Performance Comparison of CIR and CIREAM in Ontario

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ABSTRACT

In 2003, the first trial of Cold In-Place Recycled Expanded Asphalt Mix (CIREAM) was constructed adjacent to a Cold In-Place Recycling (CIR) mix on Highway 7, east of Perth, Ontario. The major difference between the two processes is that CIR uses emulsion and CIREAM uses foamed asphalt as binding agent. From this successful trial, CIR and CIREAM have become established cold recycling pavement treatments used by Ministry of Transportation Ontario (MTO).

After 20 years in service, this section of highway has reached its end of lifecycle. Continuous performance monitoring of these two sections have been performed over the years. Laboratory testing was carried out to determine the resilient modulus and indirect tensile strength (ITS) of the mixes. Falling Weight Deflectometer (FWD) testing was carried out to monitor the performance, and Ultrasonic Pulse Velocity (UPV) testing was completed to assess the overall quality of the mixes. In addition, typical pavement condition performance monitoring was done using the Ministry's Automated Road Analyzer (ARAN).

This paper summarizes the pavement performance conditions and the results over the years and provides documentation of the end of lifecycle of the two sections. The results confirmed both CIR and CIREAM are performing similarly after 20 years of service.

1.0 INTRODUCTION

In 2003, Cold In-Place Recycling (CIR) and expanded asphalt technologies were introduced as Cold In-Place Recycled Expanded Asphalt Mix (CIREAM) by using expanded (foamed) asphalt, rather than emulsified asphalt to bind the mix. The first 5-km trial section of CIREAM was constructed adjacent to a 7-km section of conventional CIR mix on Highway 7, east of Perth, Ontario. This has enabled a side-by-side comparison of the two technologies.

Both CIR and CIREAM are sustainable pavement technologies utilized by the ministry to-date. The conventional CIR uses emulsified asphalt as a binding agent, which requires a 14-day curing period to allow the emulsion to set, and moisture and compaction requirements to be met. The application of CIR is usually limited to the warmer, drier months. As for CIREAM, it uses expanded (foam) asphalt as the binding agent, where a small amount (1%) of cold water is injected to the asphalt cement to create the foam asphalt for coating the particles with a reduction in curing time of 3-days. CIR is more a coating technology whilst CIREAM is disbursing technology. The chemistry of the two processes is different, but the performance outcome of the resultant mixes as a pavement binder course are comparable.

After 20 years in service, this section of highway has reached its end of life. Numerous technical papers have been published over the years and documented the performance comparison of the two technologies. The results are summarized and documented in this paper.

2.0 BACKGROUND

The CIR/CIREAM demonstration project is located on Highway 7, from Innisville westerly to the Town of Perth, Ontario, for a contract limit of 15.4 km (Figure 1).

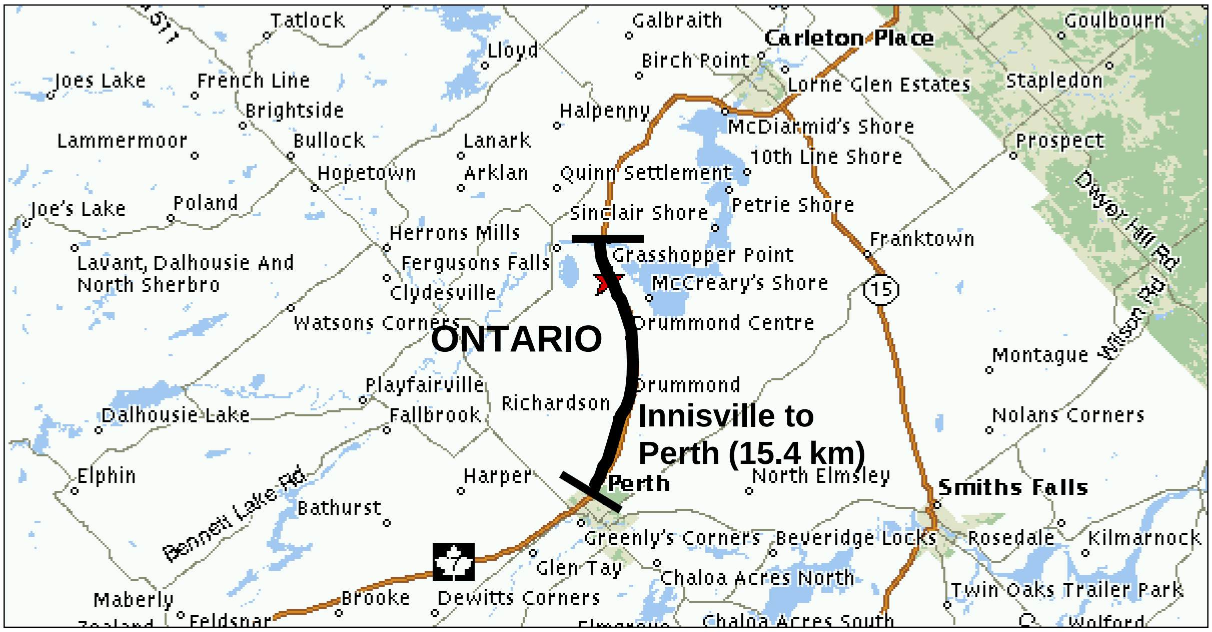

Figure 1. Contract 2002-4040 Limit on Hwy 7 from Innisville Westerly to Perth

This section is classified as a rural arterial, undivided King's Highway, with a posted speed of 80 km/hr. The 2008 Annual Average Daily Traffic (AADT) is 8750 with 10% trucks. The two-way Equivalent Single Axle Loading (ESAL) is 518,665 per year, with a 20-year predicted axle loading of 909,701 ESALs. A summary of the FHWA truck class distribution reveals that the most common trucks are Class 9, five axle single trailer trucks (35%), Class 10, six or more axle single trailer trucks (27%) and Class 5, two axles, six tire, single unit trucks (16%).

The pavement rehabilitation strategy on this project was 110 mm of CIR with a 50 mm HMA overlay. This pavement design was selected based on economics, pavement structural analysis, environmental considerations (reuse of existing materials, minimizing the use of new materials, reduced transportation, fuel and greenhouse gases), mitigation of reflection cracking and considerably shortening the construction time when compared to other options. The CIR contract was tendered in early spring 2003. The successful contractor submitted a change proposal to substitute CIR with CIREAM. In discussion with the Contractor, it was agreed that the project would be suitable for a demonstration project to compare the performance of CIREAM to CIR. The Ministry accepted the change proposal with a four-year warranty on the CIREAM. Details of the pavement design background are previously documented in another technical paper [1].

3.0 CONSTRUCTION AND INITIAL PERFORMANCE

Construction of the CIR and CIREAM began in early July 2003. Seven kilometers of CIR was placed over nine days from July 2-15, 2003. Five kilometers of CIREAM was placed over three days from July 7-9, 2003. Figures 2 and 3 showed the CIR and CIREAM equipment, while Figure 4 a) and b) showed the finished surface of the CIR and CIREAM respectively.

Figure 2. Cold-In-Place Recycling Train

Figure 3. Cold-In-Place Recycled Expanded Asphalt Mix Train

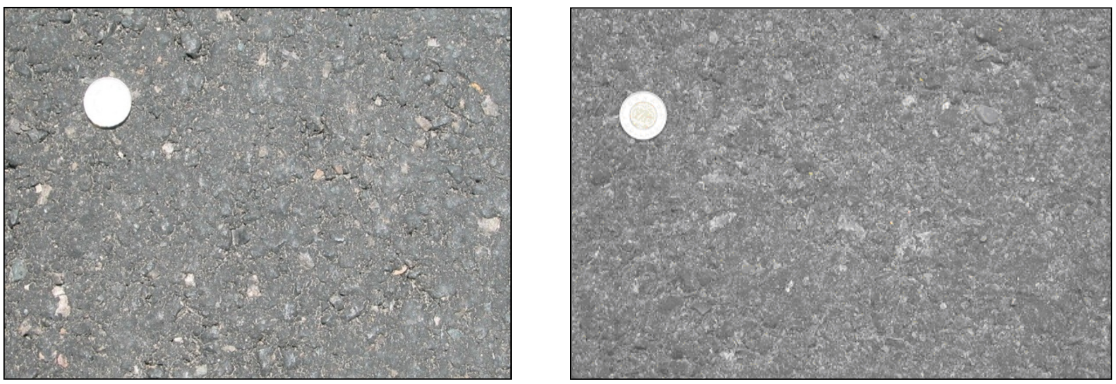

Figure 4. a) Finished Surface of CIR Mix b) Finished Surface of CIREAM Mix

Generally, the post-construction result is summarized in the Table 1 below. Details of the post-construction testing from quality assurance (QA), including indirect tensile strength (ITS), moisture, FWD, rutting and international roughness index (IRI) are documented in the previous technical paper [1]. In addition, Analysis of Variance (ANOVA) was completed on the density, FWD and IRI to confirm the two mixes are considered statistically the same.

Table 1. Post-Construction Summary of CIR and CIREAM Performance Testing

Testing	CIR	CIREAM
Dry ITS	198 ± 52 kPa	472 ± 201 kPa
Wet ITS	98 ± 32 kPa	319 ± 187 kPa
Tensile Strength Ratio (TSR)	52% ± 22%	64% ± 12%
Density	2.233 t/m^3	2.249 t/m^3
Mean Deflection (mm)	0.29	0.27
IRI (mm/m)	1.00	1.16
Surface course rutting (mm)	2.87	2.59

4.0 LONG TERM PERFORMANCE ANALYSIS

The initial evaluation based on the post-construction results indicated the CIR and CIREAM are equal in performance, and long-term performance analyses have been performed over the years to document the progression of the mixes. Annual performance review using ARAN is part of the typical monitoring program, which includes evaluation of IRI, rutting and visual distress manifestation. In addition, the following testing (Figure 5) are carried out to supplement the analysis.

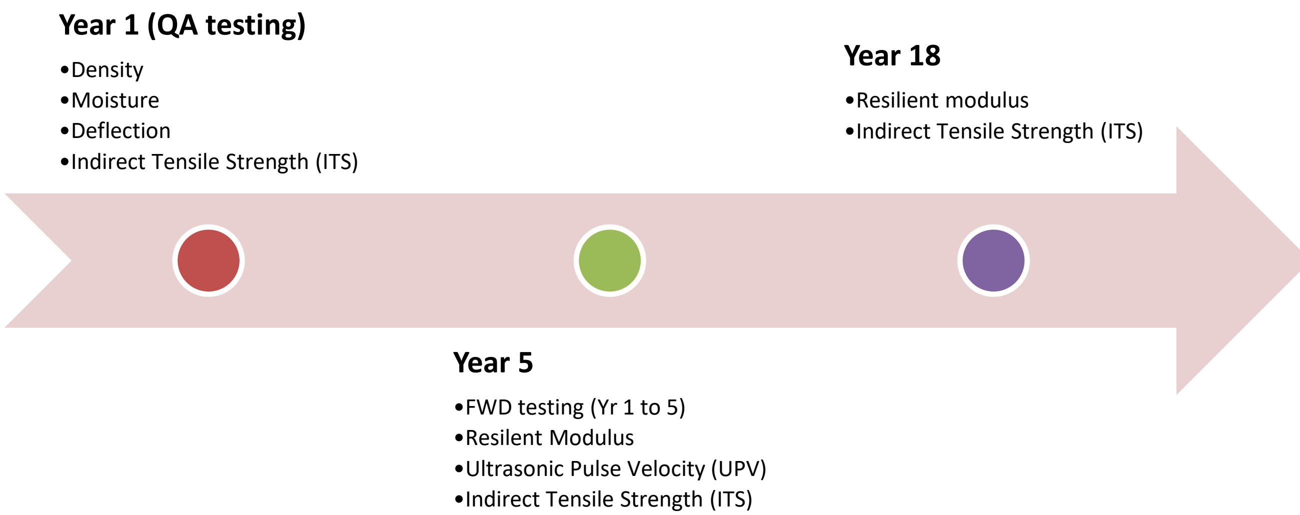

Figure 5: Performance Testing Timeline

4.1 Deflection and Resilient Modulus Results

Falling Weight Deflectometer (FWD) testing was carried out on an annual basis for the first five years as a mean of monitoring the long-term pavement performance of the CIR and CIREAM sections. Details of the data can be found in a previous technical paper [2].

FWD testing applies an impact load to the pavement surface and measures the surface deflection using geophones at set distances from the loading plate. The deflection data is recorded and used to back-calculate the material properties, such as resilient modulus which represents the strength of the material.

In 2008 (year 5) and 2021 (year 18), three cores of each CIR and CIREAM has been collected to perform the laboratory testing for resilient modulus according to ASTM D4123-82 [3]. The test in 2008 was performed by the MTO, and the result appears to be outlier, therefore it is not presented in the table below. The information has been documented in the previous paper [4]. The most recent test in 2021 was performed by an engineering service provider (EPS), with three cores for each of CIR and CIREAM. CIR cores with resilient modulus of 3112, 3257, and 2698 MPa; CIREAM cores with resilient modulus of 2356, 2498, 2840 MPa [5]. Below are the summary capturing the average normalized deflection and average resilient modulus results over the years (Table 2).

Table 2. Average Deflection and Resilient Modulus of CIR and CIREAM

Year	Average Normalized Deflection (mm)		Average Resilient Modulus (MPa)		Source
	CIR	CIREAM	CIR	CIREAM	
2003[1]	0.29	0.27	1059	1173	FWD
2004	0.17	0.17	2501	2376	FWD
2005	0.17	0.18	2360	2123	FWD
2006	0.21	0.20	2399	2219	FWD
2008	0.27	0.30	n/a	n/a	FWD
2021	n/a	n/a	3022	2565	Lab - core

Notes:
1) The modulus data in 2003 represented CIR and CIREAM layer only (without the hot mix overlay).

Based on the resilient modulus and deflection data, the strength of both CIR and CIREAM are comparable and have increased with time.

4.2 Indirect Tensile Strength Test Results

Laboratory testing for the indirect tensile strength (ITS) were performed as part of the monitoring program. In 2003, loose samples of the CIR and CIREAM mixes were collected to prepare briquette samples to perform the ITS test as part of the QA for construction. In 2008 (year 5) and 2021 (year 18), extracted cores samples were used to perform the ITS test according to MTO test method LS-297 [6].

In 2008, total of six cores are collected and sent to MTO, but only four cores were used for ITS test, as some cores have been broken during the resilient modulus testing. Therefore, two cores of CIREAM (908 and 827 kPa) and two cores of CIR (937 and 761 kPa). It is important to note that the indirect tensile strength obtained was not the average of three core as specified in LS-297 [6], but the information is still valuable and presented in the table below for reference. Result below are the summary capturing the ITS results over the years (Table 3).

Table 3. Average Indirect Tensile Strength of CIR and CIREAM

Year	Dry ITS (kPa)		Wet ITS (kPa)		Notes
	CIR	CIREAM	CIR	CIREAM	
2003	198	472	98	319	Loose sample
2008	849	867	n/a	n/a	MTO – core
2021	877	833	817	753	ESP - core

Based on previous studies completed by MTO in collaboration with the Asphalt Recycling and Reclaiming Association (ARRA), it is evident that the ITS test has a high variability between labs, so the results should only be used to compare between CIR vs. CIREAM in the same year. From the ITS data in Table 3, the strength of both CIR and CIREAM are stable, comparable, and have increased since construction.

4.3 Ultrasonic Pulse Velocity (UPV) Testing

A non-destructive test, Ultrasonic Pulse Velocity (UPV) was conducted at the University of Waterloo on the six cores collected in 2008 (year 5). Previous findings have demonstrated that wave characteristics have a strong correlation with material strength in terms of dynamic modulus. The Peak-to-Peak (PTP) amplitude is one of the wave characteristics that can be measured from the oscilloscope directly to provide indicator of the material quality. The experimental set up for the UPV testing was conducted according to ASTM C 597-02 [7].

The UPV results (Figure 6) indicate that CIREAM samples show higher wave amplitude than CIR samples, implying that CIREAM has achieved better bonding at the aggregate-binder interface. Since this is not a recognized testing method to test the quality of asphalt material, this is presented for information and reference purpose only.

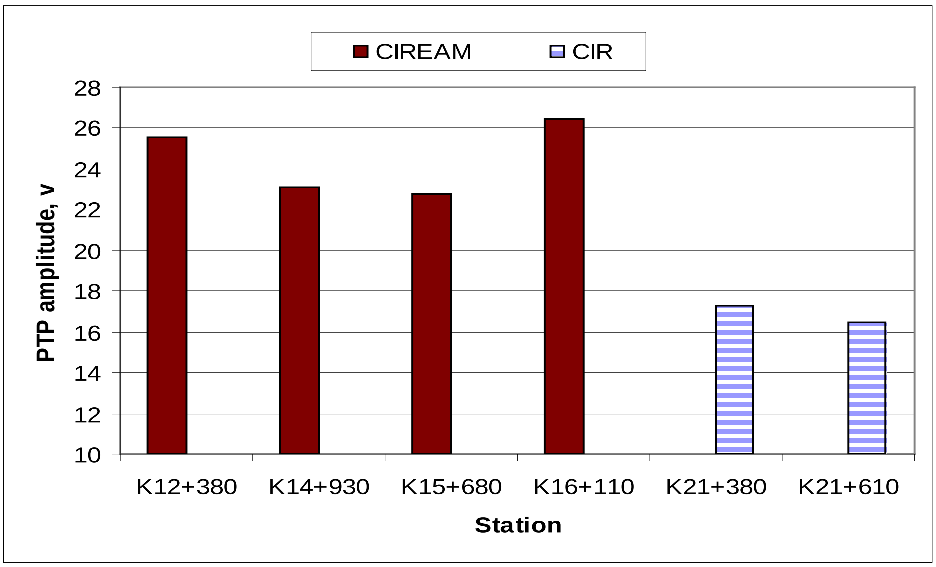

Figure 6. UPV Test Results of CIR and CIREAM

4.4 Annual Performance Monitoring with ARAN

Pavement distress survey was carried out annually using ARAN to provide comparison of these sections' performance. The two sections of CIR and CIREAM have been performing similarly since 2004 and remain in good condition after 20 years in service. The first 10-year performance has been documented in another technical paper [8]. It is apparent by reviewing the international roughness index (IRI) and the rutting to confirm the two sections are similar.

4.4.1 International Roughness Index (IRI)

In 2021 (year 18), the average IRI was 1.24 m/km for CIR and 1.20 m/km for CIREAM (Figure 7). For an 18 years old pavement, the pavement sections are still in very good condition considering the ministry's typical design of terminal IRI of 2.7 m/km for collector road. The IRI deterioration (Figure 7) shows a steady increase in roughness at a very slow rate, and far better than the anticipated terminal IRI of 2.7 m/km.

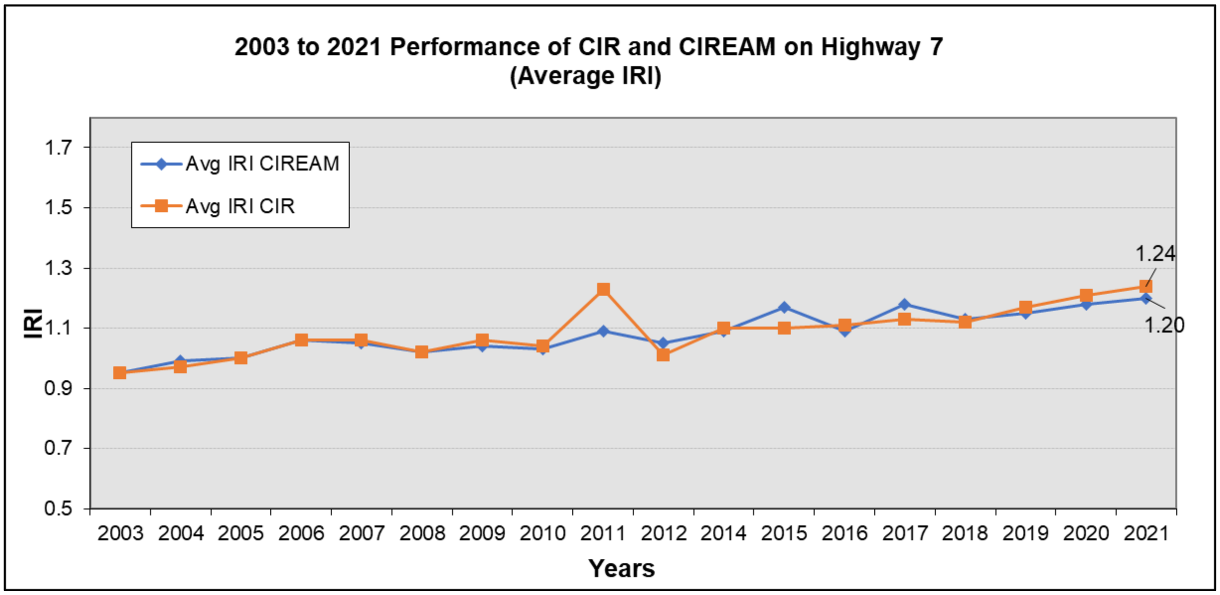

Figure 7. 2003 to 2021 Performance of CIR and CIREAM – Average IRI

<u>4.4.2 Rutting</u>

Similarly, rutting performance has been nearly identical for the two sections, with an average rut depth of 4.10 mm for CIR and 3.92 mm for CIREAM (Figure 8). Given the typical design of terminal pavement rutting is 17 mm for collector road, these 18 years old sections are performing exceptionally well.

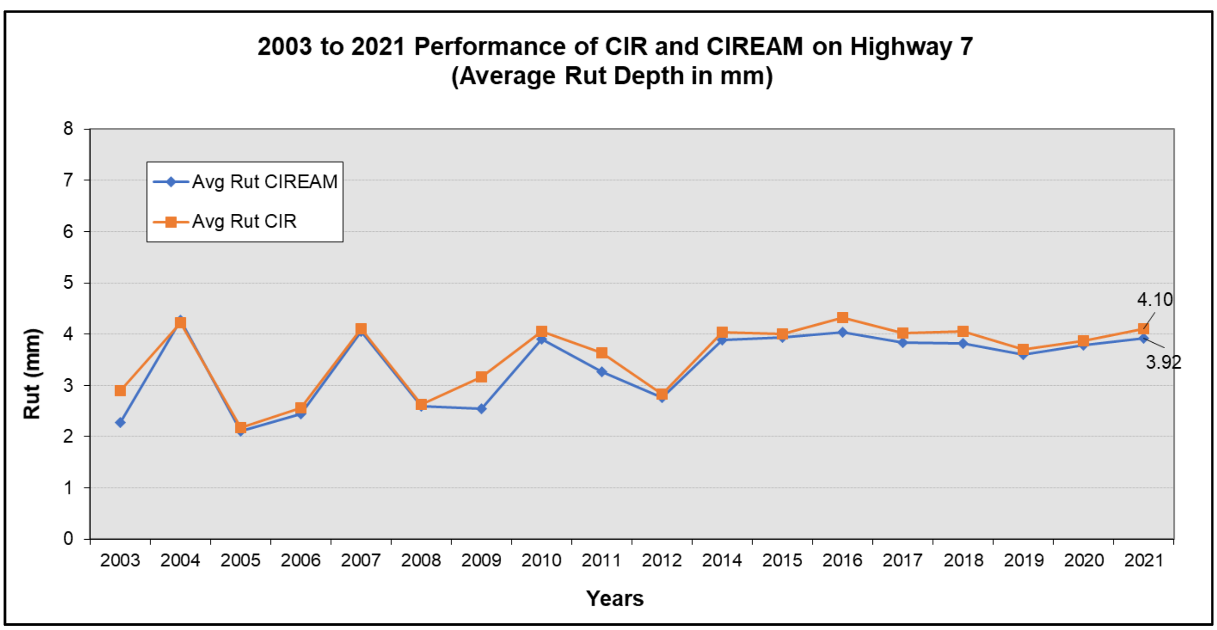

Figure 8. 2003 to 2021 Performance of CIR and CIREAM – Average Rut Depth

4.4.3 Visual Distress - Cracking

Visual distress surveys were carried out annually for the CIR and CIREAM sections. The pavement distress survey represents the combined performance for the CIR and CIREAM sections. Figures 9 and 10 below show the progression of cracking from year 2012 to 2021.

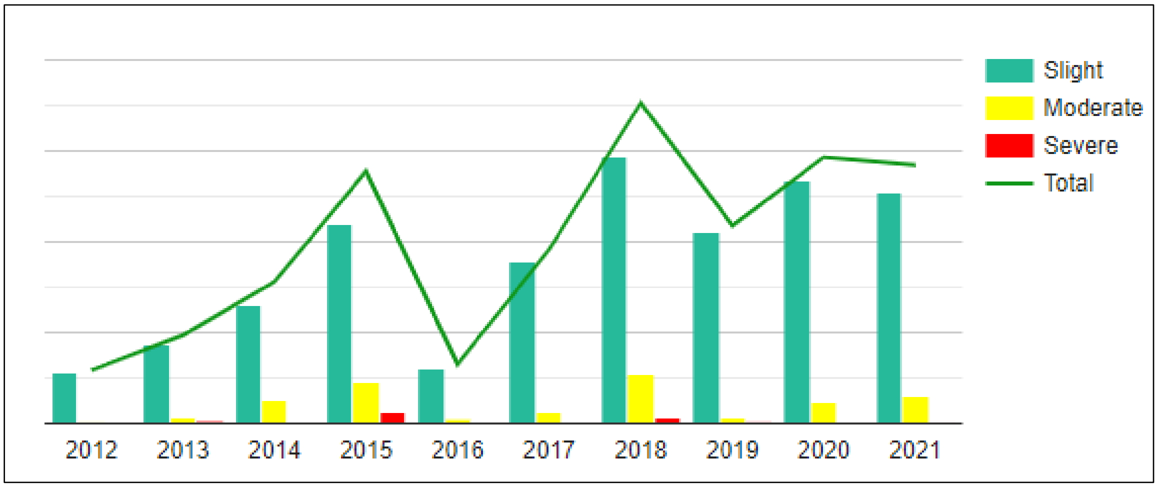

Figure 9. 2012 to 2021 Total Crack Length for Combined CIR and CIREAM Sections

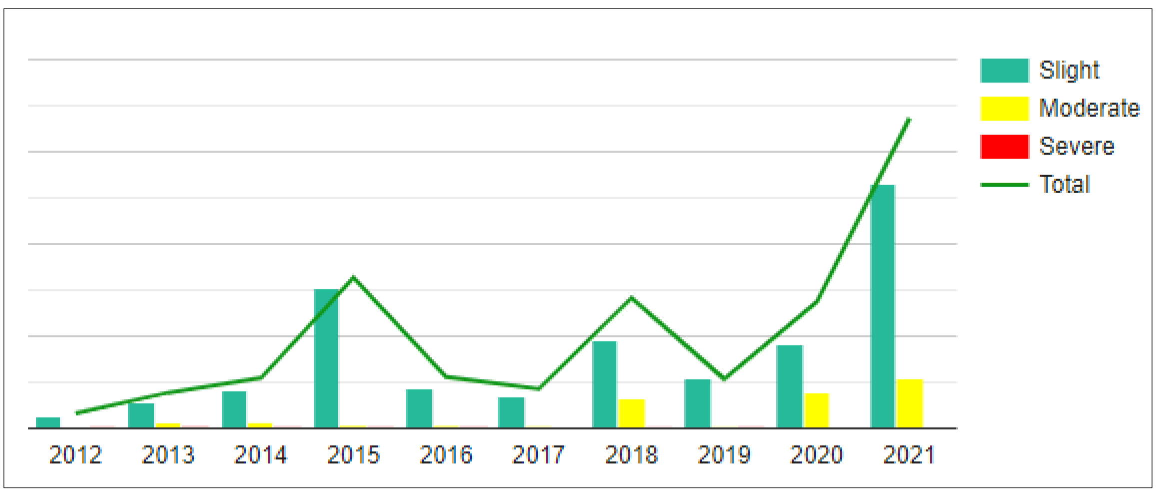

Figure 10. 2012 to 2021 Total Crack Area (Alligator) for Combined CIR and CIREAM Sections

After 18 years of service (2021), the combined pavement section is performing well with the following distresses summarized in Table 4 and 5 below.

Table 4. 2021 Total Crack Length (m) for CIR and CIREAM Combined Section

Crack Type	Slight	Moderate	Severe
Left joint longitudinal	0	0	0
Wheelpath longitudinal	1919	44	0
Transverse	2061	232	10
Combined zone longitudinal	1090	321	7
Total	**5070**	**597**	**17**

Table 5. 2021 Total Crack Area – Alligator Cracking (m^2)

Crack Type	Slight	Moderate	Severe
Centreline pattern	62.67	71.62	0.5
Wheelpath pattern	370.90	13.09	0
Midlane pattern	34.01	16.57	0
Edge pattern	63.32	6.38	0
Total	**530.90**	**107.66**	**0.5**

The visual distresses identified are mostly slight in severity, and the quantities of distress are small considering a 12 km section. This indicates the pavement distresses are minor with no significant performance issues on these sections after 18 years of service. The flexible cold mix binder is one of the contributions to the low percentage of cracking. This again substantiated the CIR and CIREAM has a crack mitigating property that improves the long-term pavement performance.

4.4.4 Visual Distress – PCI and DMI

PCI is an objective measure of pavement performance developed for MTO that is a mathematical combination of IRI (measured by ARAN) and the DMI. PCI theoretically ranges from 0 to 100, where 0 indicates the worst condition and 100 represents an excellent condition. Currently, the DMI is the subjective distress manifestation index ranging from 0 to 100, which has been modified since 2013 where it was ranging from 0 to 10. The concept is the same, but the scale is multiplied by 10 to correlate with PCI. DMI of 0 indicates the worse condition and 100 represents an excellent condition, and it is calculated based on the frequency and severity of the distresses and further combined as a single index. The difference between PCI and DMI is that PCI also includes the roughness (IRI), which is the ride comfort component in the equation. As a result, the PCI and DMI trend are usually very similar, with DMI reflecting the distresses condition only and PCI reflecting the overall condition including the road smoothness performance.

In 2021, the pavement condition index (PCI) for this combined section is 81.68 with a distress manifestation index (DMI) of 87. The pavement performance of the CIR and CIREAM sections after 18 years of service is considered to be exceptionally good. Figures 11 below shows the last 10 years progression of PCI and DMI (year 2012 to 2021). The deterioration has been very steady and mild, which implies the foundation of the CIR and CIREAM binder course are in good condition and performed very well. In addition, Figure 12 and 13 which was taken from the ARAN data collection in July 2022, show the latest performance of the CIR and CIREAM sections.

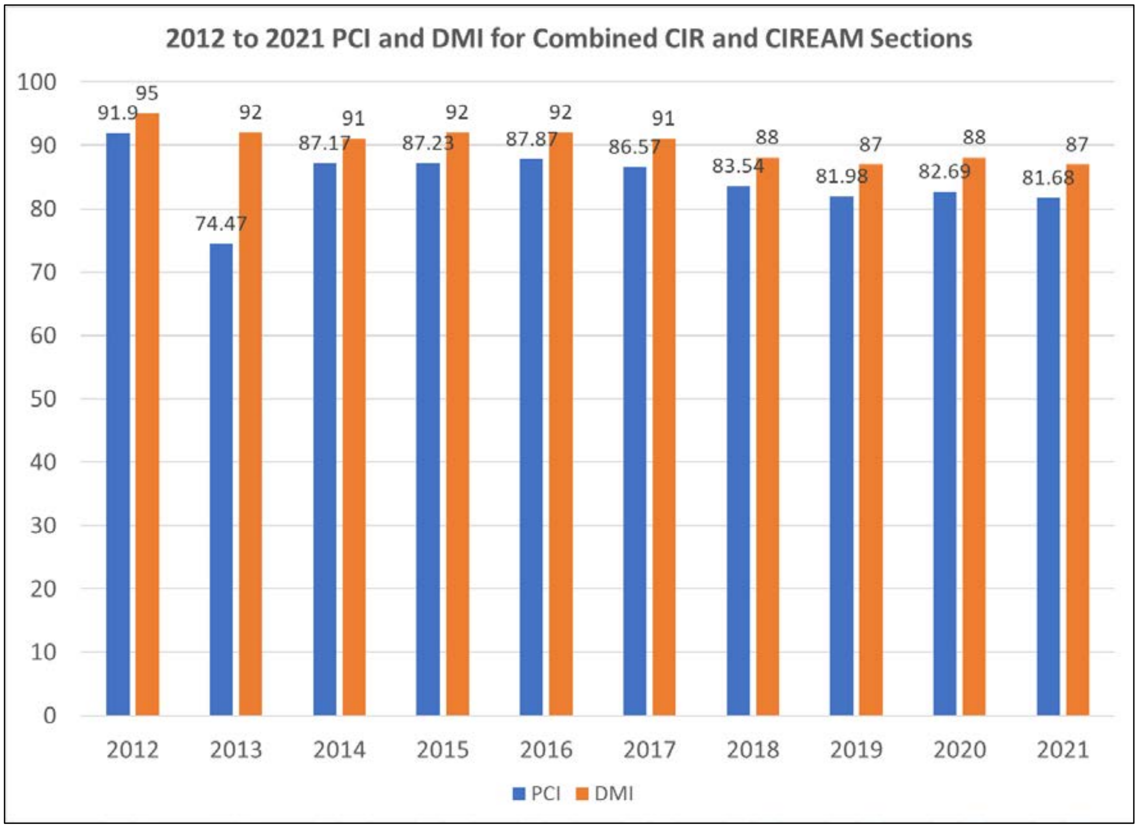

Figure 11. 2012 to 2021 PCI for Combined CIR and CIREAM Sections

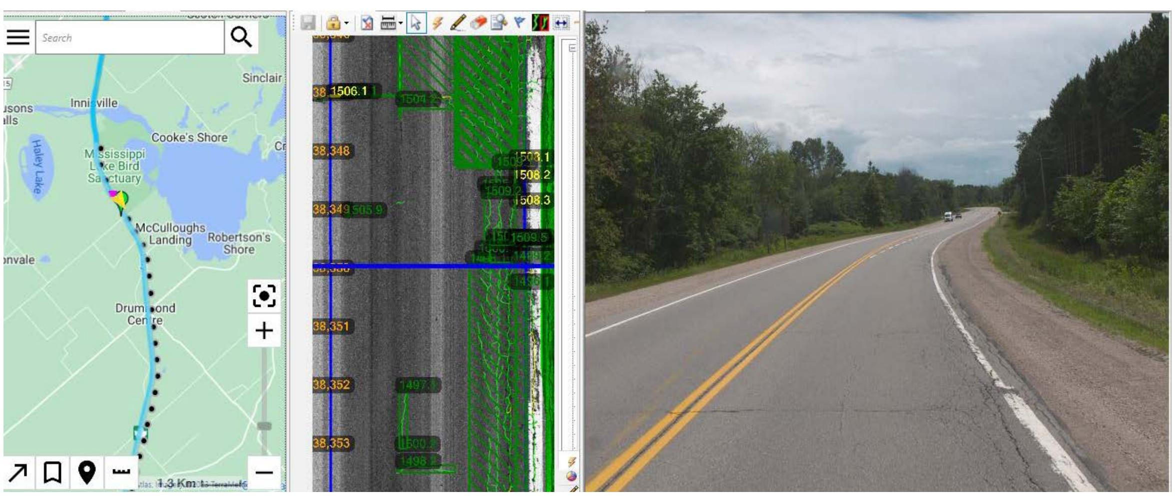

Figure 12. ARAN Data Collection on CIR Section (July 2022)

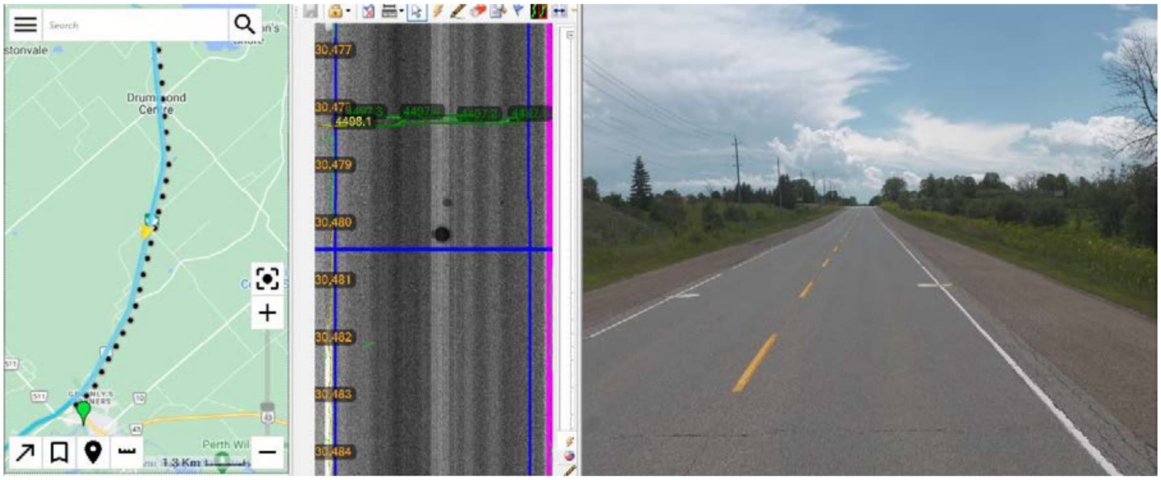

Figure 13. ARAN Data Collection on CIREAM Section (July 2022)

5.0 CONCLUSIONS

By reusing the existing hot mix asphalt (HMA) pavement (aggregates and asphalt cement), CIR is both environmentally sustainable and cost-effective. CIR has been found to be an effective pavement rehabilitation treatment with the benefit of mitigating reflective cracking, thereby extending pavement life. In 2003, CIREAM with foam asphalt technology was introduced as an alternative to CIR with emulsion technology, and this first demonstration of CIREAM section which was built adjacent to the CIR has shown to perform equivalently.

Twenty years of performance monitoring indicate that the CIREAM with a 50 mm HMA overlay provided an equivalently performing pavement structure compared to conventional CIR with a 50 mm HMA overlay. Also, these in-place recycling binder courses are performing equally or better than conventional HMA binder at a reduced cost.

In summary, the 18 years of pavement performance monitoring of this Highway 7 demonstration project indicates that the CIR and CIREAM pavements are performing exceptionally well with almost identical performance in terms of roughness and rutting. Pavement distresses at year 18 are minor with no significant performance issues. In addition, laboratory testing for resilient modulus and indirect tensile strength indicated that the CIREAM and CIR mixes are similar. The near identical performance of this CIR and CIREAM are also confirmed in previous studies using ANOVA and documented in the other technical papers [1], [2], [4], [8].

In conclusion, based on this long-term performance monitoring to compare CIR and CIREAM, it is apparent that both CIR and CIREAM are performing similarly as an acceptable in-place recycling rehabilitation strategy that conserves resources and provides an economic alternative. Ministry will continue to support both technologies as a sustainable alternative to HMA binder course.

Final note, with the exceptionally well pavement condition after 18 years, this section of highway is scheduled to be rehabilitated in 2023 using another recycling technology, Hot In-place recycling (HIR). The rehabilitation project will only be resurfacing the surface course using HIR, and the CIR and CIREAM binder course will remain. This provides a good opportunity to further assess the long-term performance of the CIR and CIREAM binder course.

6.0 REFERENCES

[1] B. Lane, S. Chan, T. Kazimerowski and M. Buelow, "Evaluation of Cold In-place Recycling with Expanded Asphalt on Highway 7 Perth, Ontario," in *Canadian Technical Asphalt Association (CTAA)*, 2004.

[2] S. Chan, B. Lane, C. Raymond, W. Lee and T. Kazmierowski, "Five Year Performance Review of Cold In-place Recycling with Expanded Asphalt Mix on Highway 7, Perth, Ontario," in *Transportation Association of Canada (TAC)*, Vancouver, British Columbia, 2009.

[3] *Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures,* ASTM 4123, 82.

[4] S. Chan, B. Lane, T. Kazmierowski, C. Raymond and W. Lee, "Comparative Performance of Conventional Cold In-place Recycling to Cold In-place Recycling with Expanded Asphalt – Ontario's Experience," in *Transportation Research Board (TRB) 89th Annual Meeting*, Washington D.C., U.S.A., 2010.

[5] S. Keeley, "Assignment 4019-E-0018 - Highway 7, Wemyss to Carleton Place, CO#4 - CIREAM/CIR Indirect Tensile Strength and Resilient Modulus Testing REVISED," McIntosh Perry, 2022.

[6] *MTO Laboratory Testing LS-297, Indirect Tensile Strength Test,* Toronto: Ronen Publishing House.

[7] *ASTM C 597-02 Standard Test Method for Pulse Velocity Through Concrete,* United States: ASTM International.

[8] B. Lane and W. Lee, "Comparing 10 Year Performance of Cold In-Place Recycling (CIR) with Emulsion versus CIR with Expanded Asphalt on Highway 7, Perth, Ontario," in *Transportation Association of Canada (TAC)*, Montreal, Quebec, 2014.