The City of Edmonton Micro-surfacing Program
A 30-Year Successful Pavement Preservation Program

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Abstract

The City of Edmonton has used micro-surfacing (MSF), as a pavement preservation program, for 30 years. Every year, the City uses MSF to resurface several neighborhoods, minor collectors, and some industrial roads.

This paper provides the latest in the City of Edmonton's MSF applications and practices and compares it with other surface treatments such as slurry seals and mill and pave. Several MSF application sites in the City of Edmonton with different ages, rate of applications, and aggregate gradations were visited, as case studies, to investigate their effectiveness. Other Alberta's municipal agencies and Alberta Transportation were contacted to learn about their MSF experiences and practices to compare them with the City of Edmonton's practices. A contractor's perspective about MSF has been included.

Based on the City of Edmonton's experience, the following are the most important considerations in a successful MSF program: a long-term project commitment, right project selection, material components (asphalt and aggregate), mix design, equipment calibration, monitoring, and local adjustment of rate of application. Environmental aspects, challenges, future improvements, and research topics in the area of MSF will be discussed.

Review of Micro-surfacing as a Pavement Treatment Method

Slurry surfacing was introduced in the 1930s in Europe. With improved emulsifiers, continuous flow machines, and set control additives, Micro-surfacing (MSF) was introduced in the mid-1970s and has been used in North America for more than 40 years [1]. These days MSF is used by most highway agencies as a pavement preventive, a routine, and a corrective maintenance method. When MSF is used in the right times and places, not only does it provide significant cost savings to road agencies, but also it saves energy and generates a smaller carbon footprint, which these days are important considerations for most agencies.

MSF is in the category of "wet mix" surface treatments which includes a mixture of 100% crushed and dense-graded aggregate, around 7% polymerized asphalt emulsion, water, and 1% mineral filler. MSF is a mixed-in-place process and should be placed when pavement or air temperature is above 10°C and freezing is not expected for at least for 24 hours. MSF is more complicated than hot mix asphalt as it has more ingredients (modified asphalt emulsion vs asphalt cement) and its performance depends on chemical interactions between its ingredients.

Generally MSF is used more by municipalities and chip sealing is used more by highways as preservation treatment methods. From a municipal road owner's perspective, some advantages of MSF are lower cost, reduced future road maintenance, extended pavement life, and quick construction and opening to traffic. For contractors, some advantages of MSF include: in place mixing, high productivity, and lower risks.

It is not easy to quantify the effectiveness and lifespan of MSF accurately. The only solution to evaluate the life of MSF projects is to monitor them by visual field observations. Some aspects of MSF service life that can be evaluated could be: percent of ravelled areas, loss of the surface texture, and delamination. The expected life of MSF has been reported from 3 to 10 years depending on several factors such as traffic and more specifically heavy traffic, plowing frequencies, road pre-construction condition, and rate of the application. The NCHRP Synthesis 411 survey from North American agencies in 2010 indicated the life of MSF from 3.6 years, as the minimum, to 13 years, as the maximum, with an average of 7 years [2].

MSF must be placed on structurally sound pavement and it does not improve the structural capacity of a road. Pavements with minor or moderate cracks and ravelling can be considered for MSF; however, roads with extensive and wide cracks or distorted cross sections should not be considered for MSF. There are different opinions about the effectiveness of MSF on preventing reflection of cracks. Marquis does not claim MSF will stop reflective cracking, but reported that MSF slows the severity of reflective cracking. Other studies are not as optimistic about MSF's ability to positively affect cracking as Kazmierowski and Bradbury declared that it does not inhibit reflective cracking [3 and 4]. When MSF is used as a rut filling with/or multi-lift and/or at high rates, it can improve the road profile and surface smoothness.

Most agencies follow the International Slurry Seal Association (ISSA) A143 as the Guide for their MSF material selection, mix design, and QC/QA. This Guide is modified frequently; therefore, it is important that agencies review and use the latest version of this Guide. The latest version of the ISSA MSF Guide is dated August 2021 [5]. ISSA also has similar Guides for other pavement preservation treatments such as chip seal, slurry seal, and crack sealing.

Comparing Micro-surfacing with other Preservation Treatments

The closest pavement preservation treatment methods to MSF are slurry seal, chip seal, mill and pave, and thin asphalt overlays. One difference between a slurry seal and MSF, based on ISSA Guides, is that slurry seal has three aggregate gradations (Types I, II, ad III), but MSF has only Types II and III of the same gradation limits. ISSA also suggests three aggregate gradations for chip seals (Types I, II, and III) that are different from slurry and MSF gradations. Other aggregate properties such as soundness and Los Angeles (LA) abrasion requirements are the same for slurry and MSF. The required Sand Equivalent (SE) requirement for slurry and MSF must be 60% and 65% respectively [5 and 6].

Another difference between slurry seal and MSF could be on their emulsions. The older version of the ISSA slurry seal guide (A105, May 2020) allows non-modified emulsions; however, ISSA A115 provisional slurry seal Guideline (July 2019) introduced a polymer modified emulsion similar to MSF for slurry seal applications [6]. As this paper was under review, ISSA replaced its July 29 slurry seal (A115, 2019 previsional) Guide with a new guide (A115, May 2022) with polymer modified emulsion and. If a polymer modified emulsion such as CQS-1hp is used, the specification testing methods and requirements are the same for both of these treatments. ISSA requires a minimum of 3% of weight polymerization for MSF asphalt emulsion; however, for a slurry seal, it allows other considerations than 3% depending on project performance expectations. Most MSF applications use 3% modification and not many studies have investigated the impact of higher levels of polymerization on construction and performance of MSF. As the aggregate gradations, cleanness, and shapes for chip seals are different than MSF and slurry seals, ISSA allows other asphalt emulsions such as RS-2, RS-2h, HFRS-2, CHFRS-2P, CRS-2, CRS-2h, CRS-2P (SBS), CRS-2L for a chip seal [7].

Most applications of MSF in North America use a CQS or CSS emulsion. CQS1hp is used by most municipalities as it breaks quicker and allows the surfaced to be opened to traffic in a short time. In most cases, asphalt suppliers use a PG 58-28 or PG 64-22 as the base asphalt binder to produce a modified emulsion for MSF. Different performances are expected from the same base asphalt binder in wet and hot processes. When suppliers make an emulsion mix for surface treatment, the binder is not subjected to the oxidation such as in the hot mix plant; consequently,

a hot process could end up relatively to “harder” in-place asphalt than in a case of an emulsion mix application with the same asphalt binder.

The differences in rate of application for Type II and III of slurry and MSF, in Table 1 from the ISSA Guides, indicates that in some cases MSF can be placed at multiple layers and at higher application rates than slurry seal. The main reason for higher rates for MSF is to allow it as a rut filling and multiple layer surface treatment [5 and 6].

Table1: Slurry Seal and Micro-surfacing (MSF) Application Rates and Locations

	Slurry Seal (Kg/m^2)	**Micro-surfacing (Kg/m^2)**	**Application Locations**
Type I	4.3 to 6.5	NA	Parking areas, urban and residential areas, and airport runways for slurry
Type II	5.4 to 9.8	5.4 to 10.8	Urban and residential areas and airport runways for both, **scratch or leveling course for MSF**
Type III	8.1 to 12.0	8.1 to 16.3	Primary and interstate routes for both, **wheel ruts, scratch or leveling course for MSF (as required)**

Some modifications in the new ISSA A115 (July 2019) Provisional Guideline for slurry seal include: options for asphalt choice, residual asphalt recovery options, higher sand equivalent value requirements (60% instead of 45%), tighter mix design performance expectations, and heavier application rates for both Type II and III gradations. These upgrades make slurry seal and MSF more interchangeable. Still one difference is that a slurry seal should not be used for multi-layer reprofiling, leveling, or rut filling applications, but a MSF can be used [5 and 6]. Based on ISSA A143, All MSF rut-filling and level-up should cure under traffic for at least 24 hours before an additional layer is placed [6].

Some agencies have reported the application of tack coat, fiber, and higher polymer emulsions (>3%) for their MSF applications; however, not enough studies were found about the effectiveness of these factors in the life of MSF. Some general consensus regarding the application of tack coat is to use it on very aged asphalt surfaces and on concrete surfaces.

In terms of warranty, based on NCHRP 411 in 2010, Alberta, British Columbia, Quebec, and Saskatchewan require one year warranty and Manitoba, New Brunswick, Nova Scotia, and Ontario require two years warranty for their MSF projects. Indiana was the only agency that asked for a 3-year warranty [2].

Review of Micro-surfacing Applications in Alberta

Several Alberta’s municipal agencies and Alberta Transportation were contacted to learn about their MSF practices. A summary of verbal discussions and email exchanges form these agencies are presented below. Contact information from these agencies is provided in acknowledgments, if more information from these agencies is needed.

City of Edmonton

A paper by Kucharek et al. in 2010 reviewed the application of MSF in the City of Edmonton as follow [8]:

> *The City of Edmonton began using micro-surfacing in 1992. At that time, it was mainly applied to industrial roads that were still in good condition, but were showing some signs of surface oxidation. This program was discontinued in the mid-90s due to budget issues, but returned in 1998. In 1999, the process started also in neighborhoods that had been resurfaced ten years prior and with time that has become the standard practice. Edmonton is calling the product micro-surfacing but the gradations used are a Type I and a Type II, with the Type I being used on residential roads. This is technically a polymer modified slurry seal. The Type I gradation is much more readily accepted on residential streets, as it delivers a very fine surface texture. In terms of volume, Edmonton's program varied widely for the last 10 years. The contribution of the micro-surfacing program to the life cycle cost improvement of Edmonton's road network is outstanding, providing more service life per dollar than any other method of intervention. The program is currently at a point where re-treatment will begin on roads that were initially surfaced ten years ago.*

The City's MSF project is a joint program between the City Life Cycle Management Section (LCM -Transportation Asset Management) which provides preliminary locations to the City Operations for each year based on past neighborhood renewal history and pavement conditions. Normally the projects are selected on roads within 8-12 years after their paving/resurfacing. The Infrastructure Maintenance Section (IM-City Operation) provides preliminary field evaluation and construction management services for this program.

Since 2010, the City of Edmonton has increased the volume of MSF projects by approximately 10%. From 2011 to 2016, approximately 1,764,000 m^2 of roads have been resurfaced using MSF. In 2017 and 2018, no MSF took place due to City contract preparation delay. After that, this program continued in a 5-year contract (2019 to 2023).

Before 2019, the City used two types of MSF seals. Type I (from slurry seal gradation) for local roads and Type II for higher truck routes, local industrial, and collector industrial. In 2019, an internal review was undertaken to include a guaranteed minimum of 650,000 m^2 per year for the next 5 years. The results of the review concluded it would be in the best interest of tax payers to increase the application rate by 25% to attain a greater life expectancy. Later, the City and the Contractor came to an agreement to utilize Type II only in residential and collector roads and Type III on high truck traffic collectors within the industrial areas. Based on this 5-year contract, 72 neighborhoods with an approximate area of 3.5 million m^2 will be surfaced by MSF which will be close to 20% of all City's neighborhoods.

As part of the MSF program, the City also allocated extra budget to complete surface preparation and repairs for asphalt surface and sidewalk prior to MSF placement. This is done primarily by the City paving crews to level and fill surface deflections and minor potholes with asphalt mix before applying MSF. Traffic marking removal and installation is the responsibility of the City and is funded under the MSF program.

The City of Edmonton has not applied any rut filling or crack sealing prior to MSF. Currently, the City has not applied a second coat of MSF to any previously completed road segments. The City uses CQS-1hp with 3% (of weight) latex SBR modified emulsion for its projects. The base asphalt is a PG 58-28 and no tack coat or rolling has been used in the City projects.

The City of Edmonton believes that the following factors have been key to the 30 year success of the MSF program: having a long term program commitment, monitoring and evaluating program effectiveness and adjusting the type and rate of the applications, ensuring proper project selection, and having a good relationship with contractors and the public. The City is exploring the use of MSF on some bridge decks to improve their surface traction in the future.

City of Calgary

The City of Calgary (CoC) has been using MSF for over a decade now. Previously the CoC has used other maintenance strategies like slurry seal and a limited application of chip seal. The City has used Types I, II, and III MSF depending on the roadway classification. Currently, the CoC doesn't have specifications for MSF and follows the ISSA Guide. On average the City applies MSF on 85,000 m^2 area every year. The City has used different combinations with MSF like having tack coat prior to application and adding fibres to Type II MSF; however, has not done any comparative studies about these applications.

The CoC uses MSF as a preventative maintenance tool to seal and restore pavement surfaces, as well as provide improved pavement skid resistance. MSF is also used to restore the cross-section of rutted pavements. For the selection of roadway candidates they must be structurally sound and the predominant distress is ravelling.

The CoC did experience some resistance to MSF application particularly when using on residential roadways. Citizens consider this as a black paint and prefer a regular overlay on their roadways. The other concern reported by citizens was the noise generated during the MSF application. Considering these challenges, the City utilized MSF in the past particularly in residential neighborhoods; while recently, MSF is mostly confined to industrial or major roadways. The CoC also has measured surface friction with different treatments at several locations and results showed significant improvement when a new paved MSF was compared with other surface treatments.

A life cycle cost analysis has been conducted to compare the economics of traditional paving (40 mm mill and inlay) against the application of MSF treatment. The outcome in terms of NPV indicated that, the Total Present Worth Cost for both treatments are within 5% and are very close.

The CoC also recognizes the following considerations when making decision for a MSF project:

- MSF will not improve the ride quality. This will trigger Visual Condition Index (VCI) earlier for rehabilitation and road users will not see any improvement. Furthermore, the backlog for pavement rehabilitation will not be reduced and hence the Key Performance Indicator (KPI) for good and very good roads will not improve.
- MSF will not improve the drainage, the number of manhole adjustments required, or result in any significant improvements along the roadsides.
- Apart from the lower initial capital cost, MSF is a preventative treatment that extends the

service life of a roadway; no milling is required and more roads can be treated within a given budget.

- The process is quick and typically can be completed in a single day, reducing the inconvenience to traffic and property owners.

- Conversely, mill and inlay is rehabilitation and provides about 25 year service life.

City of St. Albert

In 2015, the City of St. Albert (CoSA), with help of Alberta Pavement Managers User Group, did a side by side study on the northbound lane of its busiest road (St. Albert Trail) including: a Mill and Fill of SMA (with PG 76-28), a high traffic Asphalt (HT-Superpave with a PG 64-28), and a section of MSF (Type III, 16 kg/m^2 rut filling plus 18 kg/m^2 surface coarse) to compare their performances. The road had some block cracking, longitudinal and transverse cracking, and some rutting before these treatments.

Surface characteristics such as surface friction (using a grip tester) and noise were measured before and immediately after these treatments. Surface friction results showed no improvement for SMA and HT mix, but around 15% increase for MSF. The highest noise reduction at the time of measurement was 2.4, 1.2, and 0.8 dB reductions for HT, MSF and SMA respectively. In 2018 (3 years after construction), these numbers were 2.8 dB for HT, -0.5 dB for SMA, and 2.1 dB for MSF relative to pre-construction measurements.

The CoSA conducted an evaluation of high polymer emulsion MSF in conjunction with ACP in 2020. The main reason for this experiment was to improve the performance of conventional polymer emulsion MSF (CQS1hp with 3% polymer). It was expected that this would be beneficial in cul-de-sacs, residential areas, and very aged surfaces. Test sections are still being evaluated with few comments from them to date; however, early evaluation indicates better performance in these test sections.

The CoSA has also attempted to slightly increase the thickness of its MSF for local roads to improve surface texture and to achieve a more aesthetic look for residential surface textures. While this approach was successful, the higher cost of the application will challenge the application of MSF for the City.

In general, the CoSA is re-evaluating the use of MSF on its older roads and full depth asphalt local roadways. Issues with aesthetics, surface texture, cost effectiveness, and perceived levels of service to residents are being evaluated to determine metrics for future MSF applications. For collectors and arterial roadways, the City will continue to apply preservation techniques based on timing, Life CycleCost Analysis (LCCA), current performance and future demands.

City of Red Deer

The City of Red Deer (CoRD) used MSF on three bridges in 2014; however, the MSF failed within two years as the underlying top lift of asphalt was too degraded causing failure of the surface treatment and requiring the bridge decks to be milled and filled in 2018. In 2020, the City trialed MSF on one collector road and on three bridge decks with competent asphalt. The City used a Type III MSF with a tack coat for better bonding in this project. Prior to application of MSF, minor surface preparation such as milling and filling potholes/severe ravelling and spray patching wide

cracks was completed to ensure a longer lasting product. Generally the CoRD is satisfied with the 2020 MSF project and has continued the program with approximately 80,000 m^2 of MSF in 2021 and 100,000 m^2 in 2022 on a variety of arterial roadways. The City has also noticed a marked improvement in vehicle traction during winter on the bridges and roadways after applying MSF.

Sturgeon County

Sturgeon County (SC) introduced MSF into its Pavement Preservation Program in 2020. The County completed Type III MSF over 5.4 kilometers of roads with a fog coat on the shoulders. In 2021, SC increased their program from 52,000 to 94,000 m^2 spanning four different locations within the County. Type II micro-surfacing was also used for all subdivision roadways and Type III was used on collector roads and a preliminary fog coat of the entire roadway was introduced in this year as well. The traffic volume for collectors and subdivisions for MSF roads were from 1800 to 50 vpd. The 2020 MSF application was without a tack coat, but in 2021 a tack coat was used. The benefit with the inclusion of tack coats has not been discernible. SC has planned to do approximately 21.5 km of MSF in 2022.

The County believes that MSF has several advantages including: offering an affordable solution to extending the lifespan of a paved road network by 6-8 years, allows for minimal traffic disruptions due to its quick application, increasing skid resistance, and offering structural protection from moisture intrusion and oxidation. On the other hand, some concerns and challenges about MSF application are:

- Appearance to residents–Complaints were received from residents in a certain area of the County that the product was unsightly and the finished product did not feel as smooth as new asphalt.
- Transverse cracking reflected the first year after application –cracking is prevalent in areas that had transverse cracks. The 2021-2022 freeze thaw cycle played a big factor in this.
- Heavy MSF construction equipment limits its application on some roads. SC tried using MSF on a section of road; however, the road could not support the MSF paving machine.
- There are a limited number of vendors engaged in the work, as it is very specialized.
- Type II provides a smoother finish for subdivisions, but hard to match seams within the confines of a subdivision where there are bulbs and curves within. Type III has a rougher surface and generates more traffic noise.
- Traffic accommodation has a quick set time with MSF, but sometimes not quick enough, so tracking can occur and disruption to the finished mat.
- Not easy to do small repairs with MSF, thus providing less continuity on matching the existing surface.

Alberta Transportation

Alberta Transportation (AT) has a comprehensive and effective chip seal program; however, will use MSF when locations are suitable (i.e., locations are structurally sound with some surface rutting). Therefore, AT MSF applications vary year by year with some years no MSF being completed. In 2022, AT asked for a total of about 502,000 m^2 (equal to almost 68 km of a two-lane

highway) MSF treatment. AT follows the ISSA MSF Guide and only uses Type III with CQS-1hp asphalt emulsion. In the 2022 MSF application, a tack coat also was required. AT does not have any performance evaluation with or without tack coat at this time, but expects to obtain a better bond between existing surface and the MSF by using a tack coat. The AADT of the MSF locations varied from 400 to 4000 vpd. Previous AT guides specified a traffic volume of more than 20,000 vpd for MSF; however, AT changed this consideration in its latest Design Bulletin #102, in December 2019 as follow [9]:

> *Micro-surfacing may be considered for any paved road. Micro-surfacing is the preferred treatment for paved roads with AADT >20,000 that require work to be completed during off-hours (i.e. night time work); or in urban and semi-urban applications; or locations with significant turning movements. Micro-surfacing may not be used in place of Double Seal Coat, also microsurfacing can be used for rut-filling applications either with or without a subsequent pass across the entire travel lane.*

A Contractor's Perspective

Cost control is an important consideration for any contractor especially for a long-term contract. With the recent supply chain issues and higher price of the oil, it is expected that the cost of MSF will also increase. Based on the City of Edmonton contractor, asphalt emulsion makes up approximately 35%, and aggregate and construction (equipment and wages) are responsible for 65% of MSF unit rates respectively. The price of asphalt emulsion is more variable than the price of conventional asphalt cement due to the cost of the latex and the additional processes required in the refinery. As asphalt cement is responsible for approximately 64% of an emulsion, it is expected that the cost of MSF increases more than 15% just because of the higher price of oil these days. All carbon tax pricing for the asphalt emulsion and aggregate are passed to the owner agencies. Also, if health and safety regulations change, it will impact the owners' costs. One example was when Manitoba Highways changed their specifications that flaggers can no longer be alone, consequently the cost of traffic control increased.

With limited aggregate sources, it is a challenge to find a high-quality aggregate source in Alberta. For the duration of the City of Edmonton's project, the same aggregate was utilized due to its proven mix design. For the aggregate used in this project, LA Abrasion data ranged from 23-29%, as an ISSA requirement. The ISSA A143 specification requires SE of 65 which is often difficult to meet. As a result, City results range between 60-65. Oversize aggregate is often introduced through contamination during the aggregate processing. For this reason, before leaving the City's facility, all aggregate is additionally screened to remove any oversized material. Any large stones will leave marks and cause defects on the road.

Calibration is done at the start of the project for each mixing machine and each mix type. Calibration is documented and generally done in the City's yard with easy access to a high precision scale. Calibrating the trucks ensures that the proper ratios are achieved between the aggregate, emulsion, and cement. All material weights are recorded throughout construction and checks are made on a regular basis to ensure the appropriate application rates are followed.

Surface preparation is a crucial step which is often overlooked. Roads are pre-swept using a regenerative air sweeper. A blower is then used directly in front of the operation to catch any remaining debris. Blowing in front of the operation is most important in the latter part of the

season when leaves begin to fall. Areas that are not able to be cleaned by the sweeper, typically clay, are identified and are cleaned by washing ahead of time. If there is oil or grease on the road, it will require additional cleaning. If the weeds are not adequately removed, they will grow back and cause cracks in the final product. Weeds are removed down past the roots using a hot air lance similar to crack treatment preparation. The road is pre-wet with sprayers in front of the truck to break surface tension and promote adhesion.

To ensure the utilities are fully protected, all catch basins, manholes, and water valves are removed and wrap them entirely with a thick vapor barrier. Once they are wrapped, they are placed back until the MSF is cured. Once cured, we remove them again, take the vapor barrier off, and put them back. Depending on the thickness of the micro-surfacing at the utility, some hand work may be required to smooth the transition and make it aesthetically pleasing.

Precipitation is closely watched. Cure time varies depending on various factors, including ambient temperature, emulsion temperature, humidity, etc. Operations will cease if perception is expected before adequate cure time is achieved.

Communication is the key to residents, business owners, and city services. Advertising boards are placed in the work areas to provide advanced notice. Before mobilizing, written notices are delivered to all affected business owners/residents that indicate what will be done with contact information. Further to this, the traffic control crews will go door to door before closing off the road and accommodate anyone who needs out. Dealing with traffic is often the most challenging part of the operation. Depending on weather and mixing conditions, around 4 hours is required before residents can drive on the road. During this time, full closures are in place and monitored by a traffic control crew. If traffic is permitted on the road too early, it can cause tear-outs and noticeable indentations that affect the aesthetics. In some cases, this can result in large sections that need to be re-done. In most cases, work will not take place on local garbage collection days as the work impedes collection and the large trucks can damage the paved surface.

Given the low traffic speeds in the residential areas, the joints are not as critical as on a highway project where every bump is noticed. Joints are feathered to make the transition smooth as possible, but the further emphasis is on ensuring the proper application rate is applied and no gaps are left at the joints. Along the edge of the road, cracks are filled between the curb and the existing asphalt. During the curing time, we will have a crew “cut the curb” manually and clean up any spilled material that has run in the curb.

Daily checks on application rates are performed. Emulsion suppliers follow their relative QC plans and provide tickets of conformance. Aggregate is checked for gradation and SE periodically from the stockpile location. Infield samples are taken from the back of the pugmill by both the City and Contractor. These samples are then burned to obtain an asphalt content and gradation.

One issue surrounding MSF, especially in residential areas, is the brown color that often occurs. This varies depending on the conditions when the material is cured and some roads will turn browner than others. We are currently exploring mix designs that would introduce “carbon black” into the mix. This should give the end product a more desirable black color that lasts longer. We have also experimented using a double modified CQS1hp within the MSF in the City of St. Albert. This process involves using modified emulsion with higher polymer content. In theory, this should resist shear force better and reduce the tear-outs from dry steering and improve the longevity in intersections. This experiment will be monitored in the future.

Environmental Benefits of Micro-surfacing

Several studies have investigated the environmental aspects of various pavement treatment methods including MSF.

Chehovits and Galehouse compared Type II and III MSF with two hot mix asphalt overlays (18 and 50 mm thicknesses) and concluded that MSF requires almost 9 to 15.7 times less energy and generates between 16 to 33 times less GHG Emissions [9].

Zheng et al. studied five different pavement maintenance techniques including fog seal with sand, MSF (10 mm thickness), composite seal (20 mm thickness), ultra-thin asphalt overlay (25 mm thickness), and thin asphalt overlay (30 mm thickness) in China using a “birth to death” approach and concluded that fog seal with sand and MSF can lower life cycle environmental by more than 50%. A sensitivity analysis was also conducted to investigate the LCA results at different decreasing service life rates (0%, 10%, 20%, 30%, and 40%) concluded that service life may not create a significant impact on life cycle analysis results to some extent [10].

Uhelman et al. conducted an Eco-Efficiency Analysis (EEA) study for BASF to evaluate the life cycle cost and environmental impact of an asphalt emulsion based MSF modified with SBR polymer and a Mill and Fill for urban roads. The Customer Benefit applied to both alternatives for an urban road to a similar profile and performance using best engineering practices over a 40 year period. The application of MSF was based on ISSA Guides as 10.8 kg/m^2 for wheel rutting, conservatively applied across the entire road surface, with an additional 13.5 kg/m^2 for the final surface treatment. A 50 mm application was assumed for the Mill and Fill with 10.9 years life with 10% RAP. The MSF and Mill and Fill life expectancy were considered as 5.9 and 10.9 years. Based on these considerations, MSF showed the lowest carbon footprint, which resulted in the emission of around 145,000 kg of CO_2 equivalents per customer benefit. This was almost a 45% reduction compared to Mill and Fill [11].

Foth and Berthelot quantified the whole CO_2 generation for different pavement treatment methods including MSF and Mill and fill. It was shown that the average CO_2 generated by MSF was higher than seal and slurry seals; however, it was the lowest than all other pavement treatment methods. Results of this study showed that a Mill and Fill generate almost 17 times more CO_2 than a MSF [12].

The general consensus is that MSF reduces the required energy and generates less GHGs compared with other asphalt pavement treatments.

City of Edmonton Field MSF Evaluation

Several MSF site locations in the City of Edmonton with different ages, MSF application rates, and mix types were visited in April 2022 to assess their effectiveness. Observations from these locations are explained in the next sections.

Case Study I - Athlone Neighborhood (Type I, application rate 6.81 Kg/m^2, placed in 2014)

Field observation showed that at high traffic locations with turning movements, MSF has failed due to delamination and ravelling. At lower traffic areas, MSF still was in place. Certainly the effectiveness of the MSF was lower at the locations with many reflected cracks. One interesting observation was around a roundabout boulevard with only local traffic which MSF was still

effective after 8 years. Photos 1 and 2 show the difference between high and low traffic locations. It was concluded that MSF has done its job and still is effective at low traffic locations. Also, the difference between the parking and driving lanes were clear. It is not expected to resurface this neighborhood with another MSF in the future as it needs a mill and fill or rehab in most locations.

Photo 1: Ravelled areas after 8 years (left) and Photo 2: A better MSF performance in a roundabout boulevard was still effective after 8 years

Case Study II - Prince Rupert Neighborhood (Type I, application rate 8.84 kg/m^2, placed in 2015)
This MSF application was placed with low rate and fine gradation and was 7 years at the time of inspection. Images from pre-construction condition of roads indicated that MSF was placed at the end of this surface life with aged surface and many repaired and unrepaired cracks that have been reflected. In different locations, 20% to 60% of MSF was still visible. Delaminated/ravelled areas were at high traffic locations and mainly in the wheelpaths. Although a mill and fill was more effective, MSF has performed reasonably to postpone the rehabilitation. Photos 3 and 4 show a ravelled area and the difference between a non-treated and MSF treated surface.

Photos 3 and 4: Delaminated MSF area (left) and difference between untreated and MSF treated surface after 7 years (right)

Case Study III- Jasper Place Neighborhood (Type I, application rate 6.54 kg/m^2, placed in 2016)
Images from pre MSF application indicate that MSF was placed on a surface with many cracks, but was structurally sound. MSF was ravelled in the wheelpath areas, but was in place in other areas. This MSF was with the slurry seal fine gradation (Type 1) and with a low rate of the application; therefore, a life of 5 to 6 year could be considered as a reasonable performance. Due to extensive cracks, another MSF is not recommended for this road in the future. Photos 5 to 8 show the condition of MSF at this location.

Photos 5 to 8 show the condition of MSF after 6 years. Some ravelled areas between the wheelpaths were observed.

Case Study IV - Sherbrooke Neighborhood (Type II, application rate 14.82 kg/m^2, placed in 2020)

Images from pre-construction indicate that MSF was placed at the early ages (8-10 years) after paving which was in a good condition without many cracks. At the time of inspection no failure or delamination was observed. Not many reflected cracks existed, only limited transverse cracks were reflected. Photos 9 to 12 show the effectiveness of MSF at the time of inspection after 2 years. Another MSF can be applied at this location in 5-7 years.

Photos 9 to 12: Effectiveness of MSF at different locations after 2 years

Case Study V- 114 Ave (Type III, application rate 20.06 kg/m^2, placed in 2020)

114 Avenue between 149 and 170 Streets located in an industrial area, with two lanes per direction, high truck traffic, and subjected to frequent snow plowing. It seems the latest paving was in 2008; therefore, it was 12 years old when treated with MSF. Pre-treatment images show some repaired and unrepaired transverse and longitudinal cracks, a reasonable cross section, minor fatigue cracking, several utility patches, and few repaired potholes. Review of FWD testing data in 2014 indicated that a segment of this road between 163 and 166A Streets (before and after a railway crossing) had structural deficiencies and normally a MSF should not be used for this segment. City maintenance crew mentioned that this road was in a very bad condition with many failed locations before MSF treatment. The objective of MSF was to extend the life of the surface until the future rehabilitation.

Based on field observations, this location was an extreme application for a MSF and it is not expected to last more than 5 years. Some damaged areas close to the curbs reflected in both directions. Most cracks reflected after the first winter. At two localized locations some surface delamination existed. One failed location was close to the rail crossing that had structural problems and another location could be related to dirty surface before MSF application in front of an approach. Except for these two locations, MSF was effective in other locations. If the main objective of this MSF was to provide short-term ride improvements and to postpone the next rehab, it can be claimed that MSF has done its job and has improved the ride significantly. Photos 13 and 14 show two delaminated areas close to the railway crossing. Photos 15 and 16 show locations with better MSF performance.

Photos 13 and 14: Two localized failed MSF locations

Photos 15 and 16: Area with reasonable MSF performance. Difference of surface colors between two lanes was noticed

Case study VI - Millwood Road at Knottwood North (Type II, application rate 14 kg/m^2, placed in 2021)

This MSF project was less than one year old at the time of inspection. MSF was in place without any ravelling or delamination. Limited longitudinal cracks were reflected. One observation was the presence of drag marks in most locations. Photos 17 and 18 show before and after MSF application conditions of this road.

Photo 17 : Pre-treatment condition (left). Photo 18: MSF condition after the first year. A drag mark was visible in most locations (right)

General Observations from the City of Edmonton MSF Projects

The following summarizes some general findings from the limited number of City of Edmonton MSF projects based on field observations and communications with the City's maintenance crews:

- The City's MSF project has been a success due to program perseverance and adjustment of rate of application to find the best mix, type and rate of application. Based on limited observed locations for this paper, the expected life of MSF could be 5 to 10 years as a function of traffic volume and rate of MSF application. A section of road with localized traffic was expected to last more than 8 years.

- Based on limited field observation, the City of Edmonton MSF applications can be categorized in two groups: preservation, those that were placed in an early stages with

good surface condition which is possible to apply another MSF after the life of the first application (like Sherbrooke location), and corrective, those that MSF postponed the rehab for 3-5 year like 114 Ave.

- Winter maintenance can be done on MSF roads without any issues. No significant damage from plowing was observed.

- Cracks normally reflected after the first winter. This will impact the life and effectiveness of the MSF depending on the extent and severity of cracks before placing MSF.

- MSF is sensitive to traffic volume; therefore, type and rate of the application must be adjusted even inside a neighborhood as a function of traffic volume. One challenge in the application of MSF, in specific neighborhoods, is that some roads with higher traffic and buses need different MSF type and rate of application which makes its construction difficult.

- At higher rate of the application, the wheelpath locations were observed darker and smoother than the area between the wheelpaths due to traffic compaction and consequently higher density.

Summary, Challenges and Future Improvements to Micro-Surfacing Projects

MSF is an economical, effective, and environmentally friendly surface treatment when it is placed at the right times and locations. The City of Edmonton's experience with MSF indicated that agencies could initiate and monitor their MSF applications to find the best road condition and mix type for their traffic conditions. Adjustment of the MSF rate of the application is an important factor in smoothness and durability of MSF. There are several technical and non-technical issues that could be investigated to improve the MSF performances in the future. Some topics in this area are explained briefly below:

- The existing MSF material selection, mix design, and testing procedure need improvements. Some tests such as ignition oven, distillation methods, residue binder tests, and mix design tests are not performance-based or have high variabilities [2, 13 and 14]. There are several efforts to improve the existing MSF mix design and testing. Caltrans has proposed new mix design methods for MSF, a German Method has tried to predict mixing time by measuring mixer torque, and a French adaptation of the wet track abrasion test using wheels in place of the rubber tube are some examples are moving on more performance based mix design method and testing [15]. Other research topics in this area could be the impact of rolling, tack coat, and fiber applications on performance of MSF and improving its crack resistance.

- Rate of applications of a MSF need localized calibration and adjustment. Agencies should adjust the application rates for different roads by monitoring to optimize their MSF applications.

- Lack of competition is a challenge for some smaller municipal agencies. Creating a multi-year MSF program could address this issue. In a long-term contract, the cost adjustment must be defined clearly.

- Effective communication with the public and contractors/consultants is critical in an effective MSF program. The owner agencies can communicate the benefit of LCC of MSF, relative to other surface treatments, to the public to address their concerns.

- With the escalation of oil prices, it is expected that the price of MSF will also increase; however, agencies must pay attention that this also will impact other pavement preservation treatments such as mill and fill. The impact of carbon tax will be higher for hot mix applications relative to wet mixes such as MSF.

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