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Field Evaluation of Red-Coloured Hot Mix Asphalt Pavements for Bus Rapid Transit Lanes in Ontario, Canada

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Abstract: Coloured pavements have been implemented by metropolitan areas to denote dedicated lanes for bus rapid transit to maintain a high level of safety. Transit benefits of these installations are well documented. However, field performance of various types of coloured pavement has not been investigated systematically, with questions not being answered. In collaboration with the Regional Municipality of York (ON, Canada) where red pavement sections have been in operation for years for its bus rapid transit lanes, the Centre for Pavement and Transportation Technology at the University of Waterloo (Waterloo, ON, Canada) assessed the performance of various types of red pavements including epoxy paint and red asphalt mixes. It was found that, with significant lower texture depth, epoxy paint surface has disadvantages to red asphalt pavement from a pavement texture and safety perspective. The red asphalt sections in this study were observed as lower yet compatible frictional levels to conventional black pavement. Various types of contamination onto the red pavement were observed during field survey. In addition, the ultraviolet radiation degraded the colour of red asphalt pavement over time and may make it less effective for lane designation. Long-term monitoring is recommended to evaluate the functional and structural performance of red asphalt pavement.

Keywords: red asphalt pavement; bus rapid transit; pavement texture; friction; field evaluation

1. Introduction

Many metropolitan areas around the world have implemented coloured pavements in their infrastructure to denote dedicated lanes for bus rapid transit (BRT) [1]. This concept moves away from car dependency around active modes of public transit and pedestrian facilities. However, developing a BRT system that is easily understood by right-of-way users is a necessity in order to maintain a high level of safety. This is traditionally accomplished through signage and lane markings, but the most effective solution is to have a different surface colour for designated lanes [1].

Lane colouring can be achieved by painting, applying a coloured thermoplastic, or laying a thin wearing course of coloured asphalt mixture. One of the major concerns is their durability under significant volumes of vehicle traffic and winter maintenance operations [2]. In collaboration with the University of North Carolina Highway Safety Research Center (Chapel Hill, NC, USA), the City of Portland investigated colour options for bike lane identification in the 1990s, and their analysis provides a broad analysis of material durability. It was reported that the most durable solution would be a dyed asphalt wearing course; however, this was not tested due to the high cost of implementation. Portland installed test sections of painted and thermoplastic colours and found that while the painted material wore away after the first winter, the thermoplastic proved to still be in good condition after one year [2].

A solution to the durability issue is to colour the entire surface by using a coloured asphalt mixture. This can be accomplished through a number of methods, depending on the desired colour of the pavement, including using coloured aggregates, adding pigments to conventional binders, adding pigments and using a clear synthetic binder, or a combination of the above methods. The most vibrant colours can be obtained by using a clear synthetic binder. However, these technologies have not been studied for their long-term performance characteristics, nor been considered for the long-life pavement designs. Additionally, the cost of using a clear binder is estimated to be five to eight times more than a conventional binder; depending on the asphalt grade.

Carry et al. [3] found that epoxy street paints produced the most durable solution, while asphaltic-based mixtures including Hot Mix Asphalt (HMA) and slurry surface treatment were promising and required further investigation. Moreover, the study concluded that, regardless of age and condition of the asphalt road surface, treatments experience intense wear at bus stops. This wearing was suggested to be due to factors including friction caused by buses' stopping and starting, and prolonged heat exposure from bus engines.

Lee and Kim [4] investigated HMA overlays incorporating coloured synthetic binders for use in bus lanes in Seoul. They performed Marshall stability test, indirect tensile strength, and modified Lottman moisture sensitivity tests to evaluate the strength and moisture susceptibility of the overlays. The results showed that the designed overlay was of higher strength and lower moisture susceptibility than conventional asphalt mixtures. Thermal properties have also been extensively studied as one of the major benefits of coloured asphalt is reduced heat absorption, reducing the impact that the pavements have on urban heat island (UHI) generation [5]. Coloured asphalt reduces the amount of thermal energy absorbed compared to black asphalt. This can reduce the urban heat island effect which has major benefits for cities. Other parameters that affect the thermal and ultraviolet (UV) absorption of asphalt are permeability, thermal conductivity, convection and heat capacity. A challenge with coloured asphalt might be an increased solar reflectance, causing glare problems for drivers. Since light-coloured layers reflect some light that is in the visible part of the solar spectrum, some of the reflected light could be reflected at lower angles and travel into the sight of drivers and pedestrians. Glare is not often reported as a major cause of accidents, but might play a significant role in the case of rain events, early morning and late afternoon.

Friction is of high importance for safe vehicle operation. Adding paints and polymers to the roadway surface may increase the risk of making a driving surface too smooth [3]. Researchers [6,7] have reported positive relationship between pavement friction and various texture indices.

Transit benefits of coloured pavement installations are well documented in terms of vehicle violation of the lanes. However, structural and functional performance has not been investigated systematically and data are scarcer [8]. This paper presents a field evaluation conducted by the Centre for Pavement and Transportation Technology (CPATT). The field evaluation includes amplitude of pavement surface texture, frictional, functional, and environmental characteristics of the coloured asphalt pavements for BRT lanes in York Region, Canada.

2. Test Site and Mixtures Design

Located in north of Toronto in the Province of Ontario in Canada, the regional Municipality of York has adopted a combination of coloured aggregate and red pigment for its BRT lanes as shown in Figure 1. The coloured asphalt pavement was to improve the level of safety through enhanced visibility.

Figure 1. A section of coloured bus rapid transit (BRT) lane at York Region, ON, Canada.

The test site consists of three sections as shown in Table 1. Initial mixture of red HMA consisted of a pink granite aggregate blend, red proprietary pigment and polymer-modified Performance Graded (PG) 70-28 asphalt binder. The aggregate blend consisted of 12.5 mm coarse aggregate, and crusher fines (washed, and unwashed) to meet the physical requirements of Superpave (Superior Performing Asphalt Pavements) 12.5 FC2 mixture type for use in Traffic Category ”D” as per Ontario Provincial Standard Specification [9]. This type of mixture is intended to provide superior rutting resistance and skid resistance for a 20-year Equivalent Single Axle Load (ESAL) level of 10–30 million.

Table 1. Information of tested sections.

Section (As-Built Material)	Age at Test Date (Year)	Field Assessment
Epoxy paint	3	(1) surface texture
Red HMA -initial mix	3	(2) frictional property
Red HMA -new mix	1	(3) distress survey

HMA = Hot Mix Asphalt.

In brief, Superpave is a standard procedure of designing asphalt mixtures in the Canadian pavement industry. Initiated by the United States Department of Transportation Federal Highway Administration (FHWA) (Washington, DC, USA) during the late 1980s, Superpave was adopted in Canada as an improved mixture design procedure over the Hveem and Marshall methods. The Superpave is a system of mixture design for asphalt mixtures based upon mechanistic concepts, which includes: (1) an asphalt-grading system called Performance Grading (PG) with the intention of matching the physical binder properties to the desired level of resistance to rutting, fatigue and low-temperature cracking, subjected to local climate and environmental conditions, and (2) an approach to help design the aggregate structure based on volumetric analysis and requirements.

It should be noted that the pink aggregate used in the initial mixture is the same source as the aggregate Type B [9] with aggregate mineralogy and physical properties. After three years in service, sections of BRT lanes paved with initial red mixture exhibited cracks that raised concern about the integrity and performance of the initial red mixture. To address these concerns, a new red HMA mix was introduced by modifying the initial red mixture. The physical properties of the mixtures are shown in the Table 2.

Table 2. Red hot-mix asphalt and binder course asphalt properties.

Property	Sieve Size (mm)	OPSS [1] Requirement	Red HMA-Initial Mix	Red HMA-New Mix	Binder Course
Gradation (% passing)	19.01	90–100	–	–	95.9
	16.0	–	100	100	88.4
	12.5	90–100	98.2	94.7	79.5
	9.5	45–90	83.4	79.1	70.8
	6.7	–	65.2	64.0	60.3
	4.75	45–55	56.2	55.0	53.2
	2.36	28–58	48.0	43.0	41.1
	1.18	–	36.9	33.0	29.3
	0.600	–	27.9	24.3	22.1
	0.300	–	17.5	13.7	15.6
	0.150	–	10.2	6.4	8.20
	0.075	2–10	5.8	3.3	4.20
N_{des} (%G_{mm}) [3]		96.0	96.1	96	96
N_{ini} (%G_{mm}) [3]		≤ 89.0	89.1	89	88.5
N_{max} (%G_{mm}) [3]		≤ 98.0	97.8	97	97.3
Air Voids (%) at N_{design}		4.0	3.9	4.0	4.0
Voids in mineral aggregate (% minimum)		14.0	14.1	14.3	13.0
Asphalt binder performance grade		–	PG 70-28 P [2]	PG 64-34P [2]	PG 64-28 P [2]
Voids filled with asphalt (%)		65–75	72.1	72.2	72.0
Dust proportion (%)		0.6–1.2	1.33	0.7	1.0
Tensile strength ratio (%)		80	97.6	91.3	83.7
Asphalt film thickness (μm)		–	6.8	9.0	7.9
Asphalt cement content (%)		–	4.9	5.0	4.65

Note: [1] Ontario Provincial Standard Specification; [2] P stands for polymer-modified asphalt binder; [3] N_{des}, N_{ini}, N_{max} are number of gyrations at different compaction levels (design, initial, and maximum); G_{mm} is theoretical maximum specific gravity; PG, Performance Graded/Performance Grading.

3. Field Quantitative Evaluation

3.1. Three-Dimensional (3D) Pavement Surface Texture

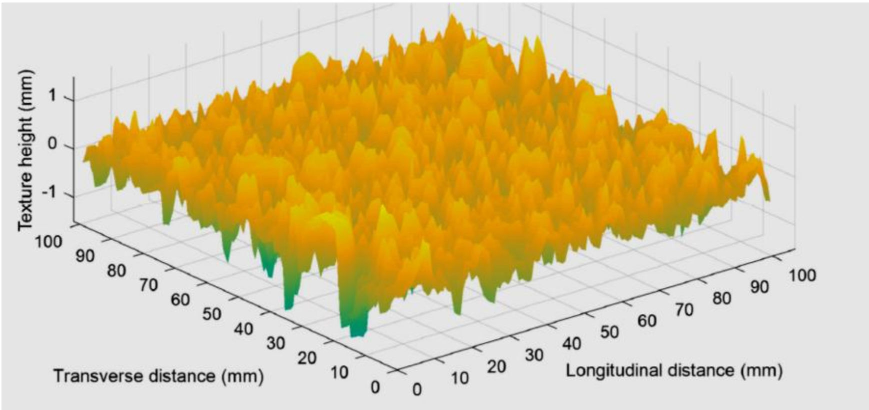
The pavement surface texture was assessed by using a line-laser scanner, 3D non-contact line-laser pavement texture measurement system (Version 1002.05.20, Measurement Instrument Technology, Austin, TX, USA) [10] and based on the laser triangulation principle for a 3D texture measurement. The width of laser line for the line-laser scanner is 0.1 mm. A centre of gravity algorithm is employed to refine the laser line position for precise measurement to achieve the horizontal sampling interval of <0.05 mm. The line-laser scanner produces 3D surface texture measurements with a horizontal sample interval finer than 0.05 mm, and covering partially both microtexture and macrotexture ranges of the pavement surface. The accuracy of the line-laser scanner vertical texture height measurement is better than 0.05 mm. The recovered 3D texture height map was decomposed by using discrete wavelet transform to classify macrotexture and microtexture at various scales. Figure 2 shows a line-laser pavement texture scanner and a recovered 3D texture height map.

The digitally simulated 3D mean texture depth (MTD3) was calculated to represent macrotexture amplitude as shown in Equation (1). Detailed information about MTD3 can be found elsewhere [6,11].

$$\text{MTD3} = h_{2\%} - \frac{1}{A}\sum_{i=1}^{M}\sum_{k=1}^{N}\frac{1}{3}ah_{ik} \tag{1}$$

where MTD3 = Digitally simulated 3D mean macrotexture depth from the line-laser scanner, $h_{2\%}$ = Texture height corresponding to 2% threshold of the bearing area curve of the macrotexture heights, A = The area of surface texture measurement (100×100 mm^2), a = The area of each data point of the macrotexture heights, h_{ik} = The elevation of any data point of the macrotexture heights, M and N = The number of data points in each direction of the macrotexture heights.

(**a**)



(**b**)

Figure 2. Pavement texture measurement: (**a**) a line-laser scanner; (**b**) a recovered 3D texture height map.

3.2. Pavement Frictional Property

Pavement frictional property was assessed by using a British pendulum tester (BPT) (Munro Instruments, Harlow, UK) following ASTM E303 standard [12]. BPT can provide an indirect measure of relative micro-texture and the well accepted pavement friction index: the British pendulum number (BPN) [13]. Figure 3 shows field test by using a BPT. The BPT tests were conducted in outer wheelpath at a surface temperature of 21 ± 1 °C. Other temperatures were not tested.

The calculated 3D mean macrotexture depth and measured pavement frictional values are summarized as shown in Table 3.

Figure 3. Pavement friction assessment by using a British Pendulum tester (BPT).

Table 3. Field test results.

Section	Age at Test (year)	British Pendulum Number (BPN)	3D Mean Texture Depth (MTD3, mm)
Epoxy paint	3	–*	0.16
		–	0.27
		–	0.26
		–	0.30
		–	0.22
Red HMA–initial mix	3	61	0.63
		58	0.57
		54	0.62
		59	0.59
		59	0.46
Red HMA–new mix	1	70	0.53
		77	0.39
		76	0.32
		67	0.44
		66	0.44
Conventional HMA	1	79	0.60
		79	0.47
		77	–
		78	–
		84	–

* sections that are not tested.

As it can be seen from Figure 4, the averaged frictional values, BPN, varies from section to section with the conventional black asphalt section being the highest. In general, similar levels of frictional values were observed at the time of the test. Traffic conditions and ages of the tested sections were not considered for this test.

The calculated 3D mean macrotexture depth was plotted as shown in Figure 5. As expected, the epoxy paint section was observed as the lowest mean texture depth. This observation is in agreement with the findings from another study [3], that adding paints to the roadway surface may increase the risk of making a driving surface too smooth.

To test if the means of the calculated 3D texture of the three sections (conventional HMA being excluded because of too few measurements being conducted) are statistically different, the analysis of variance (ANOVA) was carried out for the MTD3. Table 4 presents the results of one-way ANOVA analysis for the MTD3 which has been previously found a reliable macrotexture index [11]. The purpose of one-way ANOVA is to test if the three sections have a common mean, and to determine whether MTD3 values are statistically different. The null hypothesis, there is no significant difference of the MTD3 among the three sections, is rejected given that p-value, 2.095×10^{-5}, is much smaller than the significance level, which is 5% in this study. It can be concluded that the mean values of MTD3 for epoxy paint, red HMA-initial mix, and red HMA-new mix are significantly different. Multiple comparisons between all pair-wise means of MTD3 were conducted to determine how they differ from one another. As it can be seen from Figure 6, which shows the mean values of MTD3 and their standard deviations for each of the three mixes, these comparisons suggested that epoxy paint surface has disadvantages to red HMA pavement from a surface texture point of view.

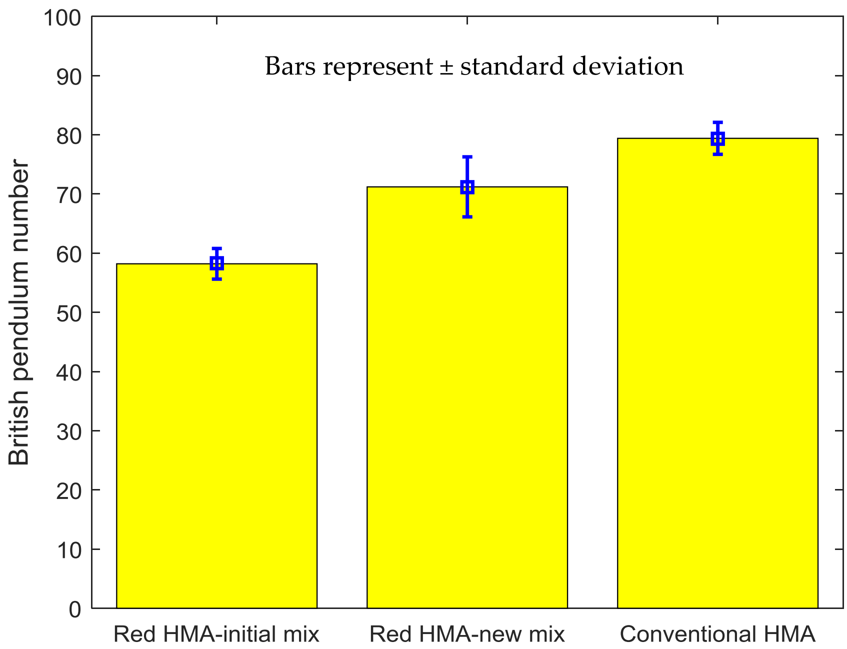


Figure 4. Pavement frictional values of tested sections.

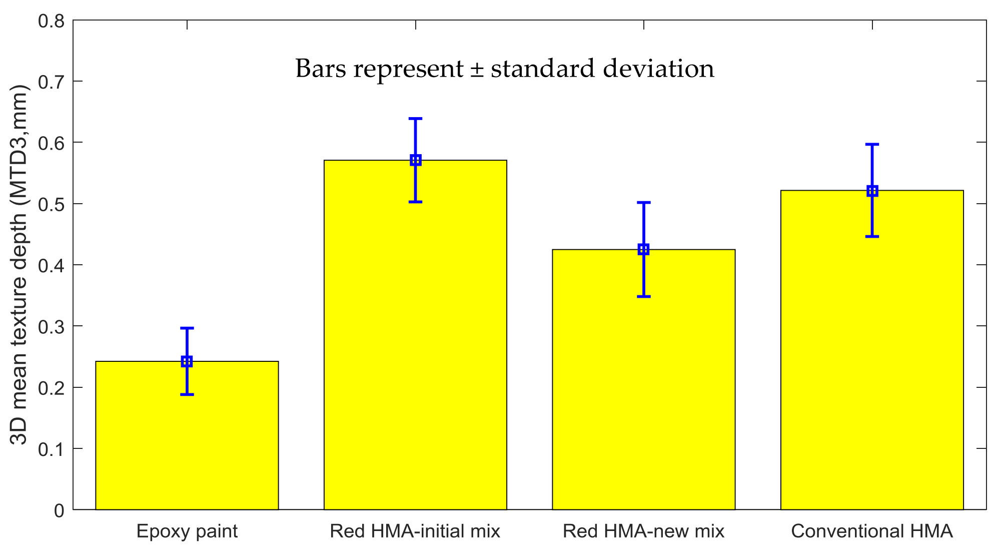


Figure 5. Pavement 3D mean macrotexture depth of tested sections.

Table 4. One-way analysis of variance (ANOVA) results for 3D mean texture depth (MTD3).

Source of Variability	Sum of Squares (SS)	Degrees of Freedom (DF)	Mean Squares (SS/DF)	*F*-Statistic	*p*-Value
Among sections	0.271	2	0.135	30.14	2.095×10^{-5}
Within section	0.054	12	0.005	(*F*-critical = 3.885)	
Total	0.325	14	–		

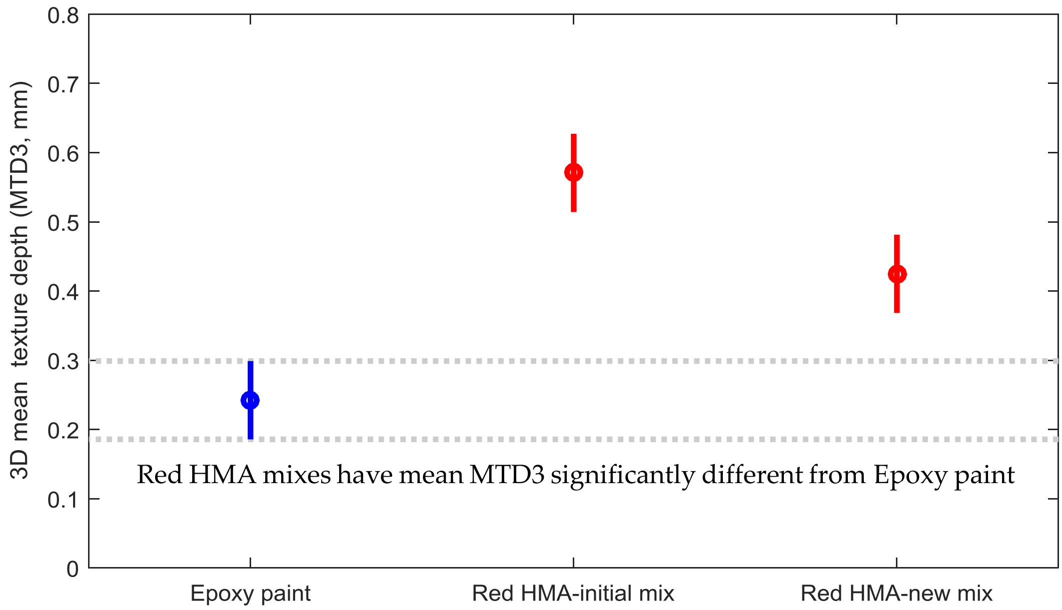


Figure 6. Pavement 3D mean macrotexture depths of tested sections.

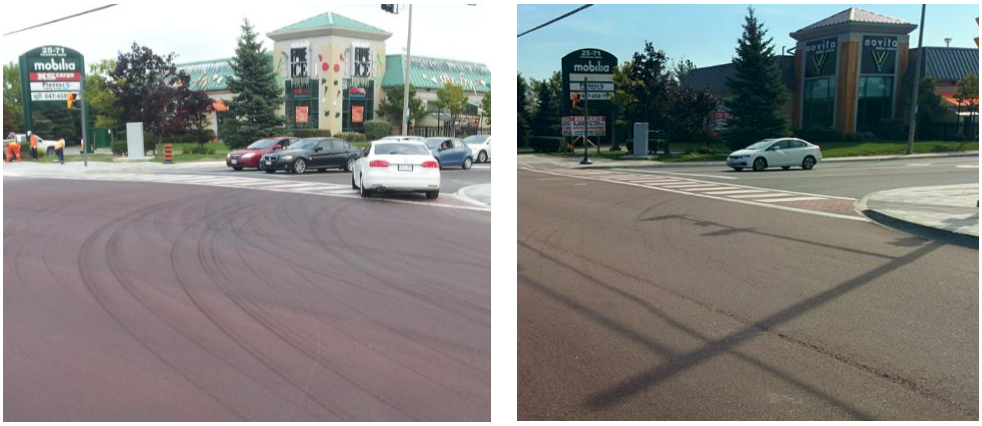
The significant higher 3D mean texture depth of the two red HMA mixes than that of epoxy paint indicated a better friction for the red HMA sections based on the positive relationship between 3D texture amplitude and the pavement friction values [6,7]. These observations suggested that the red HMA pavement has significant advantages to the epoxy paint section of the BRT in York Region from pavement texture, friction, and traffic safety perspectives.

4. Field Pavement Survey

4.1. Pavement Surface Visualization

During the paving of red HMA-initial mixture, a site visit was conducted to assess the paved sections which exhibited surficial tire scuff marks as shown in Figure 7a. Although the appearance of scuffing and tire marks was found to be aesthetically unpleasant, they did not seem to affect the overall performance of the pavement sections, nor indicate a sign of poor workmanship or improper materials. After reviewing the aggregate properties as shown in Table 2, it was noted that more than 50 percent of the aggregate blend was consisted of a fine aggregate (passed sieve size of 4.75 mm) combined with a proprietary red pigment. This resulted in promoting a tighter surface texture and more aesthetically pleasing finish, which may cause the surface texture to be sensitive to tire scuffing. This sensitivity is even expected to be higher during warm periods (i.e., summer times). It seems that the tire scuffing disappeared, Figure 7b, in time under normal traffic conditions, becoming less visible. Tire scuffing was mitigated by using the New Red asphalt mixture after using coarser aggregate blend in the design.

Another visible aesthetic problem was found to be the appearance of oil, grease, fuel, or other automotive fluids dripped onto the pavement. These oil spots were found to be dominating at bus stops, and behind the intersections with buses at the full stop. It should be noted that the appearance of so called "oil spots" can be spotted at road sections that carry a higher rate of heavy commercial truck traffic. Accumulation of these drips over time can create a continuous streak that causes discoloration of the pavement as shown in Figure 8. Besides being aesthetically unpleasant, oil drips/streaks were suspected of containing minerals that dissolve or soften the asphalt binder and can result in surface deterioration and defects over a longer period of time. A preventive maintenance activity was suggested for inclusion in the life cycle to clean oil spots on a regular basis.



(**a**) (**b**)

Figure 7. Tire marks at red asphalt sections paved by the Initial Red mixture: (**a**) newly paved section; (**b**) two-year-old section.

Figure 8. Monitored discoloration caused by oil drips and formation of oil streaks.

The UV properties of a coloured surface are important as UV radiation will degrade the colour over time and may make it less effective for lane designation. Figure 9 compares the colours of the tested sections in this research. It should be noted that these sections were compared under same levels of traffic loading and climatic conditions.

(**a**) (**b**)

Figure 9. Visualization of tested surfaces: (**a**) Red HMA-initial mix and epoxy paint; (**b**) Red HMA-initial mix and Red HMA-new mix.

4.2. Pavement Distress Assessment

It was observed that sections paved with the initial red HMA mixture exhibited early signs of premature transverse (thermal cracking) and longitudinal (fatigue cracking) as shown in Figure 10. This field observation was evidenced by laboratory flexural beam fatigue test [14], which suggests that adding pigment may have caused the average fatigue life to decrease significantly for the red HMA-initial mixture in comparison to a conventional black asphalt mixture [15]. Same laboratory study suggests improved level of fatigue and thermal cracking resistance for the red HMA-new mix.

A site visit conducted after one year of paving confirmed no premature thermal cracking and fatigue cracking for sections with the red HMA-new mixture.

(**a**) (**b**)

Figure 10. Early signs of cracks observed in sections paved with the Initial Red mixture after few years of in-service: (**a**) premature thermal cracking; (**b**) wheelpath fatigue cracking. The white colour of cracks is because of a chalk used for mapping.

5. Conclusions

The functional and structural performance of three sections of red coloured pavement including epoxy paint section and two types of red asphalt mixes were evaluated in the field by CPATT at the University of Waterloo. Epoxy paint surface was observed as the lowest texture depth, which may raise the concern that colouring the pavement by using epoxy paint may make a driving surface too smooth. The two types of red asphalt sections were observed as lower yet compatible frictional levels to conventional black asphalt pavement.

Surficial tire scuff marks were observed for newly paved red asphalt pavement sections. These tire scuffings were becoming less noticeable in time under normal traffic conditions. Another visible aesthetic problem was found to be the appearance of oil, grease, fuel, or other automotive fluids dripped onto the pavement. Besides being aesthetically unpleasant, oil drips/streaks were suspected of containing minerals that dissolve or soften the asphalt binder and can result in surface deterioration and defects over a longer period of time. The ultraviolet radiation degraded the colour of red asphalt pavement over time and may make it less effective for lane designation. Early signs of premature thermal cracking and fatigue cracking were observed for the section of red asphalt with initial mix in this research. This field observation was evidenced by laboratory flexural beam fatigue test which found that adding pigment decreased the average fatigue life significantly for red asphalt initial mix compared to conventional back asphalt mixtures. After one year in service, no premature thermal cracking and fatigue cracking occurred for the red asphalt section with new mix design.

This paper highlighted the texture, frictional, and structural performance of the red asphalt pavements which were three or one year old at time of field assessment. Long-term evaluation is recommended to monitor the performance of the red asphalt pavement for bus rapid transit dedicated lanes.

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