Mixture Design and Field Experience: Coloured Hot Mix Asphalt on Bus Rapid Transit (BRT) Lanes in Ontario

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ABSTRACT

The Regional Municipality of York, in collaboration with Metrolinx (an agency of the Government of Ontario), has implemented Bus Rapid Transit (BRT) lanes along the three most heavily travelled roads in York Region. To enhance visibility and assist motorists when navigating this new transit system, a special red-coloured asphalt mixture was employed as a surface layer. The colour was achieved by using a selected aggregate blend, colouring pigment, and specially formulated asphalt mixture.

This paper provides information on steps employed in the design of coloured asphalt mixture such as: (1) selection of a performance graded asphalt cement suitable for the Region's climatic conditions and traffic loadings, (2) designing an aggregate blend to match the desired colour, (3) performing a volumetric analysis for the special Hot Mix Asphalt to meet physical requirements of Superpave 12.5 FC2, and (4) performance testing to capture the impact of pigment on the mixture's strength and durability at different in-service temperatures. Performance testing was performed at the Centre for Pavement and Transportation Technology located at the University of Waterloo. Production and paving experience with the coloured asphalt mix are also included in this paper, as well as field performance in terms of manual and automated distress survey.

RÉSUMÉ

La municipalité régionale de York, en collaboration avec Metrolinx (une agence du gouvernement de l'Ontario), a mis en place des voies d'autobus rapide (BRT) le long des trois routes les plus fréquentées dans la région de York. Pour améliorer la visibilité et aider les automobilistes à naviguer dans ce nouveau système de transit, un mélange spécial d'asphalte de couleur rouge a été utilisé comme couche de surface. La couleur a été obtenue en utilisant un mélange de granulats sélectionnés, de pigment colorant et un mélange de bitume spécialement formulé.

Cet article fournit de l'information sur les étapes utilisées dans la conception du mélange de bitume coloré, telles que : (1) la sélection d'un bitume performant adapté aux conditions climatiques et aux charges de trafic de cette région, (2) la conception d'un mélange de granulats correspondant à la couleur souhaitée, (3) effectuer une analyse volumétrique pour l'enrobé spécial afin de satisfaire aux exigences physiques de Superpave 12.5 FC2 et (4) des tests de performance pour mesurer l'impact du pigment sur la résistance et la durabilité du mélange à différentes températures de service. Les tests de performance ont été effectués au Centre de technologie des chaussées et des transports situé à l'Université de Waterloo. L'expérience de production et de pavage de mélange de bitume coloré est également comprise dans cet article, ainsi que les performances basées sur des relevés de détresse manuel et automatisé effectués sur le terrain.

1.0 INTRODUCTION

York Region, located in Greater Toronto and Hamilton Area (GTHA), is the sixth largest municipality in Canada with a population of 1.14 million in 2014, representing a 16 percent share of 2014's GTHA population. The Region's population is expected to grow to 1.8 million by 2041. To meet the rapidly increasing need for public transit, York Region has installed dedicated Bus Rapid Transit (BRT) lanes along the three most heavily travelled roads in the Region; Yonge Street, Highway 7, and Davis Drive. In order to increase visibility of the BRT lanes, York Region used a combination of coloured aggregate and red pigment as surface course (Figure 1).

Figure 1. Highway 7 Bus Rapid Transit (BRT) Lane, York Region, Ontario. Picture Taken in 2016.

A number of options were provided to the Region in helping visually distinguish the BRT lanes from adjacent general traffic lanes. Options included: (1) epoxy street paints, (2) coloured paving bricks, (3) a combination of clear petroleum-based synthetic binder with coloured aggregate, and (4) colouring pigment in combination with coloured aggregate and asphalt binder [1].

Eight hundred (800) metre trial sections were applied to evaluate the effectiveness of street paint and paving bricks. However, due to concerns regarding potential loss of surficial friction, quality of ride, and long-term durability, neither option was considered by the Region. Use of clear synthetic binder in combination with coloured pigment and aggregate was evaluated in the laboratory. This option was not cost effective [1], while a combination of colouring pigment, asphalt binder, and coloured aggregate was selected for further mix development.

2.0 MIXTURE DESIGN DEVELOPMENT

2.1 Overview

Coloured Hot Mix Asphalt (CMHA) was designed by using a pink granite aggregate blend, red proprietary iron oxide pigment, and polymer modified PG 70-28 asphalt binder. The first challenge was selecting an aggregate blend that met the physical requirements of Superpave 12.5 Friction Course Type II (FC2), as well as matching a desired colour tone to help mitigate darkening of the mixture toward colour tone of asphalt cement over time.

Another challenge [1] was optimizing the percentage of the pigment in the mix as mineral filler to balance colour tone against the volumetric properties listed in Table 1 (referred to as "Initial Coloured Mix"). This mix was designed for a Superpave 12.5 FC2 mixture type for use in Traffic Category 'D' as per Ontario Provincial Standard Specification (OPSS) 1151. 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 to 30 million.

Table 1. Coloured Hot Mix Asphalt and Binder Course Asphalt Properties

Property		OPSS 1151 Requirement	Initial Coloured Mix	New Coloured Mix
	Sieve Size (mm)			
Gradation (% Passing)	12.5	90 – 100	98.2	94.7
	9.5	45 – 90	83.4	79.1
	6.7	-	65.2	64.0
	4.75	50 – 65	56.2	55.0
	2.36	39 – 58	48.0	43.0
	1.18	-	36.9	33.0
	0.600	-	27.9	24.3
	0.300	-	17.5	13.7
	0.150	-	10.2	6.4
	0.075	2 – 10	5.8	3.3
N_{des} (% G_{mm})		96.0	96.1	96
N_{ini} (% G_{mm})		≤ 89.0	89.1	89
N_{max} (% G_{mm})		≤ 98.0	97.8	97
Air Voids (%) at N_{des}		4.0	3.9	4.0
Voids in Mineral Aggregate, VMA (% minimum)		14.0	14.1	14.3
Asphalt Binder Performance Grade		-	PG 70-28 P[1]	PG 64-34P
Voids Filled with Asphalt, VFA (%)		65 – 75	72.1	72.2
Dust Proportion, DP		0.6 – 1.2	1.3[2]	0.7
Tensile Strength Ratio, TSR (%)		80	97.6	91.3
Asphalt Film Thickness (μm)		-	6.8	9.0
Asphalt Cement Content (%)		-	4.9	5.0

Note: [1]P means polymer modified asphalt binder.
[2]selected values are slightly larger than specified limits to promote finer gradation, colour tone, and texture as recommended to the Region.
OPSS is Ontario Provincial Standard Specification
N_{des}, N_{ini}, N_{max} are the number of gyrations at different compaction levels (design, initial, and maximum).
G_{mm} is theoretical maximum specific gravity.

After a few years, sections of BRT lanes paved with initial red mixture exhibited cracks, raising concerns about the integrity and performance of the initial red mixture. To address these concerns, a performance evaluation was performed to provide insight to the decision makers to modify the initial red mixture to a mixture referred to as "New Coloured Mix". Both mixtures were evaluated by CPATT and the results are included in this paper. Pigmented and non-pigment laboratory-produced mixtures were also included in this study, which were produced in the CPATT laboratory under controlled conditions. This was to determine the effect of pigmentation on the mixture's performance. These mixtures were produced following a mixture design provided by the manufacturer of CHMA.

2.2 Effect of Pigment on Mixture Performance

To provide an assessment of the performance of the in-situ materials and the expected long-term behaviour, materials collected during paving operations and those produced under controlled laboratory conditions were systematically evaluated to determine the impact of colouring pigment on the mixture's strength. The following sections provide the results of this assessment, while Figure 2 shows the tests employed in this assessment.

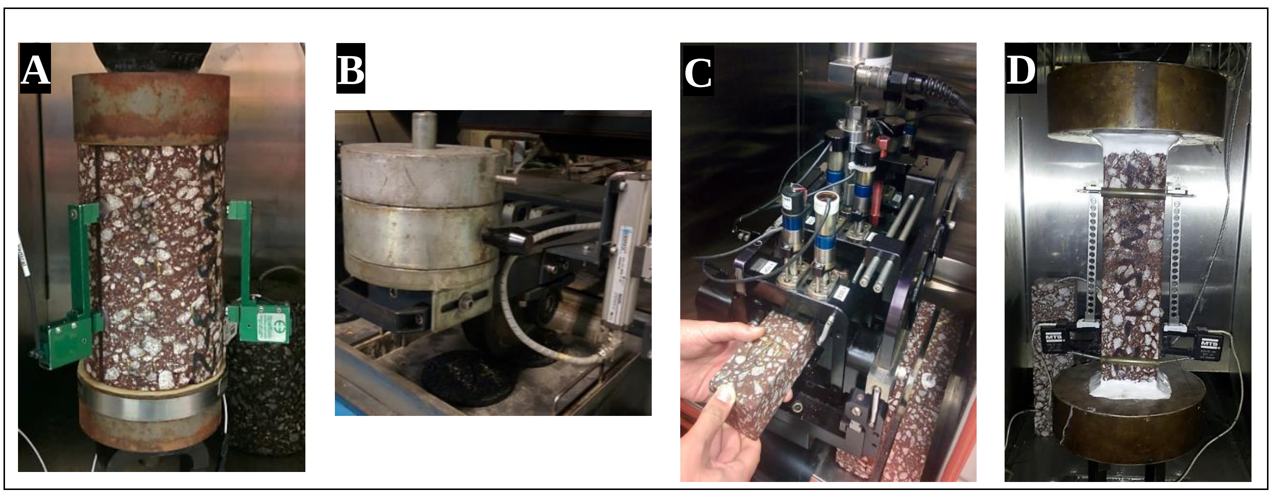

Figure 2. Test Setups Employed to Evaluate Performance of Coloured Hot Mix Asphalt Mixes: (A) Dynamic Modulus, (B) Hamburg Wheel Tracking Test, (C) Four point Flexural Fatigue Bending Beam Test, and (D) Thermal Stress Restrained Specimen Test.

2.2.1 Dynamic Modulus

To capture the effect of pigment on the mixture's overall stiffness, dynamic modulus testing at CPATT was used to determine dynamic modulus (|E*|) of the specimens. The cored specimens were tested at six loading frequencies (0.1, 0.5, 1, 5, 10 and 25 Hz) and five different temperatures (-10, 4.4, 21.1, 37.8 and 54.4°C) to obtain |E*| in accordance with AASHTO T 342-11 [2].

Measurements obtained from this test were further combined to obtain a master curve as shown in Figure 3 in accordance with AASHTO PP62-09 procedure, "Standard Practice for Developing Modulus Master Curve for Hot-Mix Asphalt" [3].

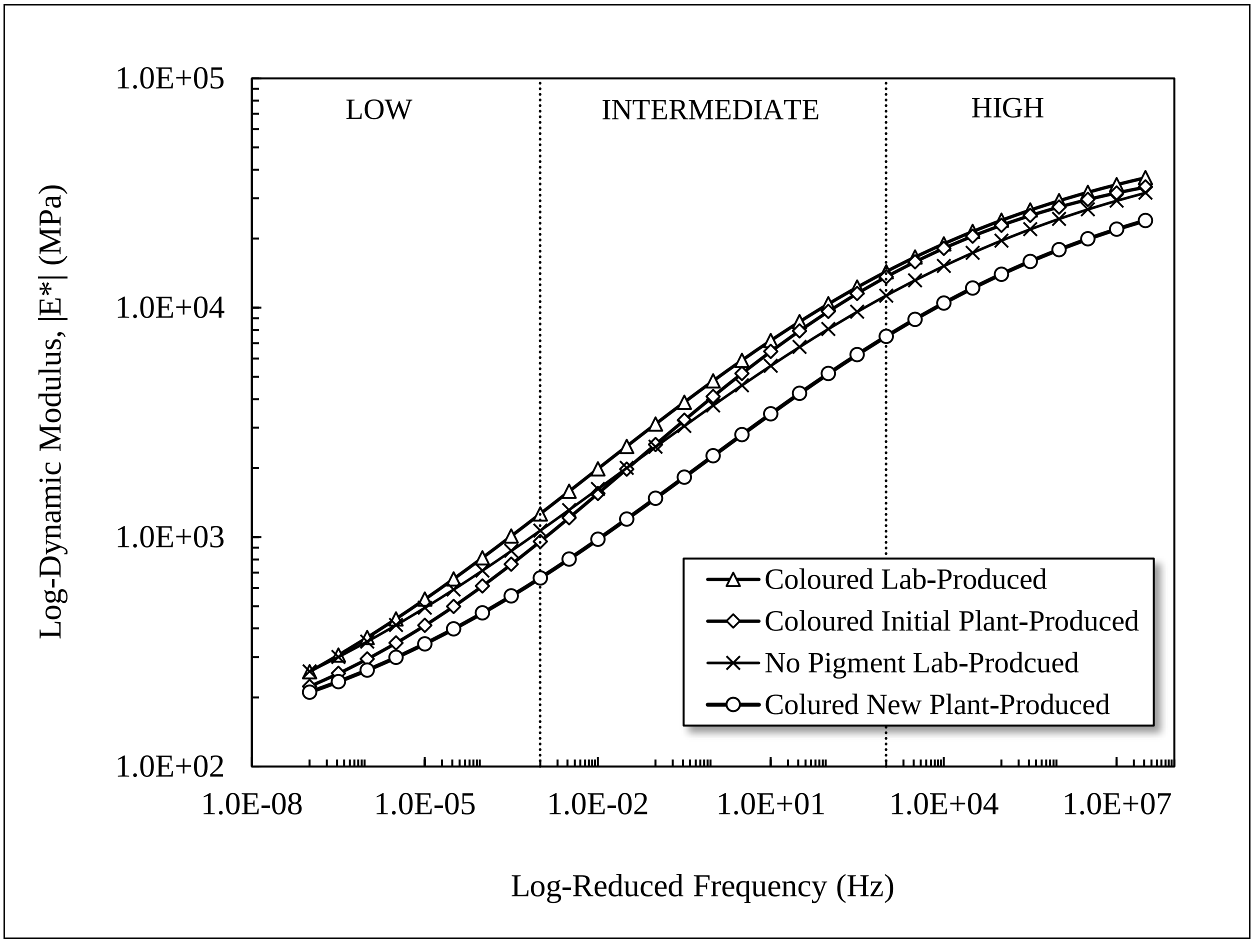

Figure 3. Master Curve Results for Coloured Hot Mix Asphalt Mixtures

To better analyze the results, Master Curves were divided into three zones illustrating lower, intermediate, and higher frequencies. Previous studies at CPATT demonstrated that different frequency ranges can be used to compare the potential for different types of distresses [4].

Development and comparison of the master curves was followed by a statistical analysis of dynamic modulus values to determine if any significant difference between the mixes. Given the combination of five testing temperatures and six frequencies, 30 values of |E*| were analyzed for each mixture. Comparing all of these values was found to be labour intensive and not informative. For this reason, three |E*| values were selected from each mix to evaluate the stiffness at temperatures and frequencies used as indicators of three main surface distresses: (1) thermal cracking at temperature of -10°C and high frequency of 25 Hz, (2) fatigue cracking at 21.1°C and intermediate frequency of 10 Hz, and (3) rutting at high temperature of 54.4°C and low frequency of 0.1 Hz. The statistical analysis was performed as presented in Table 2 using the paired t-test method. The statistical software of Minitab© was used to conduct the analysis at a 95 percent significance level.

Table 2. Statistical Analysis of Coloured Hot Mix Asphalt (CHMA) Stiffness

Temperature (°C)	Frequency (Hz)	Paired Mixes		$\lvert T_{observed} \rvert$	$T_{critical}$	Significantly Different?
-10	25	CIPP	NPLP	3.81	2.57	**YES**
		CLP	NPLP	0.41		NO
		CIPP	CNPL	9.58		**YES**
		CIPP	CLP	2.8		**YES**
21.1	10	CIPP	NPLP	0.87		NO
		CLP	NPLP	0.15		NO
		CIPP	CNPL	9.73		**YES**
		CIPP	CLP	0.48		NO
54.4	0.1	CIPP	NPLP	1.74		NO
		CLP	NPLP	0.63		NO
		CIPP	CNPL	0.85		NO
		CIPP	CLP	0.24		NO

Note: CIPP is Coloured Initial Plant-Produced, CLP is Coloured Laboratory Produced, NPLP is No Pigment Laboratory Produced, and CNPL is Coloured New Plant-Produced.

As shown in Figure 3, the Coloured New Plant-Produced (CNPP) mixture exhibited lower elastic modulus compared to all other mixtures. This might suggest lower level of rutting resistance for this mixture. It should be noted that CNPP was produced using a softer grade asphalt binder (PG 64-34P), which explains slightly lower level of resistance to rutting when compared to mixtures containing a stiffer grade asphalt binder (PG 70-28P). However, this difference in stiffness was determined to be insignificant, as presented in Table 2. All other surface layer mixtures exhibited similar elastic modulus at the lower frequency zone; suggesting similar level of rutting resistance for these mixtures. Results presented in Table 3 confirm the observation that resistance to rutting is not significantly different across all mixes.

In Figure 3, it was observed that CNPP exhibited lower stiffness in comparison to the other mixtures. This might be because of the softer grade asphalt binder used in the mixture which may have improved the level of resistance to fatigue cracking. The difference in stiffness was found to be significant, as presented in Table 2. It was also observed that the mixture containing no-pigment exhibited slightly lower stiffness compared to Coloured Initial Plant-Produced (CIPP) and Coloured Lab Produced (CLP). This might suggest that pigmentation may have impacted the level of resistance to fatigue cracking by increasing the mixture's stiffness. However, results presented in Table 2 suggest no significant difference in resistance to fatigue cracking across all mixes.

Pigmented mixtures of CIPP and CLP exhibited slightly higher stiffness compared to No-Pigment Lab-Produced mixture (NPLP) in higher frequency range, as shown in Figure 3. This suggests that pigmentation has impacted the level of resistance to thermal cracking compared to non-pigmented mixture. However, paired statistical analysis presented in Table 2 found only CIPP to be significantly different when compared to NPLP. This difference seems to be significantly mitigated by using a softer grade of asphalt binder as CNPP exhibited lower stiffness compared to CIPP and NPLP.

2.2.2 High Temperature Performance

The CPATT Hamburg Wheel Tracking tester was used to measure rutting susceptibility of coloured asphalt mixtures. Since the coloured hot mix asphalt mixtures under study contained much stiffer asphalt binder (i.e. PG 70-28P), the decision was made to torture test such mixtures to 60,000 wheel passes as opposed to the 20,000 cycles specified in AASHTO T 324-11 [5]. This was to ensure that specimens will deform enough to enable better comparison. Results of the Hamburg rutting test for CHMA mixtures are presented in Table 3, while Table 4 presents paired t-test statistical analysis of these results to determine if any significant difference exists between the mixes.

Table 3. Rutting Depth Results for Coloured Hot Mix Asphalt Mixtures

Mixture Type	Average Rut Depth (mm)	Standard Deviation (mm)
Coloured Initial Plant-Produced (CIPP)	1.47	0.30
Coloured Lab-Produced (CLP)	1.49	0.23
Coloured New Plant-Produced (CNPP)	3.91	0.45
No Pigment Lab-Produced (NPLP)	2.15	0.28

Table 4. Statistical Analysis of Coloured Hot Mix Asphalt (CHMA) Rut Depth Results

Paired Mixes		$\lvert T_{observed} \rvert$	$t_{critical}$	Statistically Significant?
CIPP	NPLP	45.7	3.18	**YES**
CLP	NPLP	19.9		**YES**
CIPP	CLP	0.20		NO
CIPP	CNPL	23.1		**YES**

Note: CIPP is Coloured Initial Plant-Produced, CLP is Coloured Laboratory Produced, NPLP is No Pigment Laboratory Produced, and CNPL is Coloured New Plant-Produced.

As listed in Table 3, both pigmented CIPP and CLP mixtures exhibited a slightly higher level of rutting resistance when compared to the mixture with no pigment. This minimal difference was found to be significant based on results presented in Table 4. However, in general, CIPP, CLP, NPLP mixtures provided excellent resistance to rutting. It should be noted that the CNPP exhibited lower resistance to rutting compared to other mixtures. This difference between CIPP and CNPP was determined to be significant based on results presented in Table 4. The difference is expected to be due to the softer binder used in producing CNPP mixture (i.e., PG 64-34P). However, the CNPP mixture still provided more than adequate rutting resistance. Similar trends can be noted for manual rut measurements, as well as shear upheave measurements.

2.2.3 Intermediate Temperature Performance

Effect of colouring pigment on the resistance to fatigue cracking was evaluated by performing the flexural beam fatigue test in accordance with the AASHTO T 321-07, “Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) subjected to Repeated Flexural Bending” [6]. The CPATT test setup used for this test is shown in Figure 2(C). For this testing, beams measuring 380 mm long by 63 mm wide by 50 mm thick were saw-cut from asphalt slabs and compacted using an Asphalt Vibratory Compactor (AVC). Slabs were compacted to a targeted air void content of 7 ± 1 percent.

The testing procedure involved subjecting an asphalt beam to flexural loading applied in a cyclic manner with loading frequency of 10 Hz at a 700 micro-strain level. Fatigue failure is defined as the number of load cycles until initial stiffness is reduced by 50 percent. It should be noted that the testing frequency and strain level were selected to simulate heavy traffic loading similar to that expected for bus lanes. Test results of fatigue testing, performed at a 700-micro strain level at an intermediate temperature of 21ºC, are listed in Table 5.

Fatigue test results at the specified testing conditions (strain level, temperature, and frequency), indicated that adding pigment decreased the average fatigue life by almost 70 percent for laboratory-produced and 86 percent for plant-produced mixtures. It was also noted that the pigmented plant-produced mixture exhibited less resistance to fatigue cracking compared to the pigmented mixture produced in the laboratory. This might be due to a higher degree of aging during the production process (also referred to as "short-term or production aging"). It should be noted that conclusions drawn from the fatigue test are only valid for the tested strain level, temperature, and frequency. It is well-documented that asphalt aging during production is mainly associated with asphalt binder oxidation at the molecular level. This phenomenon is an irreversible chemical reaction between the asphalt binder components and atmospheric oxygen. This reaction depends greatly on the chemical composition of asphalt binder and temperature.

Table 5. Fatigue Results for Coloured Hot Mix Asphalt Mixtures

Mixture Type	Average Number of Cycles To Failure[1]	Standard Deviation
Coloured Initial Plant-Produced (CIPP)	15,410	2,594
Coloured Lab-Produced (CLP)	34,421	12,221
No Pigment Lab-Produced (NPLP)	111,245	19,176
Coloured New Plant-Produced (CNPP)	115,312	14,074

Note: [1]Four replicates were tested for each mix at 700-micro strain level at intermediate temperature of 21ºC and testing frequency of 10 Hz.

To further understand the problem, an x-ray fluorescence spectrometer was used to analyze the composition of the pigment. Iron was found to be the predominant element present in the pigment. When iron is oxidized, it becomes iron oxide, more commonly known as rust. Rust is known to be detrimental to asphalt as it may cause swelling of the aggregate leading to raised bumps or micro-cracks. Furthermore, iron is also a strong catalyst, contributing to accelerated aging rate for asphalt binder. Additional elements and compounds were also found to be abundantly present in the pigment included: Magnesium Oxide, Aluminum Oxide, Chromium, and Manganese. These compounds are also known to act as catalysts during the oxidation process of asphalt; thus contribute notably to accelerating the aging of the asphalt binder. In general, all these minerals and compounds found in the pigment may have resulted in excessive oxidative aging of CIPP, thereby increasing the stiffness of the binder excessively. This could result in a decreased level of resistance to fatigue and thermal cracking.

2.2.4 Low Temperature Performance

The Thermal Stress Restrained Specimen Test (TSRST) setup at CPATT was used to evaluate the resistance to thermal cracking developed at lower pavement temperatures. The TSRST was performed using the same Multi-Testing System (MTS) loading frame and environmental chamber used for dynamic modulus in accordance with the AASHTO TP 10-93, “Standard Test Method for Thermal Stress Restrained Specimen Tensile Strength” [7]. The TSRST testing procedure involved restraining a rectangular beam from contraction while being simultaneously subjected to a constant cooling rate of 10ºC per hour. Resistance to thermal cracking was then evaluated as a temperature in which a fracture is developed within the length of specimen. TSRST test results are listed in Table 6.

Table 6. Thermal Cracking Results for Coloured Hot Mix Asphalt Mixtures

Mixture Type	Fracture Temperature (ºC)	
	Mean	**Standard Deviation**
Coloured Initial Plant-Produced (CIPP)	-29.57	2.29
Coloured Lab-Produced (CLP)	-35.02	5.16
No Pigment Lab-Produced (NPLP)	-42.13	2.01
Coloured New Plant-Produced (CNPP)	-32.84	2.60

The TSRST results indicate that adding pigment caused a decrease in the level of resistance to thermal cracking when compared to the no-pigment mixture produced in the laboratory. It is also noted that the CIPP mixture exhibited slightly less resistance compared to the pigmented mixture produced in the laboratory. This might be due to a higher degree of aging during the production process, which may require further investigation of short-term aging protocols in the laboratory for mixtures containing pigment and/or modified asphalt binders. In general, TSRST results indicate that all mixtures exhibited adequate level of resistance to thermal cracking by meeting the lower PG grade requirement of -28 ºC.

2.2.5 Long-term Durability

The materials used within the pavement layer need to resist not only the construction and traffic loading, they must also resist environmental stresses such as freeze-thaw. To evaluate if the pigmentation has impacted the mixture’s strength to resist freeze-thaw, previously presented dynamic modulus specimens were saturated in accordance with a modified AASHTO T 283 [8] (the modified Lottman) test method. For this conditioning approach: (1) specimens were vacuumed to saturation range of 75 ± 3 percent, (2) covered tightly with plastic film, (3) placed inside a polymer bag containing 10 mL of distilled water, (4) sealed by using a controlled vacuum system, and (5) subjected to one month of freeze-thaw cycles (31 cycles); each cycle consisted of 16 hours at a freezing temperature of -20ºC followed by 8 hours at a thawing temperature of +25ºC. The selection of temperature range was based on previously presented field and laboratory observations to capture the effect of pigmentation on the long-term behaviour of the mixture.

To quantify the freeze-thaw durability, the percent of |E*| retained after one month freeze-thaw cycle was calculated for values obtained at a testing temperature of 21ºC and frequencies of 0.1, 1, and 10 Hz. This temperature was selected to translate the impact of pigmentation on the long-term behaviour. This temperature was also selected to minimize variability such as that observed at 37 ºC or 54 ºC. For this reason, only results of 21ºC are presented in this paper as shown in Figure 4. In this figure, error bars represent one standard deviation from the average value of two replicates tested, with Dynamic Modulus Ratio (DMR) results shown above the bars of dynamic modulus values.

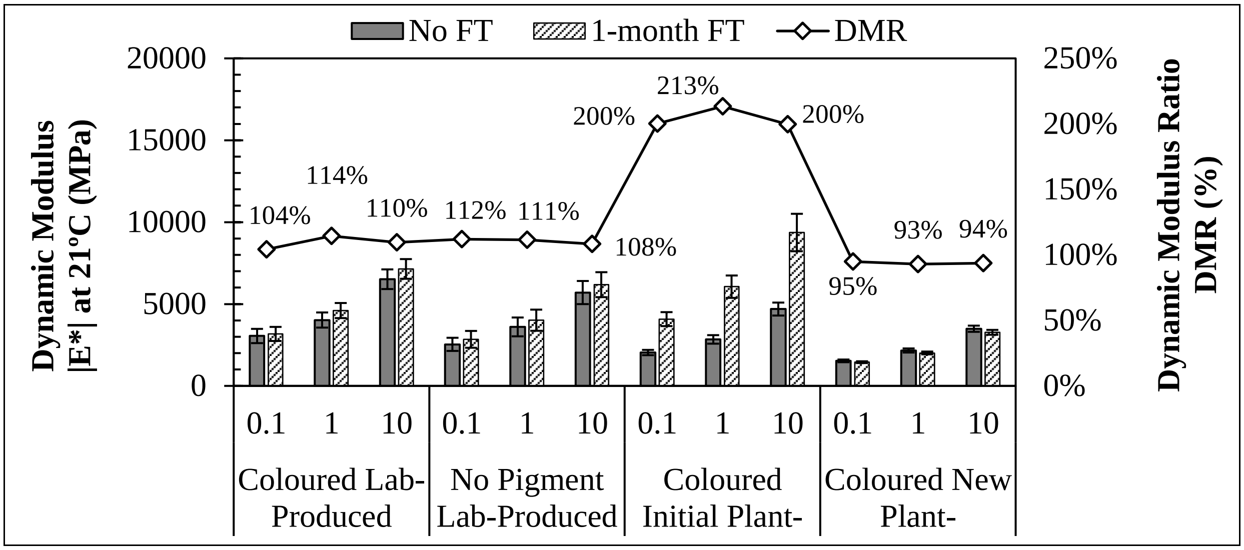

Figure 4. Effect of Pigmentation on Durability of Coloured Hot Mix Asphalt Mixtures

As shown in Figure 4, it is evident that CIPP mixture has been excessively hardened. This may suggest a lowered level of resistance to fatigue cracking, as CIPP might not have the same level of flexibility as other mixtures of CLP and NPLP. It is also observed that using a softer grade of asphalt binder in CNPP has helped the mixture to exhibit better performance when subjected to multiple freeze-thaw cycles.

3.0 PLANT PRODUCTION AND PAVING EXPERIENCE

The manufacture of red asphalt needs to conform to a series of steps to ensure consistency in colour and quality. The production involved care and control of the pigment through all phases of manufacturing and placement with special consideration for the hot mix plant and the paving equipment. The equipment must be cleaned prior to mixing or placing mix with red pigment and then cleaned again, when the equipment returns to placing conventional hot mix. Contractors must be diligent to ensure all phases of the plant are cleaned since the slightest remnant will appear in consecutive mixes. Proper cleaning ensured both the red and conventional mix will meet aesthetic expectations of the client.

The pigment was introduced into the mixing chamber of the hot mix plant at the dosage prescribed by the mix design with special consideration given to ensure each batch contained a consistent quantity of pigment. The pigment was available in packaging designed to melt in the CHMA plant as shown in Figure 5(A). Mixing times vary depending upon the type of plant utilized, and therefore, trials were required to ensure the pigment was mixed homogeneously within the mix.

The mix was delivered to the roadway by conventional haulage equipment and placed with conventional paving equipment shown in Figure 5(B). Again, special consideration was taken to ensure the paver was properly cleaned before and after placing the red asphalt to prevent colour contamination. Trucks required thorough cleaning to remove any remaining black hot mix and other contaminants. Trucks were inspected prior to loading nightly to ensure the boxes were clean. Release agent was strictly monitored for proper application as any over application could also cause detrimental effects to the hot mix.

Figure 5. (A) Red Pigment in Packaging Designed to Melt, and (B) Conventional Paving Equipment Used in Paving Highway 7 Bus Rapid Transit (BRT) Lanes in Ontario

For the initial shifts, additional trucks were booked to compensate for any trucks unable to achieve the level of cleanliness required. Additional care was taken on return rounds as well to ensure that each truck was properly cleaned out. Since strict adherence to the release application rate was required, re-application was needed each round.

The project specified the use of tack coat, which posed a unique challenge for the placement crew as the tack coat was conventionally black. The challenge was to ensure that the haulage trucks, shuttle buggy, and paver in contact with the tack coat, were not permitted to drive on the red asphalt mix. If permitted, the equipment would leave a film of black tack coat, thereby staining the surface and leaving an undesirable mat appearance. Therefore, staging and truck routes were scheduled in a manner that eliminated the potential for tack coat staining. However, it was observed that the newly paved red asphalt sections exhibited surficial tire scuff marks particularly at the intersections as shown in Figure 6(A). Although the appearance of scuffing and tire marks were found aesthetically unpleasant, they did not appear to impact the overall performance of the pavement sections, nor were they indicative of poor workmanship or improper materials.

After reviewing the aggregate blend, it was noted that more than 50 per cent of the aggregate blend consisted of a fine aggregate (passed sieve size of 4.75 mm) combined with the red pigment. This resulted in promoting a tighter surface texture and more aesthetically pleasing finish, which may cause the surface texture to be more sensitive to tire scuffing.

The tire scuffing was monitored closely and pictures were taken during a site visit conducted one year later as shown in Figure 6(B). It appears that over time and under normal traffic conditions, the tire scuffing became less visible. It should be noted that tire scuffing was not experienced with the Red New Mix.

Figure 6. (A) Tire Marks Observed the Day After Paving the Initial Red Mix in 2014, and (B) Tire Marks Disappeared Under Normal Traffic After One Year at The Same Location

4.0 FIELD PERFORMANCE

A manual pavement condition survey was performed by CPATT and liaisons from York Region at different sections of the Highway 7 BRT lanes, as shown in Figure 7(A). This was to document the performance of these sections and obtain a better understanding of automatic distress data made available to CPATT research team. Automated distress data were collected by a consultant hired by York Region, as part of automated surveys on Regional roads conducted every two years.

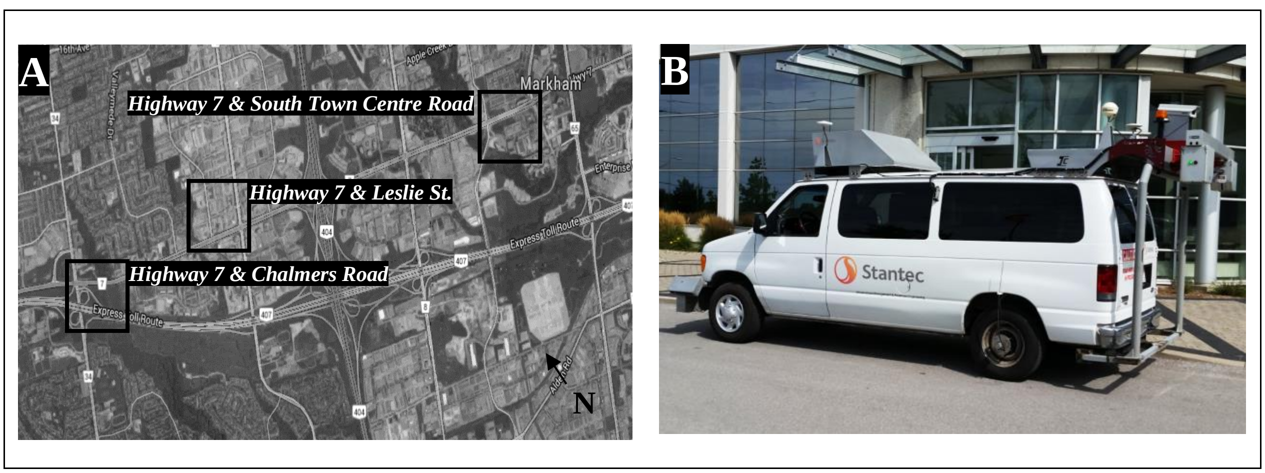

Figure 7. (A) Sections Selected to Perform Manual Distress Survey (B) Vehicle Used to Perform Automated Distress Survey for York Region

Figure 7(B) shows an example of automated survey vehicle used to collected data including International Roughness Index (IRI), rut depth, pavement surface distresses, and high definition digital images of their right-of-way. Collected data are then incorporated into the Region's Pavement Management System (PMS) to assess pavement condition as an index ranged from zero to 100 corresponding to conditions listed in Table 7.

Table 7. York Region's Pavement Condition Index (PCI) Ratings

Condition Category	Pavement Condition Index (PCI)	
	Upper Limit	Lower Limit
Very Good	100	90
Good	89	80
Fair	79	60
Poor	59	50
Very Poor	49	0

The 2014 pavement condition survey data showed medium to severe pavement segregation and a few low to medium transverse and longitudinal cracks on the BRT lanes. The observed distresses are not typical of new construction. The visual distress survey completed suggested the same observations. The 2016 pavement condition assessment results indicate the pavement is performing well and there are no significant pavement distresses observed.

5.0 CONCLUSIONS AND FINDINGS

This paper provided results of a collaborative study between public and private sectors, with the main objective of advancing knowledge of employing coloured asphalt mixture in Canada. Materials collected during paving operations and materials produced under controlled laboratory conditions were systematically evaluated at CPATT and the potential impact of colouring pigment on mixture strength was quantified. Pavement conditions observed across a few sections of BRT lanes surfaced with the Initial Red Mix raised concerns regarding the mixture design. These concerns led this collaborative work to develop mixture with improved resistance to surface distresses.

Although not included in this paper, results of this collaborative study were further incorporated into the state-of-the-art AASHTOWare's Mechanistic-Empirical (M-E) Software at the most accurate level of analysis, referred to as "Level 1". ME analysis outputs were then used to develop prediction models for a design life of 50 years that can be used to establish Life Cycle Cost Analysis (LCCA). Based on LCCA analysis, the New Red Mixture showed significant improvement when compared to the Initial Red Mix over the long-term performance [8]. LCCA analysis also indicated that BRT lane structure surfaced with CHMA is more expensive to construct and maintain in comparison to a similar structure surfaced with HMA located in York Region. However, this cost difference is expected to decrease in the near future as contractors become more familiar with t design and production.

As part of this collaboration, two other products were developed by McAsphalt Industries Limited: (1) red hot-applied crack sealant, and (2) red cold mix patch. These products were developed to seal joints and random cracks, as well as fill potholes and utility cuts on BRT lanes. These specialty products were engineered to match the colour tone and appearance of the BRT lanes. These products have been applied on different sections of BRT lanes, with positive feedback after years of performance.

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