Five Year Performance Review of Cold In-place Recycling and Cold In-place Recycling with Expanded Asphalt Mix on Highway 7, Perth, Ontario

Susanne Chan, M.A.Sc., P.Eng.
Pavement Design Engineer
Pavements and Foundations Section
Materials Engineering and Research Office
Ministry of Transportation
Downsview, Ontario

Becca Lane, P. Eng.
Head, Pavements and Foundations Section
Materials Engineering and Research Office

Chris Raymond, Ph.D., P.Eng.
Senior Pavement Design Engineer
Pavements and Foundations Section

Warren Lee, M.A.Sc., P.Eng.
Pavement Design Engineer
Pavements and Foundations Section

Tom Kazmierowski, P. Eng.
Manager, Materials Engineering and Research Office

Paper prepared for presentation

at the Sustainability of Asphalt Mixes Session

of the 2009 Annual Conference of the
Transportation Association of Canada

Vancouver, British Columbia

ABSTRACT

Cold in-place recycling (CIR) is an established pavement rehabilitation method that processes an existing hot mix asphalt (HMA) pavement, sizes it, mixes in additional asphalt cement, and lays it back down without off-site hauling and processing. The added asphalt cement is typically emulsified asphalt, a blend of asphalt cement and water which requires 14-day curing period before applying the new HMA surface. A recent development in CIR technology, termed Cold In-Place Recycled Expanded Asphalt Mix (CIREAM), is the use of expanded (foamed) asphalt, rather than emulsified asphalt to bind the mix. The advantage of CIREAM is that a new HMA surface can be applied after 3 days, and the process is less dependent on warm, dry weather which is required for the curing of the CIR.

The Ministry of Transportation Ontario (MTO) constructed its first 5-km trial section of CIREAM on Highway 7, east of Perth in July 2003, adjacent to 7-km of CIR mix with emulsified asphalt. Annual performance review on both sections was carried out using Falling Weight Deflectometer (FWD) and Automatic Road Analyzer (ARAN). The five year performance review on CIR and CIREAM was analyzed using ANOVA, and the results indicate similar performance.

CIREAM technology is a promising alternative to conventional CIR, and provides the same environmental benefits while extending the construction season and reducing the time required before application of the HMA surface. MTO will continue to monitor the long-term performance of this innovative rehabilitation technology.

1. INTRODUCTION

Cold in-place recycling (CIR) is an established pavement rehabilitation method that typically processes up to 125 mm of an existing hot mix asphalt (HMA) pavement using a cold milling machine, sizes it, mixes in additional asphalt cement, lays it back down with a hot mix paver and compacts the material to form a binder course layer. This process involves no off-site hauling and processing. The added asphalt cement is typically emulsified asphalt, a blend of asphalt cement and water droplets. A new HMA surface is placed after the emulsion has set, and moisture and compaction requirements have been met, typically ranging from14 to 30 days.

A recent development in CIR technology is the use of expanded (foamed) asphalt, rather than emulsified asphalt to bind the mix. In this new process, hot asphalt cement is pumped through an expansion chamber on the cold recycling unit, where a small amount of cold water, typically 1 %, is injected and immediately vaporizes. This creates thousands of tiny bubbles within the hot asphalt cement causing it to rapidly expand (foam). The expanded asphalt is then mixed with the reclaimed asphalt pavement. As with conventional CIR, the material is then placed with a hot mix paver and compacted to form a binder course layer. This combination of CIR and expanded asphalt technologies is termed Cold In-Place Recycled Expanded Asphalt Mix (CIREAM).

With conventional CIR, Ontario specifies a minimum 14-day curing period to allow the emulsion to set, and moisture and compaction requirements to be met. Application of CIR is usually limited to the warmer and drier months. The major advantage of CIREAM is that a new HMA surface can be applied following a 3-day curing period, if tensile strength and compaction requirements have been met. The process is less dependent on warm and dry weather which is required for the curing of CIR, allowing for an extended construction season.

MTO is committed to using technologies to help build a more sustainable transportation system that supports today's needs while protecting the environment for future generations. CIR and CIREAM technologies support this philosophy of a sustainable transportation system. These technologies support a "zero waste" approach to pavement rehabilitation where the existing road material is reprocessed and reused in place, without offsite transportation. Essentially, no resources are wasted and the need for additional pavement materials is minimized. More specifically, CIR and CIREAM meet the criteria for a sustainable pavement: safe, efficient, economic, environmentally-friendly pavement meeting the needs of present-day users without compromising those of future generations.

2. BACKGROUND

The project is located on Highway 7, approximately 90 km southwest of Ottawa, Ontario for a distance of 15.4 km (Figure 1). This section of Highway 7 is classified as a rural arterial undivided King's Highway, with a posted speed of 80 km/hr.

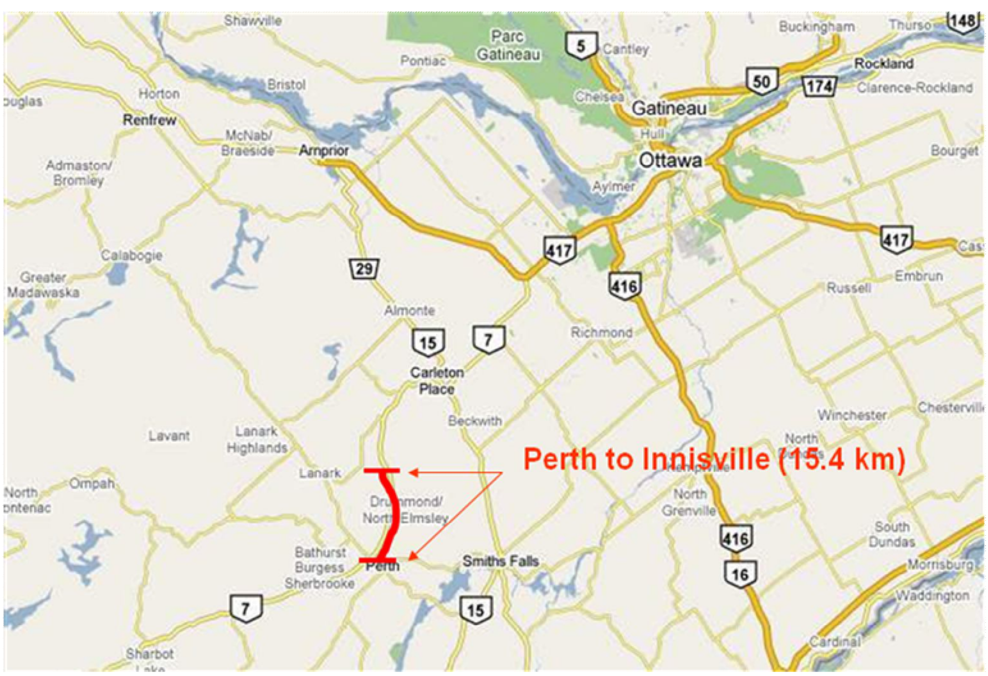

Figure 1. Highway 7 from Perth Northerly, Ontario

This section of Highway 7 was originally constructed in 1957 and 1958. Widening and resurfacing was carried out in 1967. A pavement investigation carried out in 1985, showed an average HMA thickness of 207 mm. In 1985, 30 mm of the surface course was milled off prior to resurfacing with 80 mm HMA, resulting in an average HMA thickness of 255 mm. The resurfacing consisted of 40 mm of recycled HL1 surface course over 40 mm of open graded HL4 binder course. More pavement design details can be found in [1] and [2].

CIR to a depth of 110 mm with a 50 mm HMA overlay was selected as the preferred pavement rehabilitation strategy on this project based on life cycle costing, pavement structure analysis and constructability. CIR has proven to be an effective rehabilitation treatment for extensively cracked pavements in Ontario, as the CIR mix mitigates reflection cracking from the underlying pavement.

The CIR contract was tendered in early spring 2003. The successful contractor bid the contract as conventional CIR, and submitted a change proposal in April 2003 to substitute 5 km of CIR with CIREAM. The Ministry accepted the change proposal with a four-year warranty on the CIREAM.

3. CONSTRUCTION

Construction of the CIR and CIREAM began in early July 2003. Eight km of CIR was placed over a nine-day period from July 2-15, 2003. The average production rate for the CIR was 6622 m^2/day for a single lane (10,500 m^2 best production rate). Five kilometres of CIREAM was placed over a three-day period from July 7-9, 2003. The average production rate for CIREAM was 12,500 m^2/day for a single lane (16,387 m^2 best production rate). The CIR and CIREAM sections were constructed by different contractors with the same contractor placing the HMA surface course. At the contractor's discretion, the CIR process involved micromilling prior to overlay to improve ride and correct cross-section, but the CIREAM did not. Figures 2 and 3 are photos of the CIR and CIREAM train respectively. Figures 4 and 5 below show the typical surface texture for CIR and CIREAM mixes.

Figure 2. Cold-In-Place Recycling Train

Figure 3. Cold-In-Place Recycling with Expanded Asphalt Train

Figure 4. Surface Texture of CIR Mix

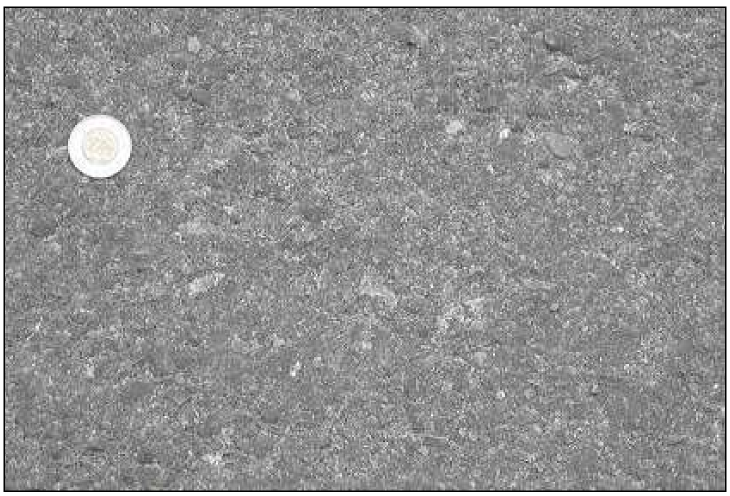

Figure 5. Surface Texture of CIREAM

4. FALLING WEIGHT DEFLECTOMETER TESTING

Falling weight deflectometer (FWD) testing was carried out on Highway 7 prior to and following construction to determine the change in the overall strength of the pavement structure, and to compare strength of the CIR and CIREAM. FWD testing was carried out on an annual basis as a means of monitoring the long-term pavement performance of the CIREAM.

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 data is recorded and can be used to back-calculate the material properties of individual layers of known thickness.

4.1 Overview of FWD Data

Table 1 below summarizes the FWD testing analysis for CIR and CIREAM sections. Based on the data presented in Table 1, the two mixes have been performing similarly over the past 5 years. In later sections, statistical analysis is used to determine if the two mixes are performing statistically the same or different.

Table 1. Summary of FWD Testing Data

	Average Normalized Deflection (mm)				**Average Resilient Modulus (MPa)**			
	CIREAM		**CIR**		**CIREAM**		**CIR**	
	Deflection	***STDEV***	**Deflection**	***STDEV***	**Modulus**	***STDEV***	**Modulus**	***STDEV***
2003	0.27	*0.034*	0.29	*0.025*	1173[1]	*n/a*	1059[1]	*n/a*
2004	0.17	*0.017*	0.17	*0.021*	2376	*219*	2501	*512*
2005	0.18	*0.018*	0.17	*0.024*	2123	*221*	2360	*551*
2006	0.2	*0.031*	0.21	*0.039*	2219	*386*	2399	*615*
2007	n/a	*n/a*	n/a	*n/a*	n/a	*n/a*	n/a	*n/a*
2008	0.30	*0.077*	0.27	*0.069*	n/a	*n/a*	n/a	*n/a*

Note 1: The modulus data in 2003 represented CIR or CIREAM layer only (without the HMA overlay).

The resilient moduli were backcalculated based on the normalized deflection data (with 40 kN load at 21˚C). It is noted that the average resilient modulus data presented in Table 1 are combined HMA modulus (CIR or CIREAM + HMA), except for year 2003 data of which the moduli are for the CIR or CIREAM layer only. The fully cured CIREAM and CIR mixes are expected to have a resilient modulus ranging from 1400 to 1700 MPa. According to Table 1, the two mixes had not been fully cured to achieve their optimum strengths during the post-construction FWD testing in 2003. It is also noted that the CIREAM had higher resilient modulus than CIR at the beginning (immediately after construction in 2003) and but was similar to the CIR in the following years.

The annual average normalized deflection indicates that the deflections for both mixes have slightly increased over the years. The standard deviations for the deflection data also show the same trend, indicating that the variance for the performance has increased. In general, the CIR and CIREAM mixes was fully cured and achieved its maximum strength after one year of placement in 2004. The FWD results indicate that the strength of the mix had a steady and reasonable trend after the first year (Table 1).

4.2 Detailed Analysis of FWD Data

4.2.1 Pre-Construction FWD Testing

In June 2003, prior to construction, FWD testing was carried out on the project. A total of 68 FWD tests were carried out in the inner wheel path of the driving lane, staggered in both directions.

The measured deflections were normalized to represent a deflection load of 40 kN at a temperature of 21˚C. The normalized deflection for the existing pavement ranged from 0.18 to 0.42 mm with a mean of 0.31 mm. In addition to the deflection analysis, the pavement layer moduli were back-calculated. The average back-calculated resilient modulus for each layer was as follows: 1683 MPa for the HMA, 260 MPa for the granular base, 180 MPa (assumed) for the granular subbase, and 81 MPa for the subgrade.

4.2.2 Post-Construction FWD Testing

In September 2003, following placement of the HMA overlay, FWD testing was carried out to determine the post-construction strength of the pavement structure on both the CIR and CIREAM sections. The measured deflections of the centre sensors were normalized to represent a deflection load of 40 kN at a temperature of 21˚C.

Analysis of Variance (ANOVA) was carried out on the normalized 2003 deflections to compare the post-construction FWD test results between the CIR and CIREAM sections. The result of the ANOVA analysis indicates that the two sections were statistically different (since $F = 5.28 > F_{crit} = 3.98$) at a 5% significance level with a p-value of 2.5%. The p-value provides a measure of the statistical significance as to whether the two sets of data are the same or not. In this scenario, a p-value of 2.5% means there is only a 2.5% chance that CIR and CIREAM are the same. The results of the ANOVA analysis are presented in Table 2.

Table 2. ANOVA Analysis of Post-Construction CIR versus CIREAM FWD Results

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*	*Standard Deviation*
CIREAM (5 km)	34	9.31412	0.273944706	0.001177897	0.034320502
CIR (7 km)	34	9.88334	0.290686471	0.000626622	0.025032427

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.004764874	1	0.004764874	5.281044794	0.024735597	3.986273
Within Groups	0.059549137	66	0.00090226			
Total	0.064314011	67				

From Table 2, the CIREAM pavement structure having a lower average deflection value of 0.274 mm was slightly stronger than the CIR pavement structure with a deflection value of 0.291 mm. The average back-calculated resilient modulus for the HMA overlay was 3200 MPa. The average back-calculated resilient modulus for the CIREAM layer was 1173 MPa, and the average back-calculated resilient modulus for the CIR layer was 1059 MPa.

From the back-calculated resilient moduli, it is likely that neither the CIREAM nor the CIR layer has achieved the final strength level. Testing of other CIR projects has indicated resilient modulus results in the neighbourhood of 1400 MPa to 1700 MPa after several years of in-place service (ie, when full curing has occurred). This implies that only 60% to 70% of the final strength had been achieved shortly after construction. It is therefore necessary to revisit the same sections on an annual basis to evaluate the in-situ resilient moduli of the CIR and CIREAM layers.

4.2.3 One Year After Construction FWD Testing

One year after construction, the result of the ANOVA analysis on the 2004 data indicates that the two sections were statistically the same (since $F = 0.0002 < F_{crit} = 4.0068$) at a 5% significance level, with a p-value of 98.9%. The p-value of 98.9% means there is a 98.9% chance that CIR and CIREAM are the same. The ANOVA result is presented in Table 3 below. It is interesting to note the two mixes were statistically different immediately after construction (Table 2), but when fully cured (after one year of service), the two mixes became statistically the same.

Table 3. ANOVA Analysis of CIR versus CIREAM FWD Results after One Year of Service

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*	*Standard Deviation*
CIREAM (5km)	30	5.102477128	0.170082571	0.000290323	0.01703888
CIR (7km)	30	5.100402405	0.170013414	0.000444862	0.021091751

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.17E-08	1	7.17412E-08	0.000195165	0.988901741	4.006872822
Within Groups	0.02132	58	0.000367593			
Total	0.02132	59				

4.2.4 Five Years FWD Testing Data

Using the same analogy as the previous section for the ANOVA analysis, Table 4 below shows the summary of the 5 year performance of FWD testing ANOVA results. It is noted that no FWD data was captured in 2007.

Table 4. ANOVA Analysis of 5 Years of FWD Results

Year	Summary of ANOVA Analysis on FWD Testing	
	CIREAM	CIR
2003	Mean Deflection = 0.27 mm	Mean Deflection = 0.29 mm
	Statistical significance p-value = 2.5% Therefore, CIREAM and CIR are statistically different at a 5% significance level.	
2004	Mean Deflection = 0.17 mm	Mean Deflection = 0.17 mm
	Statistical significance p-value = 98.9% Therefore, CIREAM and CIR do not differ at a 5% significance level. (Two mixes are the same)	
2005	Mean Deflection = 0.18 mm	Mean Deflection = 0.17 mm
	Statistical significance p-value = 62.5% Therefore, CIREAM and CIR do not differ at a 5% significance level. (Two mixes are the same)	
2006	Mean Deflection = 0.20 mm	Mean Deflection = 0.21 mm
	Statistical significance p-value = 5.73% Therefore, CIREAM and CIR do not differ at a 5% significance level. (Two mixes are the same)	
2008	Mean Deflection = 0.30 mm	Mean Deflection = 0.27 mm
	Statistical significance p-value = 10.8% Therefore, CIREAM and CIR do not differ at a 5% significance level. (Two mixes are the same)	

According to the ANOVA analysis results as shown in Table 4 above, the CIR and CIREAM performed differently in the first year, probably due to different curing rates soon after construction. Based on the FWD results, the two mixes became statistically the same at a 5% significance level and have been performing similarly after that first year of service. It is interesting to note the p-values for 2006 (p=5.73%) and 2008 (p=10.8%) are much lower compared to year 2004 (p=98.9%) and 2005 (p=62.5%), suggesting that the two mixes may start to deviate from each other in later years. However, the two mixes are still considered statistically the same based on the ANOVA analysis at a 5% significance level.

5. ROUGHNESS AND RUTTING

Shortly after placing the HMA surface course, MTO carried out a survey of roughness and rutting using the Automated Road Analyser (ARAN). The ARAN consists of a van traveling at highway speed, equipped with various testing and data logging systems. Rutting was measured (in mm) by a series of ultrasonic sensors that were mounted on an aluminum ‘smart’ bar at the front of the van. Roughness was measured within each wheel path by a high-speed laser based device in terms of an International Roughness Index (IRI). The IRI values presented here are the average of left and right wheel path. IRI is a roughness measure with a scale of m/km (or mm/m). The IRI scale starts from 0 m/km, which represents absolute smoothness to an unlimited scale. The lower the IRI value is, the smoother the pavement will be.

<u>5.1 Overview of Roughness and Rutting Data</u>

Figures 6 and 7 below show the overall summary of the roughness and rutting performance for the CIR and CIREAM sections after construction. The two sections have been performing similarly since 2006 and remain in very good condition over the 5 years performance, with an average IRI of 1.0 for CIR and 1.0 for CIREAM (Figure 6). Similar rutting performance has been experienced for the two sections as well, with an average rut depth of 3.4 mm for CIR and 3.2 mm for CIREAM (Figure 7).

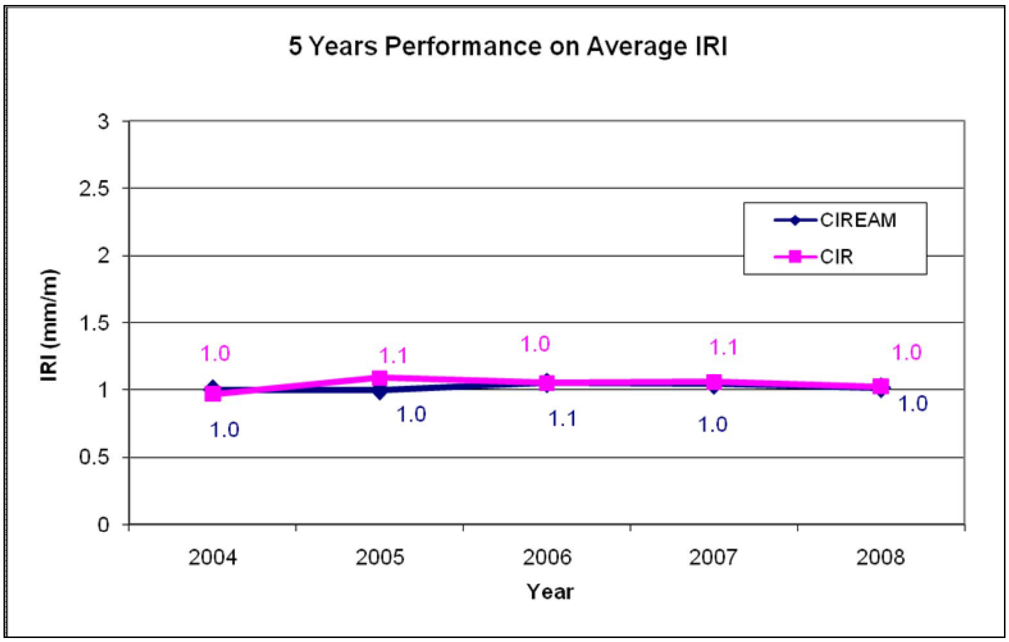

Figure 6. Roughness Comparison between CIR and CIREAM sections

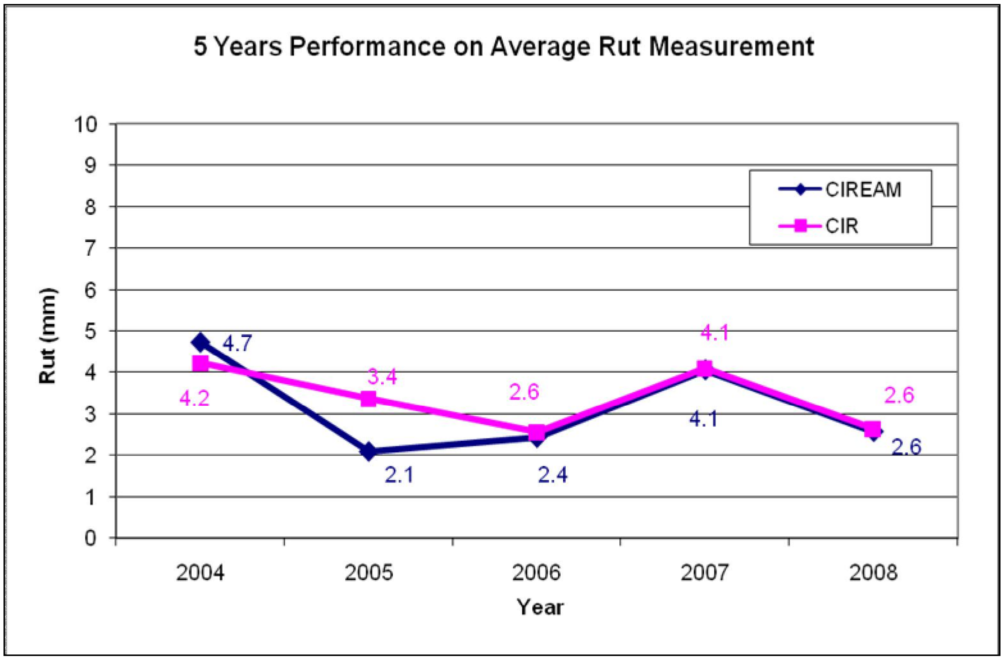

Figure 7. Rut Comparison between CIR and CIREAM sections

5.2 Detailed Analysis of Roughness and Rutting Data

5.2.1 Post Construction ANOVA Analysis Roughness Data

Post construction testing for roughness and rutting was undertaken shortly after construction prior to opening to traffic, and subsequently on an annual basis. The average IRI was found to be 1.16 for the CIREAM section and 1.00 for the CIR section, which means the CIR section was smoother than the CIREAM section. ANOVA analysis (Table 5) concluded that these results were statistically different at a 5% significance level (since $F = 10.29 > F_{crit} = 3.85$), with a p-value of 0.14%. The p-value of 0.14% means there is only a 0.14% chance that CIR and CIREAM are the same. Note that the CIR section was micro-milled to correct the profile and cross-fall prior to HMA surface course overlay, which likely improved the smoothness of the pavement.

Table 5. ANOVA Analysis of ARAN Roughness Data

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*	*Standard Deviation*
CIREAM (5 km)	499	576.93	1.156172345	0.931037328	0.964902756
CIR (7 km)	697	698.03	1.001477762	0.494210888	0.703001343

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.959088435	1	6.959088435	10.28834823	0.001374284	3.849265795
Within Groups	807.6273671	1194	0.67640483			
Total	814.5864555	1195				

5.2.2 Post Construction ANOVA Analysis Rutting Data

The average rut depth was found to be 2.6 mm for the CIREAM section and 2.9 mm for the CIR section immediately after construction. The CIREAM had demonstrated slightly less wheel rutting overall but was more variable than the CIR. ANOVA analysis (Table 6) showed that the two sets of rutting data were statistically different ($F = 22.71 > F_{crit} = 3.85$) at a 5% significance level, with a p-value of 0%. The p-value of 0% means there is no chance of CIR and CIREAM being the same.

Table 6. ANOVA Analysis of ARAN Rutting Data

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*	*Standard Deviation*
CIREAM (5 km)	501	1300.5	2.595808	1.469802	1.212353909
CIR (7 km)	701	2014	2.873039	0.645286	0.803296956

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	22.45599	1	22.45599	22.70955	2.11E-06	3.849223
Within Groups	1186.602	1200	0.988835			
Total	1209.058	1201				

5.2.3 Five Years ANOVA analysis of Roughness Data

Using the same analogy as the previous section for the ANOVA analysis, Table 7 below summarizes the ANOVA analysis results for the 5 years roughness (IRI) performance.

Table 7. ANOVA Analysis of Five Years ARAN Roughness (IRI) Data

	Summary of ANOVA Analysis on Roughness Data	
	CIREAM	**CIR**
2004	Mean IRI = 1.00	Mean IRI = 0.97
	Statistical significance p-value = 2.3% Therefore, CIREAM and CIR are statistically different at a 5% significance level.	
2005	Mean IRI = 1.00	Mean IRI = 1.09
	Statistical significance p-value = 0% Therefore, CIREAM and CIR are statistically different at a 5% significance level.	
2006	Mean IRI = 1.05	Mean IRI = 1.05
	Statistical significance p-value = 78% Therefore, CIREAM and CIR do not differ at a 5% significance level. (Two mixes are the same)	
2007	Mean IRI = 1.04	Mean IRI = 1.06
	Statistical significance p-value = 21.6% Therefore, CIREAM and CIR do not differ at a 5% significance level. (Two mixes are the same)	
2008	Mean IRI = 1.02	Mean IRI = 1.02
	Statistical significance p-value = 64.1% Therefore, CIREAM and CIR do not differ at a 5% significance level. (Two mixes are the same)	

Based on the roughness (IRI) data as indicated in Table 7 above, it is apparent that the two mixes were performing statistically different in the first 2 years (based on a 5% significance level), but they became statistically the same in the following years. Note that the CIR is smoother after the first year, possibly due to the micro-milling that was performed. After the second year, the CIR then becomes rougher than the CIREAM for which the cause is not known. Then after the third year, the CIR actually becomes smoother than the previous year and yields similar roughness to the CIREAM for years 3 to 5.

5.2.4 Five Years ANOVA Analysis of Rutting Data

Using the same analogy as the previous section for the ANOVA analysis, Table 8 below summarizes the ANOVA analysis results for the 5 years rutting data performance.

Table 8. ANOVA Analysis of Five Years ARAN Rutting Data

	Summary of ANOVA Analysis on Rutting Data	
	CIREAM	**CIR**
2004	Mean rut = 4.7 mm	Mean rut = 4.2 mm
	Statistical significance p-value = 0% Therefore, CIREAM and CIR are statistically different at a 5% significance level.	
2005	Mean rut = 2.1 mm	Mean rut = 3.4 mm
	Statistical significance p-value = 0% Therefore, CIREAM and CIR are statistically different at a 5% significance level.	
2006	Mean rut = 2.5 mm	Mean rut = 2.6 mm
	Statistical significance p-value = 0% Therefore, CIREAM and CIR are statistically different at a 5% significance level.	
2007	Mean rut = 4.1 mm	Mean rut = 4.1 mm
	Statistical significance p-value = 26.0% Therefore, CIREAM and CIR do not differ at a 5% significance level. (Two mixes are the same)	
2008	Mean rut = 2.6 mm	Mean rut = 2.6 mm
	Statistical significance p-value = 8.5% Therefore, CIREAM and CIR do not differ at a 5% significance level. (Two mixes are the same)	

Based on the rutting data as indicated in Table 8 above, it is apparent that the two mixes were performing statistically different in the first 3 years (based on a 5% significance level), but they became statistically the same in the following years. Again, this is probably due to CIR and CIREAM mixes curing at a different rate, causing the difference in performance in the beginning. In addition, the rutting data collected by ARAN has a +/- 2mm accuracy, so the differences maybe caused by data collection error. Based on the ANOVA analysis on rutting measurement, the two mixes eventually performed similarly after 3 years of service.

6. VISUAL DISTRESS SURVEY

Visual distress survey is carried out annually for the CIR and CIREAM section. The pavement distress survey represents the combined performance for the CIR and CIREAM sections. After 5 years of service (year 2008 data), the pavement section is performing very well with the following distresses [3]:

- Very slight, few coarse aggregate loss
- Very slight, few flushing
- Very slight, few longitudinal cracks
- Very slight, few centerline cracks
- Very slight, intermit transverse cracks

The visual distresses identified are few and very slight severity. This indicates the pavement distresses are minor with no significant performance problems on this section after 5 years of service.

In 2008, the pavement condition index (PCI) for this combined section is 89 with a distress manifestation index (DMI) of 9.62. PCI is an objective measure of pavement performance developed for MTO which 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 the excellent condition. DMI is the subjective distress manifestation index, theoretically ranging from 0 to 10, where 0 indicates the worst condition and 10 represents the excellent condition. The pavement performance of the CIR and CIREAM sections with PCI = 89 and DMI = 9.62 after 5 years of service is considered to be in very good condition.

7. CONCLUSIONS

MTO has successfully carried out over 55 CIR contracts including district works since the late 1980's. CIR has been found to mitigate reflective cracking, extending pavement life. By reusing existing aggregates and asphalt cement, CIR is both environmentally sustainable and cost-effective. CIREAM technology appears to be a new and promising alternative to the conventional CIR method. CIREAM on Highway 7 is an excellent example of Industry bringing innovation to the Ministry, and how cooperation between MTO and Industry led to the successful implementation and evaluation of a new asphalt technology.

Upon completion of this successful CIREAM pilot project, MTO has gained experience and confidence on this technology. To date, MTO has completed 13 CIREAM contracts, totalling 978,707 m^2 of CIREAM throughout the province.

CIREAM appears to provide an acceptable in-place recycling/rehabilitation strategy that conserves resources and provides an economic alternative to conventional CIR, extending the construction season and reducing the time required before application of the HMA surface. A visual distress survey after 5 years of service indicated the pavement is in very good condition with PCI = 89 and DMI = 9.62. The ANOVA analysis based on FWD testing data concluded that CIR and CIREAM have been performing statistically the same after one year of service. The ANOVA analysis based on ARAN roughness and rutting data concluded that CIR and CIREAM have been performing statistically the same after 3 years and 2 years of service respectively. The ANOVA analysis suggests the two mixes were not performing the same at the beginning, but after a few years of service their performance became the same. Nevertheless, the two mixes are performing exceptionally well and their performances are comparable. It is recommended that ARAN measurements and FWD testing be continued on an annual basis in the future as part of the long-term monitoring of the CIREAM.

8. REFERENCES

[1] Ministry of Transportation Ontario. Pavement Design Report, Highway 7, WP 51-98-00, Strata Engineering Corporation, June 2000.

[2] Lane, B., Kazmierowski, T. And Chan, S. "*Evaluation of Cold In-Place Recycling with Expanded Asphalt On Highway 7, Perth, Ontario*". Canadian Technical Asphalt Association 49th Annual Conference Proceedings, 2004.

[3] Chong, G.J., W.A. Phang, G.A. Wrong. "*SP-004: Manual for Condition Rating of Flexible Pavements -Distress Manifestations*". MTC R&D Branch, Downsview, 1982.