economical, and safety benefits in terms of:

- Improved compaction and joint quality;
- Improved aggregate coating at much lower temperatures compared to conventional hot mix asphalt;
- Less thermal segregation;
- Facilitating longer haul distances from the production facility to the paving site;
- Reduced fuel consumption at the asphalt mixture plant;
- Improved worker health and safety due to reduced asphalt fumes and lower mix temperature at paving sites; and
- Less potential to crack due to reduced asphalt binder aging.

To develop an EFM mix, two aggregate sources were used to prepare a design blend meeting the requirements listed in Table 2: (1) crushed stone 5-10 mm, and (2) manufactured sand 0-5 mm. For the first design trial, a straight run (unmodified) Asphalt Cement (AC) suitable for the Southern Quebec was first used in combination with a speciality chemical additive. The mix was prepared using 75 Marshall blows and a target air voids of 5.50 percent close to the lower end of 5 to 10 percent range for air voids. But this mix did not exhibit adequate stability to pass the minimum Marshall stability of 7,200 N. Then, the aggregate blend was adjusted slightly to create more stone-on-stone contact to increase stability. However, this design trial also failed the stability. This provided insight that the design blend is optimized, and stability is controlled, by the physical properties of the AC.

A modified technique was then used to increase the Useful Temperature Interval (UTI) of the base AC by 6 degrees to run the next design trial, which also failed the stability requirement by approximately 1,500 N below the minimum requirement. At this point, increasing the UTI to achieve the stability was not practical, nor economical for this type of mix. Increasing UTI by another 6 degrees not only was increasing the cost, it also could have created relatively stiffer binder that could affected production/placement temperatures as well as overall flexibility of the mix. Then, the only practical solution was to create a mix with higher binder content than the maximum specified content of 4.95 percent. After running number of trials, it was concluded that a minimum binder content of 5.20 percent was required to meet the minimum Marshall stability and flow. For all these trials, the aggregate blend and type of AC was kept consistent, while AC content varied from 5.0 to 6.0 percent in 0.25 increments.

After optimization of the design trial based on Marshall stability/flow, the selected design trial was advanced to the next phase of performance testing for rutting, as well as overall and low temperature flexibility. During this phase, fine adjustments to the binder's UTI as well as aggregate blend were applied. For the purpose of this paper, only two trials with two different asphalt binders are presented with physical properties listed in Table 3. This is to provide a better understanding of the testing sensitivity to the physical properties of the asphalt binder.

Table 3. Selected Physical Properties of Asphalt Binder Type A and B

Performance Measure	Unmodified PG 58-28	Binder Type A	Binder Type B
Non-recoverable Creep Compliance at 3.2 kPa, J_{nr} (1/kPa)	3.45	0.96	1.32
Percent Recovery at 3.2 kPa, R (%)	1.2	51.5	54.5
Multiple Stress Creep Recovery Test Temperature (°C)	58	58	52

2.2 Permanent Deformation

The rutting resistance of the asphalt mixtures was evaluated by the Laboratoire Central des Ponts et Chaussées (LCPC) wheel tracker (also known as the French Rutting Tester, FRT) following the MTQ testing method LC 26-410, "Resistance to deformation of asphalt in the rutting test" [2]. For this test, a pneumatic tire (400 mm in dimeter and 80 mm wide) was tracked across slab samples at a frequency of 1.0 Hz. The slab samples were prepared by using a French rolling wheel compactor following the method outlined in testing method of LC 26–400, "Manufacture of LCPC compactor specimens" [3]. A tire pressure of 87 ± 4.35 psi (600 ± 30 kPa) and applied load of 1124 ± 1.12 lbs (5000 ± 5 N) was used to conduct 10,000 loading cycles on slab samples with dimensions of 50 mm thick, 180 mm wide, and 500 mm long. The rutting depth was then measured as percent deformation of the test slab thickness. The FRT test was conducted at the École de Technologie Supérieure (ETS) in Montreal, Quebec.

Figure 2 shows rut deformations measured for two mixes with the same mixture properties, except the binder types were different in terms of overall stiffness. As shown, the rutting resistance is controlled by the aggregate skeleton or stone-on-stone contact as opposed to the physical properties of the binder or mixture of binder and fines (also referred to as the mastic portion of the mix). This is based on the minimal difference between the two mixtures in terms of percent deformation. Moreover, the results also verified that achieving the adequate Marshall Stability and flow may suggest relatively good performance in terms of rutting.

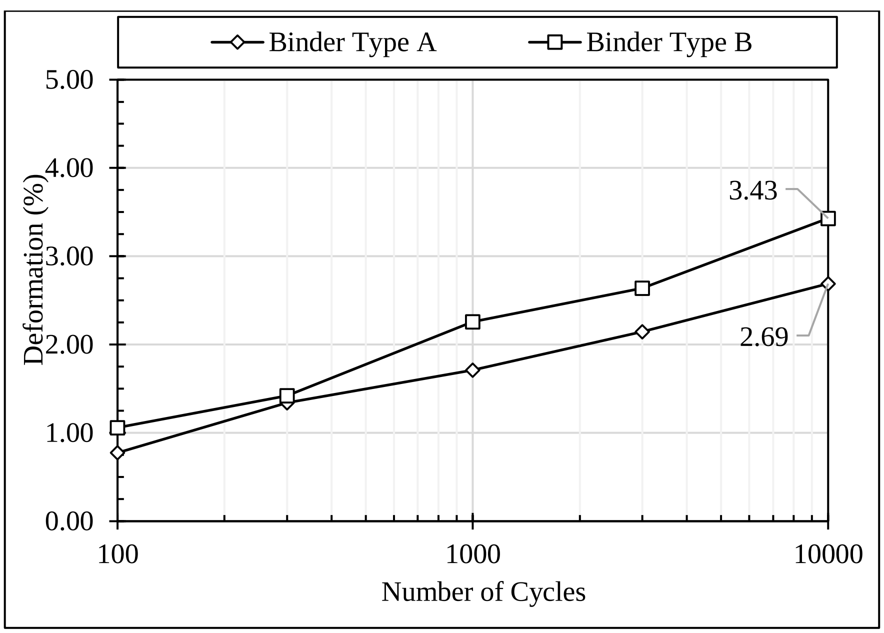


Figure 2. French Rutting Test Results

2.3 Fatigue Cracking Evaluation

The fatigue resistance of the mixtures was evaluated by following a method prescribed in EN 12697-26, Annex C, "Bituminous Mixtures, Test Methods, Stiffness – Indirect Tension Test" [4]. For this test, diametral compressive force was applied on a Marshall-sized specimen (100 mm in diameter) using cyclic loading to measure maximum vertical load required to reach a controlled dimeter deformation of 5 micro-strain. The resilient modulus was then calculated using Equation 1 at three temperatures of -10, 0, and 10°C. These temperatures are specified to give an indication of overall mixture flexibility at intermediate in-service temperature range. The resilient modulus test was conducted at the ETS.

$$S_m = \frac{F(\nu + 0.27)}{z.h} \quad (1)$$

Where: S_m is Stiffness modulus in MPa;
F is the peak value of the applied vertical load in N;
ν is the Poisson's ratio;
z is the amplitude of the horizontal deformation obtained during the load cycle in mm; and
h is the mean thickness of the cylindrical specimen in mm.

Figure 3 presents average resilient modulus values at different temperatures measured by using an indirect tensile method, while the error bars represent one standard deviation. It is evident that fatigue resistance of both mixes was significantly sensitive to the stiffness of the binder. Binder Type B was relatively softer compared to binder Type A, and the difference in stiffness translated into significantly better fatigue resistance. It should be mentioned that the mix with binder Type A failed the fatigue requirements listed in Table 1 at the three testing temperatures, while the mix with Type B met the requirements.

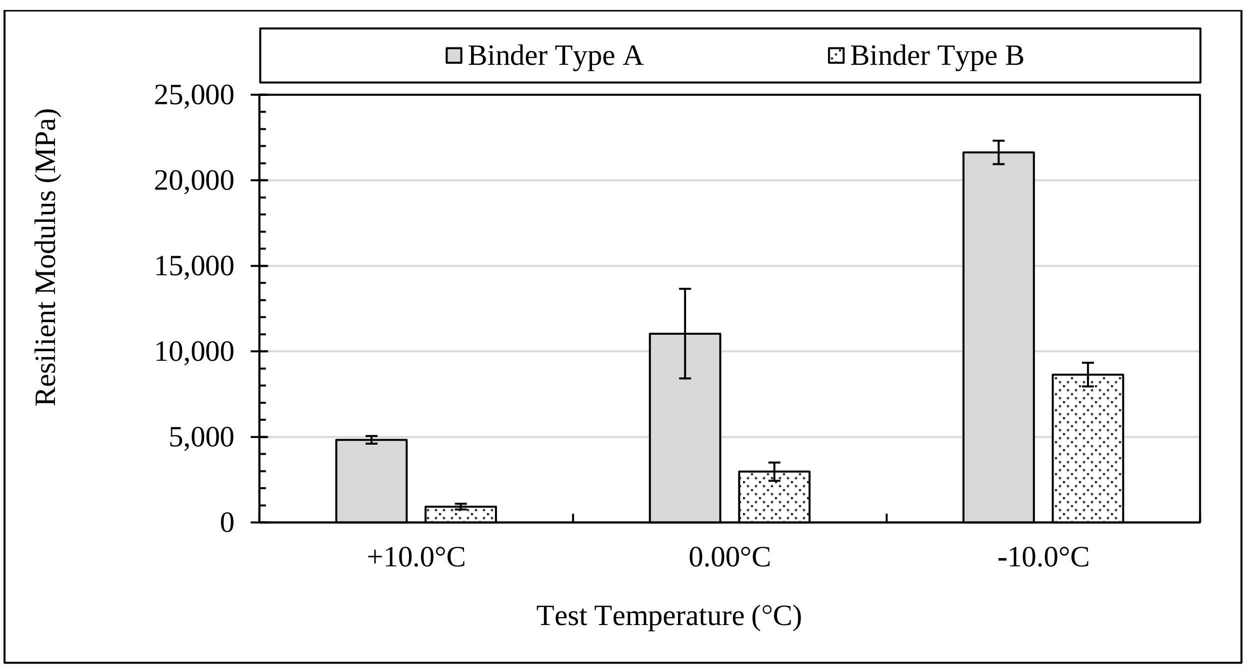


Figure 3. Indirect Tensile Resilient Modulus Results

2.4 Thermal Cracking

The flexibility of the mixtures at lower temperatures was performed in accordance with AASHTO TP 10-93, "Standard Test Method for Thermal Stress Restrained Specimen Tensile Strength" [5]. The testing procedure involved restraining a cylindrical sample from contraction while being simultaneously subjected to a constant cooling rate of -10ºC (14ºF) per hour. Resistance to thermal cracking was then evaluated as the temperature at which a fracture was developed within the length of specimen. Cylindrical sample measuring 60 mm in diameter by 250 mm in height were cored from a slab compacted to a target air voids by using a French rolling wheel compactor. Coring was carried out transversely to the compaction plane to simulate the direction of thermal cracking relative to the road. The TSRST was conducted at ETS.

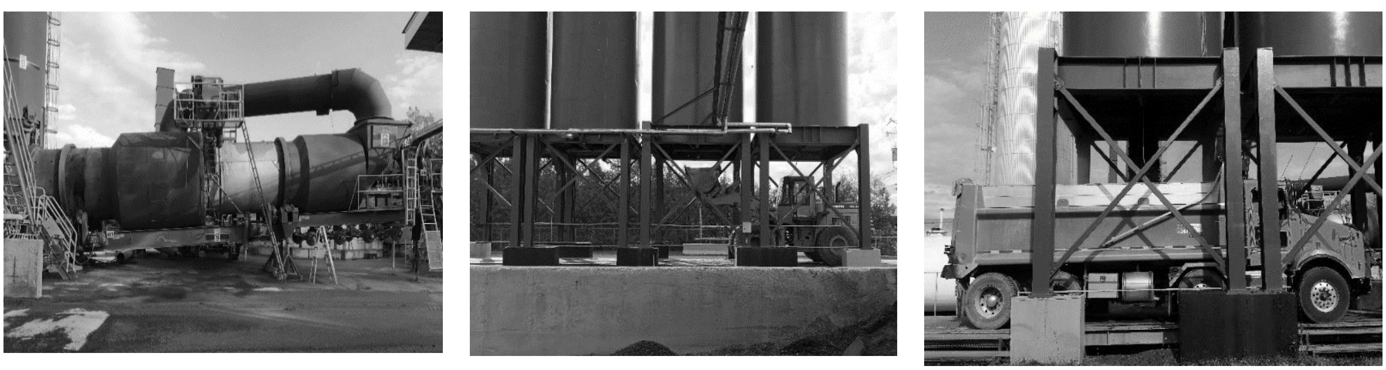
The mean fracture temperature and stress for both mixtures are provided in Table 4, which indicates very good performance for both mixes in terms of colder fracture temperature. The temperature range of -37 to -41°C are far more sufficient to cover cold temperature range for the majority of road sections within the province, as well as other provinces in Canada. On the other hand, fracture stress for the mix with binder Type B indicates much more relaxed fracture during at the fracture temperature. This may suggest that the mix with binder Type B has greater relaxation at colder temperatures compared to the mix with binder Type A.

Table 4. Thermal Stress Restrained Specimen Tensile Strength Results

	Fracture Temperature (°C)		**Fracture Stress (kPa)**	
	Average	**Standard Deviation**	**Average**	**Standard Deviation**
Binder Type A	-37.3	0.566	3171	152
Binder Type B	-41.5	0.001	2601	78.0

3.0 PLANT PRODUCTION AND PAVING EXPERIENCE

The mix with Type B asphalt binder was selected to proceed with a field trial conducted in October 2017. The job site was located in the vicinity of St-Hugues Town in Southern Quebec. The EFM mix was produced by using the same aggregate blend used throughout the development process. A drum plant was used to produce the mix at 105 ± 5°C without any issues pumping the binder through the plant, nor any issues mixing the binder with aggregate blend to achieve proper coating. Some of the major details of the plant production are shown in Figure 4.



(a) Parallel flow drum mixer was used to produce the mix. The drum was estimated to be 12 years old. The drum was powered by natural gas and was observed in a good condition

(b) A small tonnage of the mix was produced to check discharge after the drum and silo. This was also to clean the belts and ensure the designated silo is free of contamination

(c) Silo discharge with no visible fumes

Figure 4. Production of Enrobés Flexibles Municipaux (EFM)

EFM mix was placed on a rural road section that had not been properly maintained over its service life either due to lack of effective PMS or insufficient funding. Based on a visual distress survey performed prior to paving, the road was observed to be severely distressed as shown in Figure 5: exhibiting block cracking, relatively deep ruts in the wheel paths, moisture problems, and differential settlements due to lack of drainage. EFM mix was placed in two lifts: (1) a 25 mm thick padding layer placed directly on the road to cover distresses as well as restoring transverse profile (slope), and (2) a 50 mm thick surface course to improve longitudinal profile (smoothness) of the road and possibly add strength to the existing structure by decreasing chance of stress failures in the bottom layers of asphalt. It should be noted that trackless tack coat was used in between layers to promote interlayer bonding.

(a) Relatively deep potholes formed in the wheel-path with severe wheel-path fatigue cracks and block cracks

(b) Severe outter wheel-path fatigue cracking forming so called “alligator cracking”

(c) Severe alligator cracking.

Figure 5. Road Conditions Prior to Placement of Enrobés Flexibles Municipaux (EFM) Overlay, October 2017

The EFM mix was delivered to the job site with conventional haulage equipment and placed with conventional paving equipment shown in Figure 6. A Material Transfer Vehicle (MTV) was not used in this trial and the mix was placed with no sign of segregation. Laydown temperature was measured between 90 and 100˚C throughout the job. No visible fumes were observed during the placement, as shown in Figure 6(b). The paving crew did not have any problems in terms workability and placement; in fact, positive feedback was collected from the paving crew on the rich texture, and how easy the mix was to compact with no need of using breakdown rollers.

(a) Uniform application of trackless tack coat prior to placement of 25-mm padding layer. Same rate was used between padding and 50-mm wearing coarse.

(b) Catepillar AP-1000D was used to pave 2-lanes in one extension with “Extend-a-mat” Catepillar 10-20B. No visible fumes were observed during placement.

(c) Similar rolling patterns as a typical surface course mix was used during the placement – no breakdown rollers were used.

Figure 6. Placement of Enrobés Flexibles Municipaux (EFM) Overlay, October 2017

4.0 FIELD PERFORMANCE

A number of field follow-ups were conducted since placement, but in this paper provides only observations from the latest manual distress survey conducted on May 9, 2019. The weather during the survey was a mix of sun and cloud, air temperature of 8.0°C, and light wind. During this survey, the EFM exhibited excellent performance in covering those badly distressed areas as shown in Figure 7.

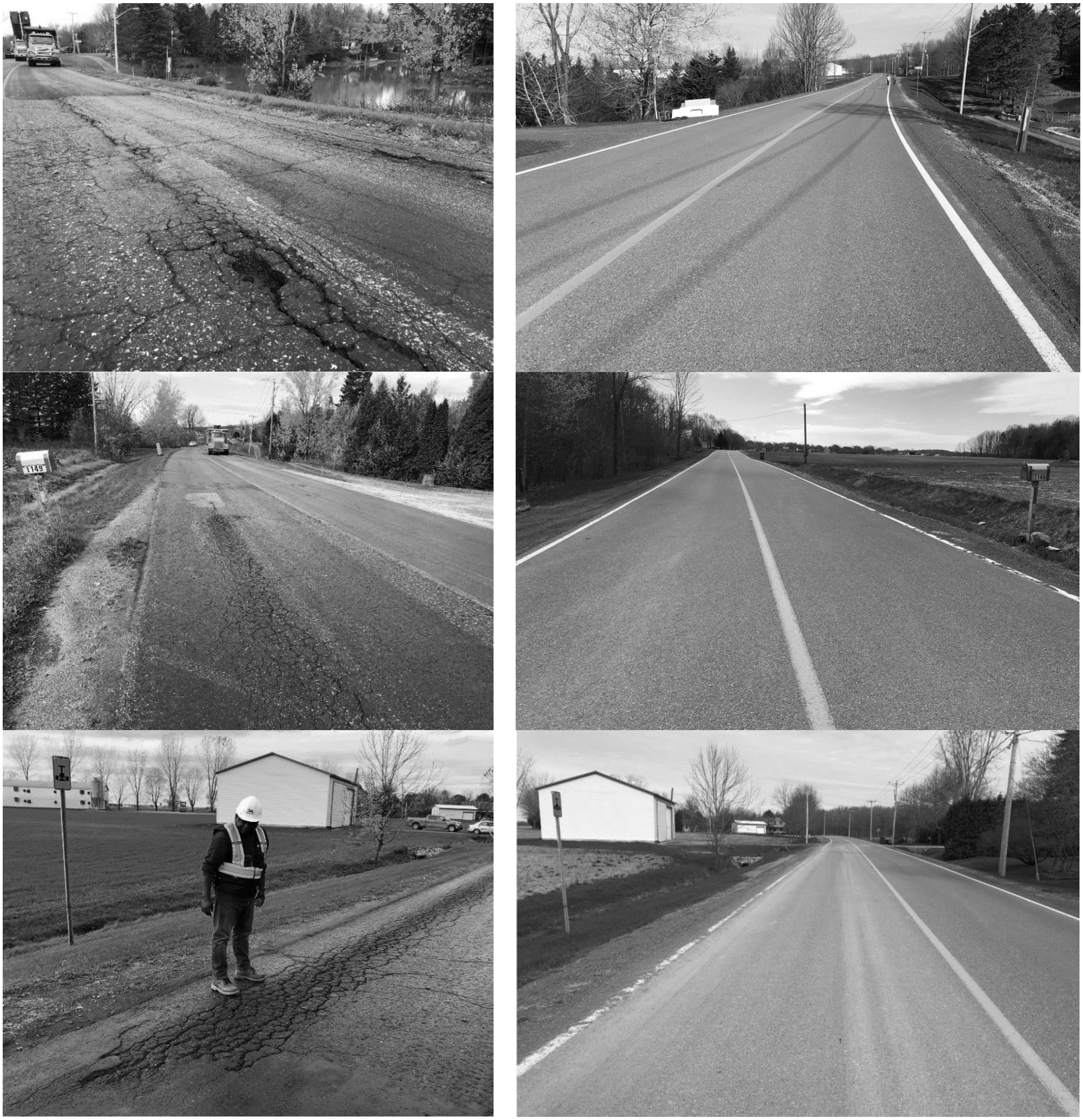
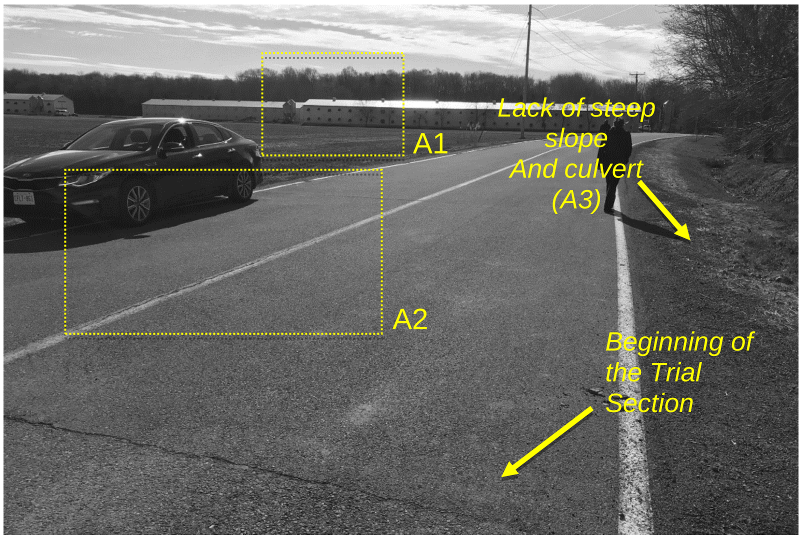
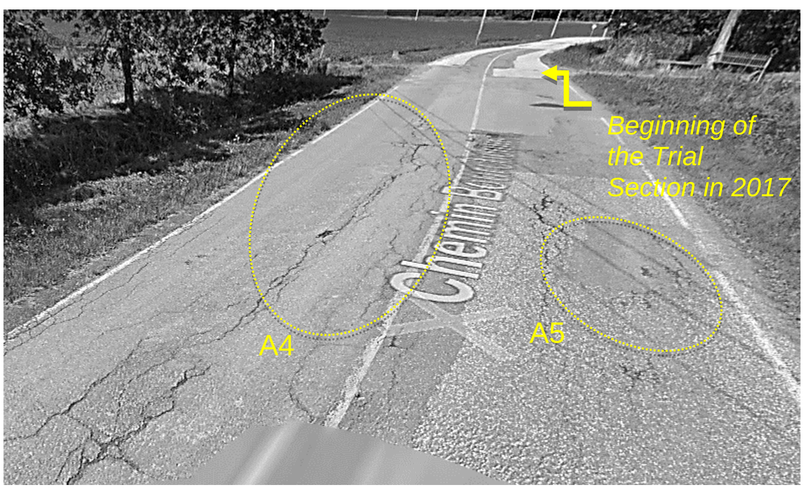


Figure 7. Distresses Documented in October 2017 Prior to Placement of Enrobés Flexibles Municipaux (EFM) Overlay (Left Column) and Same Locations in May 2019 (Right Column)

No cracks had reflected through on those badly distressed areas, expect for few longitudinal cracks located at the beginning and end of the trial sections as shown Figures 8 and 9.

After reviewing the sections more in detail, the root cause of these reflected cracks was assumed to be related to weak base/sub-base and/or lack of structural drainage. This assumption was based on visual assessment of drainage ditches illustrated in Figures 8 and 9. Low severity transverse cracks (thermal cracking) were observed to reflect through the EFM mix at some locations. These cracks were less than ½-inch (12.5 mm) wide.





Picture retrieved from Google Earth showing the road condition in August 2011. The discoloration on the surface suggests mill and patch type of repair which may have been utilized to address the drainage issue. Also, note the differential settlement in area marked as "A4" and "A5".

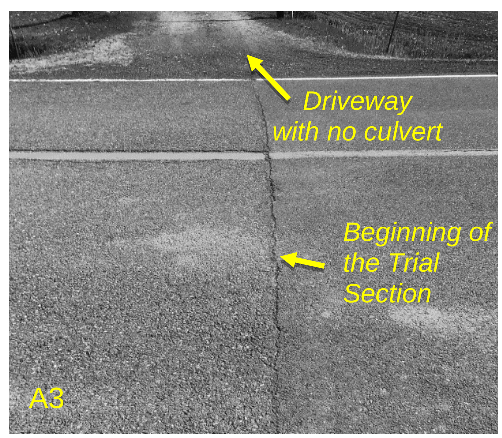


Figure 8. Isolated Longitudinal Cracks Observed on the Trial Section in May 2019 Field Follow-up

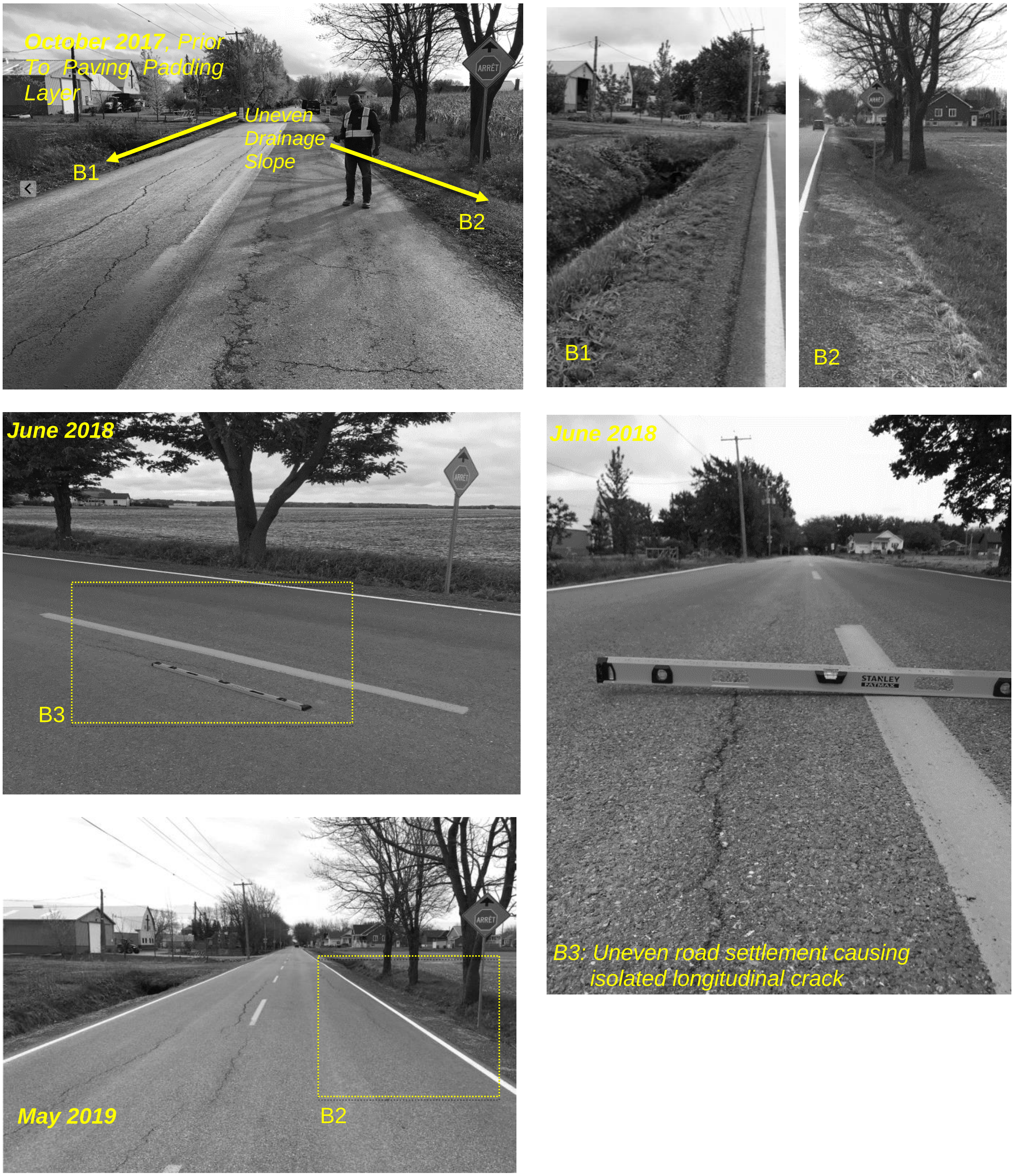


Figure 9. Isolated Longitudinal Cracks Observed on the Trial Section in May 2019 Field Follow-up

5.0 CONCLUSIONS AND RECOMMENDATIONS

EFM mix is often placed on rural roads that have not been properly maintained over their service life either due to lack of effective PMS or insufficient funding at municipal levels. For this reason, such roads could suffer from full-depth cracks, block cracking, deep ruts in the wheel paths or underlying structural problems, such as moisture or differential settlements due to lack of drainage. EFM mix is placed in two lifts: (1) a 25 mm thick padding layer to cover distresses as well as restore transverse profile (slope), and (2) a 50 mm thick surface course to improve longitudinal profile (smoothness) of the road and add strength to the existing structure by decreasing chance of stress failures in the bottom layers of asphalt.

This paper tried to shed light on efforts needed to close the gap between laboratory-performance and field-performance; in other words, how to truly design a "performance-based" mix that needs to meet certain performance-based and volumetric requirements. These requirements were expected to indicate low-temperature flexibility and long-term fatigue behaviour under repetitive stresses that would be expected from low to medium level of traffic coupled with extreme temperatures.

To experience with EFM type of mix, a mix can be created to exhibit flexibility as well as so called "self-healing" capability. This is mainly due to three main factors: (1) the open-graded nature of the mix, (2) the ability of the modified binder to exhibit so called "self-healing" when combined with the mastic portion of the mix (> 4.75 mm fines filled with asphalt), and (3) the aggregate-locking of the mix during placement at designed air voids. Moreover, based on the field experience, it is strongly recommended to address any drainage issues prior to placement of EFM mix to achieve ultimate performance of this mix. Drainage rehabilitation is an inexpensive item, which when combined with EFM, could extent the expected life. Also, crack sealing is an important option that should be considered within the first few years of EFM placement. EFM could be combined with inexpensive stress/strain relief interlayer to better combat reflective cracking, especially transverse cracks. This could be further catalogued into different combinations depending on severity and nature of cracks identified as part of pre-application distress survey.

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