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An In-Depth Evaluation of Micro-Surfacing Treatment

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Abstract

Micro-surfacing since its formal introduction in 1980 has proved to be the number one treatment option for maintenance and preservation of pavements. This paper reviews the design and equipment practice, construction process, benefits, limitations and worldwide state of the practice of micro-surfacing. Two implemented project examples are also included to corroborate why micro-surfacing is a better preservation maintenance strategy. The general consensus from the literature is that micro-surfacing is a cost effective and eco-friendly treatment but more research needs to be done to validate and quantify the less environmental impacts and energy usage it offers unlike other treatments. Suggestions like standardization of the mixture design and whether rolling of the micro-surfacing surface adds value are future research topics that will greatly improve its effectiveness. It is my hope that through this review, more developing countries under strict budgetary constraints can take up this practice and enjoy the many benefits that micro-surfacing offers.

Keywords: Microsurfacing; Maintenance and Preservation; Cost-Effective; Standardization; Budgetary Constraints.

1. Introduction

Micro-surfacing is one of the most flexible treatments available for the maintenance and preservation of roads. It is a mixture combination of well graded aggregates of the highest quality, polymer modified emulsion, water, mineral filler and other additives properly proportioned, mixed and laid on a pavement that is structurally sound [1, 2]. Unlike slurry seals, micro-surfacing treatments can be applied in thicker lifts or multiple lifts for rut filling and can cover the entire width of the roadway. This treatment can be as thin as 9.5 mm and as thick as 1.5 times the maximum aggregate size in the mixture [3]. Micro-surfacing was developed in Germany in the late 1960's when German scientists started experimenting with emulsion and aggregate mixes so as to find a way of filling deep wheel ruts in thicker layers without destroying the expensive road markings in the autobahns. They discovered that if coarser aggregates were carefully selected and combined with emulsion containing polymers a resulting stable mix could resist deformation. Dr. Frederick Raschig formerly introduced micro-surfacing to the rest of the world in the 1980's at the International Slurry Surfacing Association (ISSA) convention were he presented his slurry system called Ralumac [3, 4]. Owing to the fact that micro-surfacing and slurry seals have similar ingredients, practitioners often refer to it as a "polymer modified slurry seal". The main difference however is that slurry seals are applied in a monolayer and cures through a thermal process while microsurfacing always contains polymers, capable of being laid in multiple layers and cures quickly through a chemical reaction which allows the surface to be trafficked in a short time after application [4, 5]. Micro-surfacing is mostly used as a maintenance treatment because of its ability to correct defects such as rutting, improve surface friction, raveling, transverse and longitudinal cracks which are less than 5mm wide. It also helps to provide a surface cover thus protecting the underlying pavement from water ingress, oxidation and ageing. This consequently improves the functional

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characteristics of the pavement surface hence extending its service life [6, 7]. Micro-surfacing is a weather sensitive treatment, so as such it should be applied at ambient temperatures above 10°C (50ºF), it should be applied if there is no forecast of freezing within 24 hours after laying of the mixture and when heavy rainfall is not eminent [8].

This article aims to put up a comprehensive in-depth analysis of micro-surfacing and to validate its use as a pavement preservation treatment. A brief history of micro-surfacing, common design and equipment practices, a description of construction process, benefits and limitations make up the main contents of this work. A first of its kind state of the practice in the biggest markets of the world is discussed clearly highlighting the directions that each agency is taking in improving the durability, versatility and performance of micro-surfacing. Two examples of already implemented projects are briefly discussed to further confirm the many benefits of micro-surfacing treatment.

Finally, a conclusion and suggestions on future research direction is given with the view of further enhancing the general acceptance of micro-surfacing as a preservation treatment even to agencies under strict environmental and budgetary restrictions.

2. Micro-Surfacing as a Pavement Preservation Maintenance Strategy

In a world where tight budgets are becoming the norm and the drive towards sustainability is the order of the day, It has become much more important to ensure that the existing roads lasts longer [9]. Studies have shown that preservation maintenance is strategy which is efficient and economical in the utilization of the scarce resources [10]. To validate the economic advantage of using micro-surfacing, a lot of life cycle cost analyses have been conducted in the last decade by agencies across the globe and it has been agreed that this strategy is the most cost effective and environmentally friendly strategy [10, 11]. Pavement preservation is a program that utilizes a long term strategy on a network level that augments the performance of the pavement by employing an integrated, cost effective set of practices that increase the pavement life, enhance safety and carter motorist demands [12]. The most important point to note is that in order to have a successful preservation program, a correct treatment needs to be applied before the road deteriorates to the point of rehabilitation. Figure 1 shows the relationship that a treatment has when applied at the optimal time to the overall pavement condition.

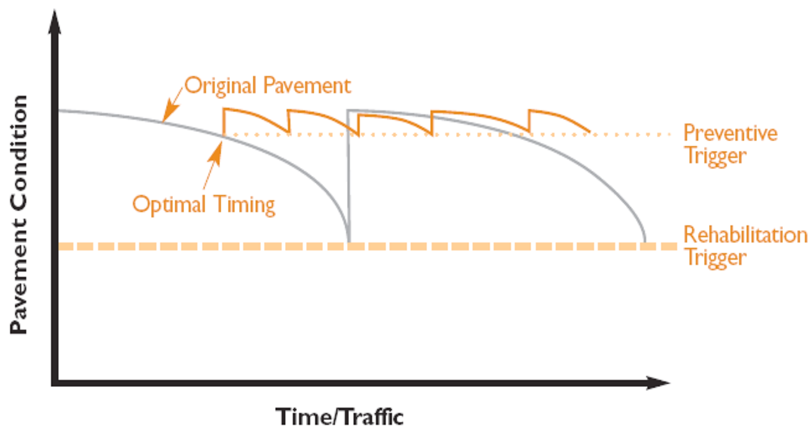

Figure 1. Pavement condition vs. time/traffic [12]

Owing to its robustness and flexibility, micro-surfacing can be used as a preventive, routine and corrective maintenance strategy as shown in Table 1.

Table 1. Micro-surfacing's relationship to preservation guidelines [13]

Pavement Preservation Guidelines						
	Type of Activity	**Increase Capacity**	**Increase Strength**	**Reduce Aging**	**Restore Serviceability**	**Micro-surfacing**
	New Construction	X	X	X	X	
	Reconstruction	X	X	X	X	
	Major Rehabilitation		X	X	X	
	Structural Overlay		X	X	X	
Pavement Preservation	Minor Rehabilitation			X	X	
	Preventive Maintenance			X	X	X
	Routine Maintenance				X	X
	Corrective (Reactive) Maintenance				X	X
	Catastrophic Maintenance				X	

The cost savings of having a pavement preservation program is illustrated by a study done by Galehouse et al. which showed that a $1 spent on pavement preservation at the right time can actually result in having cost savings of $6 in the future life cycle of the pavement [4, 12]. Figure 2 demonstrates the cost savings.

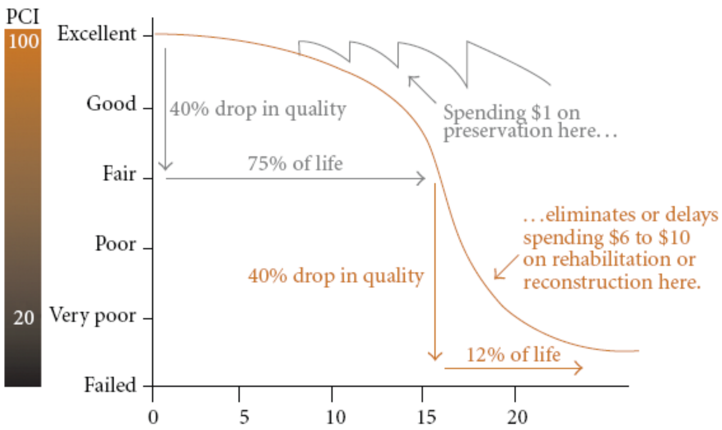

Figure 2. Pavement condition index (PCI) vs. time [12]

The use of micro-surfacing as a pavement preservation treatment has been widely validated in various literatures, a more recent study in China evaluated its performance using grey system models and grey rational degree theory. Over 5,375,000 data points including PCI, riding quality index (RDI), rut depth index (RDI) and skid resistance index (SRI) were collected, processed and analyzed. A new pavement quality index (PQI) model was developed and showed 5.7 to 11.9 years of service life of a micro-surfacing treatment but for this area considering the environmental and traffic conditions had 4.5 years of service life. This study further validated the use of micro-surfacing as a preservation tool by showing that both RQI and SRI values had a significant improvement even after 3 years of application. It also showed a reduction in RDI values and a relatively small pothole growth rate within 3 years of application [13].

2.1. Design Practices

The two basic design methods from which every agency worldwide bases there micro-surfacing designs are:

1. ISSA Design Method for Micro-surfacing (2010b): ISSA A143.
2. ASTM Design Method for Micro-surfacing (ASTM 2007b): ASTM 6372-99a.

With the International Slurry Surfacing Association (ISSA) Design Method for Micro-surfacing A143 design guidelines being the most adopted methodology [3]. The six basics design steps are as follows:

1. Road selection and characterization,
2. Material selection; emulsion, aggregate, mineral filler, additives and water,
3. Developing a mix design commonly known as a job mix formula,

4. Laboratory evaluation of the job mix formula meeting the ISAA A143 standards,
5. Determination of optimum application rates, and
6. Document preparation for construction.

ISSA clearly specifies the standard requirements of all test methods and the main ingredient, aggregate type used in micro-surfacing. The aggregate should be a high quality 100% crushed, densely graded either of Type II (less coarse) or Type III (coarser). The main difference is that type II is mainly used in urban and residential streets and airport runways while type III is used on interstate/primary routes and for rut filling [3, 14].

2.2. Equipment Practices

Construction practices and procedures vary from country to country and are normally associated with local equipment availability. On a typical micro-surfacing project, envisage finding the following types of equipment;

- Micro-surfacing mixing machine,
- Mobile support units for material replenishing,
- Brooms (rotary and suction),
- Rollers, if required.

The two main types of micro-surfacing mixing machine are the continuous self-propelled and the truck mounted mixing machine, with the former being the most recommended as it minimizes the number of transverse construction joints [3, 15, 16].

2.3. Construction Processes

Rule of thumb dictates an outside temperature of 10°C and rising prior to micro-surfacing application on the pavement. Then the pavement should be swept clean of foreign material to avoid delamination, cracks should be sealed and filled. Road markings abraded to produce a rough surface, rubber from skid marks removed, all utility inlets covered with roofing felt. Pre wetting the surface by spraying water so as to dampen the surface is normally not the norm same as applying a tack coat but if required actual specifications should be adhered [8, 14]. The mixing machine shall be a continuous flow mixing unit capable of precisely delivering and proportioning the aggregate, emulsified asphalt, mineral filler, water and additives in to a double shafted mixer with revolving multi-blades that continuously discharges the mixed product [15, 16]. A schematic of a micro-surfacing machine is shown in Figure 3.

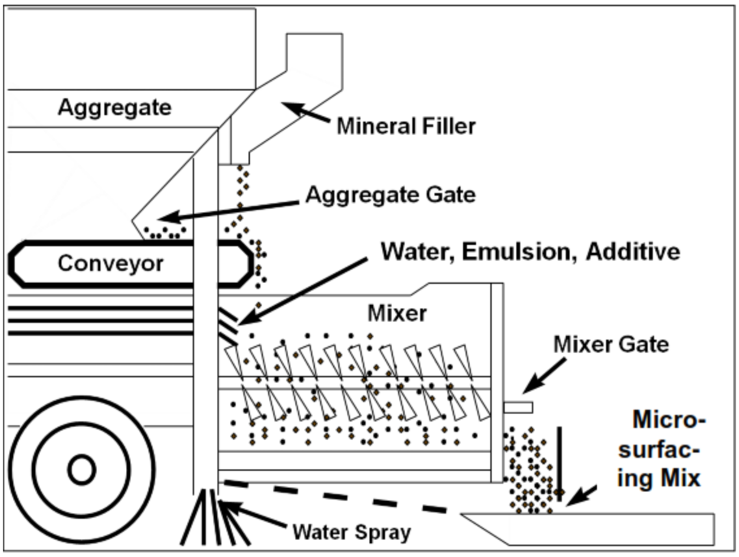

Figure 3. Schematic of a micro-surfacing machine [3]

For a full lane width application, the mixture shall be agitated and spread uniformly in the spreader box with the adjustable rear seal serving as a final strike off. If the texture is not up to expectation, a secondary rubber strike off can be provided [16, 17]. When required to fill ruts, ruts that are less than 12.7 mm (1/2 inch) deep shall be covered by a full width scratch coat which uses steel rather than a rubber as a strike off to ensure proper leveling of the resulting surface. For ruts deeper than 38 mm (1.5 inch), a rut box should be used and filled in multiple layers with a 24 hours waiting period in between lifts so that the surface cures under traffic loading [18, 19].

2.4. Benefits

The primary use of micro-surfacing is to fill ruts and re-establishing the transverse profile by filling cracks, sealing the surface and restoring the skid resistance with a service life of 5 to 7 years [2, 17, 20]. Garfa et al. in their study evaluated the effectiveness of micro-surfacing type III material in repairing the pavements rutting deformations. The results of the study showed that the longer the aging of the hot mix asphalt (HMA) pavement to be resurfaced by micro-surfacing is, the higher the rutting resistance will be. The caveat to achieving this is making sure the underlying HMA layer is well prepared to receive the micro-surfacing mix and that the application should never be done during the summer heat wave [21]. Micro-surfacing's ability to restore surface friction was evaluated in a study in Whitby, Ontario were a pavement had an initial skid number of 28 and after the application of micro-surfacing the skid number increased to 52 [22]. Standards show a skid number above 40 is generally an acceptable value. Merited by its ability to be laid in thin lifts, micro-surfacing requires no adjustment of curbs, manholes, guardrails or bridge clearances. Georgia Department of Transportation (DOT) and Oklahoma DOT found great success with micro-surfacing in correcting smoothness, moderate flushing and bleeding and low tire noise on the final pavement [8, 17]. Unlike slurry seals, micro-surfacing is not associated with loose aggregates which can lead to breaking vehicle windshields hence limiting costly claims from road users after project completion. Due to its cold application, studies show not only improved worker safety but also reduced vehicular crash incidents as Tighe found positive safety effects including 54% crash reduction factors [22]. Owing to the fact that a polymer is a prerequisite in the design mix, micro-surfacing resists deformation better than other conventional seals. The modified polymer helps to resist movement at high temperatures and cracking at low temperatures [7, 23].

Micro-surfacing if applied correctly and before any structural deficiency on the pavement is the most cost effective and durable strategy. Studies in Canada validate the cost effectiveness as they found out that the initial construction costs were 53% lower compared to the mill and HMA overlay treatment, while in the USA, the life cycle cost was 28% lower than the mill and HMA overlay with ISSA reporting costs of $17600 per lane mile while mill and HMA overlay costing $50000 per lane mile [12, 24]. On account of minimal construction plant required on site and its cold application, micro-surfacing has few environmental emissions and less energy usage. Takamura et al. in his 2001 study also concluded that the environmental footprint in micro-surfacing is lower than other preventive measures [25]. A study done in Canada suggests that a 10 mm micro-surfacing road on a square meter basis was found to emit 80% less CO_2, 86% less NO_X and 84% less SO_X compared to the 50mm mill and overlay [24]. Micro-surfacing is considered a more "green" solution than other type of treatments earning the moniker of the best sustainable option on the market. Literature shows that it uses 40 to 86% less energy than a 50 mm mill and overlay treatment and also its less usage of the aggregate [24, 26]. To put numbers in to perspective, it was found that during the life cycle of micro-surfacing and HMA, 76% less aggregate was used in micro-surfacing compared to HMA while another study in the USA showed 150% less aggregate been used [26].

A similar recent study showed that incorporating recycled asphalt pavement (RAP) and recycled asphalt shingles (RAS) into the micro-surfacing mixture further helps in reducing the embodied primary energy and greenhouse gas (GHG) emissions thereby solidifying why people call this treatment a "green" solution. These studies observed that any amount of RAP from 0 to 100% can be used in the mixture while the recommended amount of RAS to be added to the mixture is 17%. Furthermore 90% of RAP and 10% of RAS can be added to the micro-surfacing mixture while still be within the limits specified by ISSA guidelines [27, 28]. Micro-surfacing has a quick set time thereby allowing opening to traffic in 1 hour or less [3]. This aspect reduces user costs which comprise of Vehicle Operating Costs (VOC), Crash Costs and User Delay Costs even though more research is required to validate the claims [29]. In a world where people are more concerned with the aesthetic nature of pavements, a new type called pavements of color has gained attention especially in the European market. Micro-surfacing not only has good aesthetics because of the black surface texture it leaves on the road way but has showed that it is capable of producing colored mixtures with superior durability and performance compared to conventional mixes. This durability is achieved because of the ease of incorporating lower level bitumen residue while stabilizing the emulsion with nano-particles in micro-surfacing mixes [30].

2.5. Limitations

While providing the many benefits, micro-surfacing is not a cure all treatment. Numerous studies shows that it does not add any structural strength to the pavement unlike HMA overlay treatment, further analysis proves that it neither seals cracks nor prevent them from reappearing. Even though studies have shown that micro-surfacing is able to fill ruts and depressions, it is unable to level humps on the road [8]. It is therefore important to level all humps before application to avoid the reproduction of humps on the treatment surface. Labi et al. showed through their paper that micro-surfacing is effective under certain conditions. The effectiveness in the short term is generally influenced by climate, traffic loading and highway class while in the long term its effectiveness is limited by low freeze, traffic conditions and low pavement class [6]. While this study seems to suggest that micro-surfacing is not ideal on high trafficked roads, other studies found that micro-surfacing treatments can last from 3 to 7 years on medium to high volume roads [17, 31]. The main limitation of micro-surfacing is the lack of a standardized mixture design procedures. A study done by Robati et al. on the repeatability and reproducibility of micro-surfacing mixture design shows that a gradation having a higher amount of 0-2.5mm aggregates quickly sets and has a high resistance to rutting mainly due to the high surface area reaction with the asphalt emulsion. The study further found out that the same gradation has a high resistance to moisture susceptibility, early rolling of traffic and short term aggregate loss. The major conclusion was a call on the update of the current mix design method by precisely controlling the gradation of micro-surfacing and the variation acceptance on each sieve should be tightened [32]. Nazirizad et al. in their laboratory investigation of materials type effects on the micro-surfacing mixture showed that mixes containing riverine aggregates were more cohesive than aggregates of mountainous origin in a cohesion test. In the wet track test, riverine aggregates were more resistant to abrasion loads than mountainous aggregates while in the loaded wheel test, riverine aggregate were found to be more susceptible to rutting than the mountainous types. The study also explored the effect of emulsion binder and found out that CQS-1h emulsion on the wet track test showed better adhesiveness against abrasion than the CSS-1h emulsion while in the loaded wheel test the CSS-1h binder had a better resistance to rutting than the CQS-1H emulsion. The take home point of the study is that good aggregate and asphalt emulsion compatibility is very important in the micro-surfacing mixture [33]. Another recent study conducted by Robati et al. on the evaluation of a modification of the current mix design procedure showed that; optimum asphalt emulsion residue in a mixture should be selected based on the maximum rutting resistance of the same mixture, a little more or less asphalt emulsion other than the specified optimum amount can lead to cohesion loss. They further pointed out that the amount of water in a micro-surfacing mixture was found to have a significant influence on the loaded wheel and wet track abrasion test results. This study echoed the same point Mohammad and Mahmoud made that compatibility between aggregates and asphalt emulsion play an important role in the micro-surfacing mixture design procedure and evaluation [33, 34]. Even though the current design practices shown in these studies provide pavements that have overall good performance, there is still need to validate and standardize the design procedures to show the various effects of the material combinations thereby enhancing the general acceptance of this technology to the highway community [35].

3. State of the practice

3.1. United States of America

Micro-surfacing was introduced in America in the 1980's in Kansas as a pavement preservation tool. It is currently being utilized in more than 30 states and the level of implementation varies from state to state but the general conclusion is that micro-surfacing is a good preservation and maintenance tool with very few technical limitations [14]. Micro surfacing was initially marketed under the name of Macroseal by a Spanish firm Elsamex, today they have Polymac, Ralumac and Durapave on the US market [38]. There has been a steady growth and market shift from slurry seal to micro-surfacing with over 200 million square meters already paved. This shift has been because of the growing focus on skid correction on most roads and the fact that micro-surfacing provides a shift towards night work [14, 39]. Contractors in the USA are mostly assigned to design the mix with the caveat of providing a warranty while the respective agencies review and approve the final job mix formula [14]. Oklahoma DOT conducted a study on the long term evaluation of micro-surfacing and concluded that it can be a "green" alternative by using recycled waste products such as mine chat and fly ash thus making it a sustainable solution [8]. Recent studies call for a customized gradation requirement in order to combat cracking and rutting effectively and stresses the fact that project selection is critical to micro-surfacing success [35]. An example of one of a successful implemented micro-surfacing project is discussed below [36, 37];

- US 287 in Dallas District, Texas

Description:

- Miles four lane highway between south of FM 878 and south of BU 287R.
- Mix design was externally sourced but followed the ISSA A143 and ASTM 6372 design guidelines.
- 100% aggregate type III, 11% CSS-1P cationic polymer modified asphalt emulsion, 1% Portland cement as mineral filler, water of 9 to 11%.
- Micro-surfacing applied in May 2007.

Performance, Results and Observations:

- A good surface texture.
- Almost no cracks on the entire length.
- No rutting of the micro-surfacing pavement.

- There have been a total of 6 to 8 patched potholes on the entire length.
- There was a spot of softer binder left when paving thereby allowing minor bleeding and raveling.
- The beginning of the embankment showed significant distress mainly due to the settlement of fill which reflected through the micro-surfacing.
- The project service life was supposed to go up to 5/2011 but it was still performing well as of 5/2015.

Conclusions and Lessons Learned:

- This is an excellent example of a micro-surfacing project which has performed well over its entire service life.
- This project clearly shows the significance of having a structurally sound pavement as a candidate of micro-surfacing. This project reiterates what literature says of the importance of road selection and characterization for a successful micro-surfacing pavement.
- Proper care and workmanship is a prerequisite to having excellent micro-surfacing pavements as was clearly seen from the softer binder left on the pavement leading to bleeding and raveling. This shows that quality control and quality assurance (QC/QA) needs to be high on the agenda for a high quality micro-surfacing pavement.
- The project also highlighted the fact that micro-surfacing cannot correct structural deficiencies as was shown by the settlement of the embankment. All indicators of structural stability for a pavement earmarked for maintenance should be quantified and assessed to check the suitability of applying a micro-surfacing treatment.

3.2. Europe

Started in Germany in the 1970's and later spread across Europe, micro-surfacing has been successfully used on autobahns for more than 30 years [4]. In Europe, micro-surfacing accounts for 100 million square meters of paved roads with France being the lead nation with over 40 million square meters, followed by Spain with 20 million square meters and Germany accounting for 6 million square meters [40]. Other notable key nations utilizing micro-surfacing are the United Kingdom and Italy with a growth market trend moving towards Eastern Europe. In 2015, France through Eiffege Infrastructure developed a new generation of micro-surfacing. This new technology uses an emulsion improved with paraffinic asphalt instead of the naphthenic bitumen previously used. In this new design they have clearly specified the specific values of the emulsion particle sizes to maximize the good cohesion buildup of the mix and minimize the impact of traffic. Since 2015,Eiffege infrastructure has laid more than 800 000 square meters of this new design mix across France and hope to introduce it to the rest of Europe [40].

3.3. Canada

First introduced in the 1990's, micro-surfacing has been successfully utilized on numerous highways and airports across the Atlantic and Western Canada. Roughly 3 million square meters of micro-surfacing is applied every year to improve skid resistance, correct the road profile and rutting with the goal of preserving and extending the pavement service life [15, 24, 41]. In Ontario, micro-surfacing has been successfully used to fill cracks on road centerlines, observed to produce less noise and found to increase intersections skid numbers [24]. To further enhance the benefits of micro-surfacing, specifications are evolving and improving and one such specification was published in 1995 under the Ontario Provincial Standard and Specifications (OPSS) 366. These new modifications includes provisions for multiple application types, tack coat application, modified gradation and a two year warranty to mitigate potential quality induced challenges by the short term micro-surfacing season due to the cold climate [42]. A micro-surfacing project example is discussed below [14, 22];

- York Region, Ontario. Canada

Description:

- 28 sites in the York region having an AADT ranging from 1000 to 7000 plus.
- Used a uniform job mix formula following ISSA A143 standards for the whole region.
- 100% aggregate type III, 11.5%±1% of CSS-1h cationic polymer modified asphalt emulsion, 2% Portland cement as mineral filler, water of 10%.
- The study compared HMA resurfacing with micro-surfacing on the impact on safety by restoration of the skid resistance.
- The study used accident rates before and after to test the hypothesis for a period of 4 years.

Performance, Results and Observations:

- Micro-surfacing had positive safety effects on localities having AADT≥3000 vehicles per lane.

- Micro-surfacing also demonstrated to having positive safety effects on areas with higher traffic volumes susceptible to one or any combination of the following conditions;
  - ✓ Occurrence of wet or dry road surface conditions.
  - ✓ Trend in severe crashes.
  - ✓ Frequent intersection related crashes, and
  - ✓ High occurrence of rear end crashes.

Conclusions and Lessons Learned:

- The study showed that micro-surfacing is particularly effective at reducing accidents. This is valuable to countries like Australia and New Zealand that include accident rates when choosing a preservation maintenance strategy to employ.
- Micro-surfacing can be used to enhance skid resistance in areas where reduced stopping time is important due to highway features. Highways and Freeways all over the world could benefit of micro-surfacing's ability to enhance friction as these areas have unpredictable traffic were emergency stopping is inevitable.
- The study more importantly illustrated how decision making tools can be developed at the network level by integrating potential safety savings into the life cycle analysis.

3.4. China

Micro-surfacing was introduced in the 1990's and has become the number one surface treatment on expressways and primary highways in China. It is estimated that around 50 million square meters are applied every year with over 100 million square meters applied in the peak year of 2010 [43]. BeijingDOT is trying to move away from the conventional design mixture of micro-surfacing, so it is researching on fiber enhanced mixtures with the view of delaying reflection of cracks and reducing the emission to almost zero fumes [44]. Another study was done on the usage of fiber micro-surfacing on interchanges and it found out that the skid resistance was greatly improved as the inclusion of fiber improves the braking potential of vehicles [45, 46].

3.5. South Africa

Micro-surfacing was introduced in 1982 when Petrocol obtained a license from Raschig, Germany to produce and lay Ralumac in Southern Africa. There has been some changes since its inception, in early 2000 Colas France took over from Colas Southern Africa meaning Colmat™ and Colrut™ replaced Ralumac as the main micro-surfacing overlay and rut filling products respectively [47, 48]. Micro-surfacing has enjoyed wide use on most provincial roads as a rut filling and preservation treatment due to its cost effectiveness and good performance [19]. It is encouraging to see other African countries taking a leaf out of South Africa with Morocco being the latest to start using micro-surfacing on its pavements.

4. Conclusion

After a thorough review of literature, one aspect that stands out is that micro-surfacing is an effective tool for pavement preservation and maintenance. In a world where budget constraints and limitations to the construction industry is the norm, when taking into account its life cycle cost, micro-surfacing is the most cost effective treatment compared to other maintenance strategies. Even more important, micro-surfacing has the ability; to lower greenhouse gas emissions, has lower energy requirements and its less aggregate usage is a plus in this century where climate change is a trending topic. The benefits of micro-surfacing can further be enhanced by identifying additives that can improve the durability like the usage of fiber in the mixture, another research direction is to put to bed the matter of if rolling adds any type of value to the pavement surface. Furthermore additional research needs to be carried out to make micro-surfacing a nearly zero emission treatment by using sustainable ingredients and the need to incorporate waste materials like fly ash into the mixture. Lastly a standardized design mixture technology will further increase the general acceptance of micro-surfacing to the skeptics in the highway community. It is my belief that this paper will be a waking up call for developing countries to quickly adopt and incorporate micro-surfacing in its pavement preservation strategies.

5. References

[1] West,K., R. Smith and D.C. Vanskike."Micro-surfacing Guidelines for Use and Quality Assurance, Texas Transportation Institute Research Report 0-1289,College Station,Aug. 1996,49pp.

[2] Hicks, R., James Moulthrop, and Jerry Daleiden. "Selecting a Preventive Maintenance Treatment for Flexible Pavements." Transportation Research Record: Journal of the Transportation Research Board 1680 (January 1999): 1–12. doi:10.3141/1680-01.

[3] International Slurry Surfacing Association (ISSA), "Recommended Performance Guideline for Micro Surfacing." ISSA A143 (revised Feb 2010), Annapolis,Md., 2010b,16pp.

[4] Broughton, Ben, Soon-Jae Lee, and Yoo-Jae Kim. "30 Years of Microsurfacing: A Review." ISRN Civil Engineering 2012 (2012): 1–7. doi:10.5402/2012/279643.

[5] Reinke, GH, WR Ballou, SL Engber, and TM O'Connell. "Studies of Polymer-Modified Microsurfacing Materials in Highway Maintenance." Asphalt Emulsions (n.d.): 80–80–26. doi:10.1520/stp23512s.

[6] Labi, Samuel, Geoffrey Lamptey, and Siew-Hwee Kong. "Effectiveness of Microsurfacing Treatments." Journal of Transportation Engineering 133, no. 5 (May 2007): 298–307. doi:10.1061/(asce)0733-947x(2007)133:5(298).

[7] Pederson "Swede",C.M.,William,J.S., & Hixon,C.D."Microsurfacing with Natural Latex-Modified Asphalt Emulsion: A Field Evaluation. "Transportation Research Record, 1983, 108-110.

[8] Hixon, C.D. & Ooten, D.A."Nine years of Microsurfacing in Oklahoma. "Proceedings, Transportation Research Board, National Research Council, Washington, D.C, 1993, 26pp.

[9] Uzarowski,L.,Maher,M. & Farrington, G."Thin Surfacing-Effective way of improving Road Safety within Scarce Road Maintenance Budget. "Proceedings of the Annual Conference of the Transportation Association of Canada, Calgary, AB, 2005, 1-12.

[10] Simões, Diogo, Ana Almeida-Costa, and Agostinho Benta. "Preventive Maintenance of Road Pavement with Microsurfacing—an Economic and Sustainable Strategy." International Journal of Sustainable Transportation 11, no. 9 (March 16, 2017): 670–680. doi:10.1080/15568318.2017.1302023.

[11] Ding, Tingting, Lijun Sun, and Zhang Chen. "Optimal Strategy of Pavement Preventive Maintenance Considering Life-Cycle Cost Analysis." Procedia - Social and Behavioral Sciences 96 (November 2013): 1679–1685. doi:10.1016/j.sbspro.2013.08.190.

[12] Galehouse, Larry, James S. Moulthrop, and R. Gary Hicks. "Principles of pavement preservation: Definitions, benefits, issues, and barriers." TR News 228 (2003).

[13] Yu, Jiangmiao, Xiaoning Zhang, and Chunlong Xiong. "A Methodology for Evaluating Micro-Surfacing Treatment on Asphalt Pavement Based on Grey System Models and Grey Rational Degree Theory." Construction and Building Materials 150 (September 2017): 214–226. doi:10.1016/j.conbuildmat.2017.05.181.

[14] Gransberg, D. D. "NHCRP Synthesis 411 Microsurfacing,A Synthesis of Highway Practice."Transport Research Board,2010,1-73. doi: 10.17226/14464.

[15] Gransberg, D.D., Pittenger,D.M., & Tighe,S.M."Microsurfacing best practices in North America." 7th International Conference Maintenance Rehabilitation pavements Technology Control, MAIREPAV, January 2012.

[16] Bergkamp Inc., "Slurry Seal and Microsurfacing Equipment, Pavement Preservation Solutions."Bergkamp Inc., Salina, Kans., 2010, pp.11.

[17] Watson, D. & Jared,D."Georgia Department of Transportation's Experience with Microsurfacing."Transportation Research Record: Journal of the transportation Research Board, No. 1616, Transportation Research Board of the National Academics, Washington, D.C., 1998, 42-47. Doi: 10.3141/1616-07.

[18] Croteau,J.M., Davidson,J.K. & Perrone,P. "Surface Slurry Sealing Systems in Canada: Performance and Practice Slurry Sealing. "Canadian Technical Asphalt Association, 2002. pp.18.

[19] Ducasse,K., Distin,T. & Osborne,L. "The Use of Microsurfacing As a Cost effective Remedial Action for Surface Rutting. "Proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04), September, 2004, pp.11.

[20] Smith, Roger, and C. Beatty. "Microsurfacing Usage Guidelines." Transportation Research Record: Journal of the Transportation Research Board 1680 (January 1999): 13–17. doi:10.3141/1680-02.

[21] Garfa, Arbia, Alan Carter, and Anne Dony. "Rutting Resistance of HMA Rehabilitated with Micro-Surfacing." Open Journal of Civil Engineering 08, no. 02 (2018): 245–255. doi:10.4236/ojce.2018.82019.

[22] Erwin, Tara, and Susan L. Tighe. "Safety Effect of Preventive Maintenance." Transportation Research Record: Journal of the Transportation Research Board 2044, no. 1 (January 2008): 79–85. doi:10.3141/2044-09.

[23] Johnston, John B., and Gayle King. "Using Polymer Modified Asphalt Emulsions in Surface Treatments A Federal Lands Highway Interim Report." (2008).

[24] Chan, S., S. Lee, T. Kazmierowski, and W. Lee. "Quantifying the Sustainable Benefits of Preserving Ontario's Flexible Pavement Assets." In Proceedings Of The Fifty-Eighth Annual Conference Of The Canadian Technical Asphalt Association (Ctaa): St. John's, Newfoundland And Labrador, November 2013. 2013.

[25] Takamura, Koichi, Kar P. Lok, Rolf Wittlinger, and B. A. S. F. Aktiengesellschaft. "Microsurfacing for preventive maintenance: eco-efficient strategy." In International Slurry Seal Association Annual Meeting, Maui, Hawaii, p. 5. 2001.

[26] Uhlman, B., Andrews,J., Kadmas, A., Egan, L., & Harrawood,T. "Submission for Verification of Eco-efficiency Analysis under NSF Protocol P352, Part B." July 2010, pp.40.

[27] Robati, M. "Incorporation of Reclaimed asphalt Pavement and Post-Fabrication Asphalt Shingles in Micro-surfacing Mixture." Proceeding of the 58th Annual Canadian Technical Asphalt Association Conference (CTAA), November 2014.

[28] Garfa, Arbia, Anne Dony, and Alan Carter. "Performance Evaluation and Behavior of Microsurfacing with Recycled Materials." Proceedings of 6th Eurasphalt & Eurobitume Congress (June 30, 2016). doi:10.14311/ee.2016.234.

[29] Guven, Zeynep, Prasad Rao Rangaraju, and Serji Amirkhanian. "Life Cycle Cost Analysis in Pavement Type Selection." Life-

Cycle Civil Engineering (June 20, 2008): 805–810. doi:10.1201/9780203885307.ch125.

[30] Robati, M., Carter, A., Lommerts, B.J., Perraton, D. & Cotiuga, I. "New Colored Micro-surfacing Formulations with Improved Durability and Performance." Conference Paper, February 2014, pp. 29.

[31] Kazmierowski, T. & Bradbury, A. "Microsurfacing Solution for Deteriorated Freeway Surfaces." Transport Research Record, 1995, 120-130.

[32] Robati, M, A Carter, and D Perraton. "Repeatability and Reproducibility of Micro-Surfacing Mixture Design Tests and Effect of Total Aggregates Surface Areas on the Test Results." Australian Journal of Civil Engineering 11, no. 1 (2013): 41-56. doi:10.7158/c12-028.2013.11.1.

[33] Nazirizad, Mahmoud, Amir Kavussi, and Ali Abdi. "Evaluation of the Effects of Anti-Stripping Agents on the Performance of Asphalt Mixtures." Construction and Building Materials 84 (June 2015): 348–353. doi:10.1016/j.conbuildmat.2015.03.024.

[34] Robati, Masoud, Alan Carter, and Daniel Perraton. "Evaluation of a Modification of Current Microsurfacing Mix Design Procedures." Canadian Journal of Civil Engineering 42, no. 5 (May 2015): 319–328. doi:10.1139/cjce-2013-0578.

[35] Raza, H. "State of the Practice: Design, Construction and Performance of Microsurfacing."Technical Report FHWA-SA-94-051, Federal Highway Administration, DOT, Washington, DC, USA, 1994.

[36] Kim, Hyun Hwan, Benjamin Broughton, Moon Sup Lee, and Soon Jae Lee. "Microsurfacing Successes and Failures." Journal of the Korean Society of Road Engineers 17, no. 2 (April 15, 2015): 71–78. doi:10.7855/ijhe.2015.17.2.071.

[37] Broughton, B. & Lee, S.J. "Synthesis of Micro-surfacing Successes and Failures." Technical Report FHWA/TX-12/0-6668-1, January 2012, pp.234.

[38] Ali, H. & Mohammadafzali, M. "Asphalt Surface Treatment Practice in Southeastern United States." Technical Report, Southeast Transportation Consortium, July, 2014.

[39] Robinson, H. "Slurry surfacing Certification Study Guide." Highways Report, 2013, 31-32.

[40] Giorgi, Claude Emmanuel, Frédéric Loup, Delphine Simard, and Jérémy Thomas. "Design and Industrial Application of a Microsurfacing Pavement Based on Non-Venezuelan Bitumen." Proceedings of 6th Eurasphalt & Eurobitume Congress (June 30, 2016). doi:10.14311/ee.2016.213.

[41] Workman, C. "Review of Micro Surfacing: Environmental, Economical and Performance Analysis." Technical Report, Western Asphalt Products, May, 2016, pp.7.

[42] Ontario Ministry of Transport."Construction Specifications for Microsurfacing."Ontario Provincial Standard Specifications, OPSS 366, November, 2008, pp.21.

[43] Wu, D. "Review of Surface Treatments in China." Proceedings at the Pavement Preservation and Recycling Summit, Paris, France, February, 2015.

[44] Technical Guidelines for Microsurfacing and Slurry Seal. Beijing: Ministry of Transport, Research Institute of Highways, China Communications Press, 2006.

[45] Wu, Zhaoyang. "Research on Fiber Micro-Surfacing Mixture Design and Pavement Performance in Interchange's Connections." Edited by J.W. Gu, X.L. Chen, and E.H. Liu. MATEC Web of Conferences 25 (2015): 02013. doi:10.1051/matecconf/20152502013.

[46] Zhao, Fuxiao, Kuo Wang, and Shuli Zhang. "Application of Micro-Surfacing in Pavement Preventive Maintenance for Shen-Shan Freeway." 2010 International Conference on E-Product E-Service and E-Entertainment (November 2010). doi:10.1109/iceee.2010.5660899.

[47] Colas. "Road warx: Colas Paving the Way Forward." Magazine Article, 2015.

[48] Southern African Bitumen Association (Sabita). "Asphalt NEWS", Magazine Article, 2009.