Comparing 10 Year Performance of Cold In-Place Recycling (CIR) with Emulsion versus CIR with Expanded Asphalt on Highway 7, Perth, Ontario

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ABSTRACT

Cold In-Place Recycling of hot mix asphalt pavement is an effective pavement rehabilitation strategy with many social, economic and environmental benefits. These include a short construction period, reuse of existing materials, reduction in transportation of materials, reduced greenhouse gas emissions and fuel consumption, and the fact that it is a cost effective treatment.

Ontario has been using CIR with emulsified asphalt binder since 1990. CIR is considered to be an established pavement rehabilitation method. The CIR process mills up the existing asphalt pavement, sizes it, mixes in emulsified asphalt, lays the mix back down, and compacts the material without off-site hauling and processing. In 2003, a new development in CIR technology was introduced, using expanded (foamed) asphalt instead of an emulsion to bind the mix. This combination of CIR and expanded asphalt technologies was introduced as Cold In-Place Recycled Expanded Asphalt Mix (CIREAM).

The Ministry of Transportation Ontario (MTO) constructed its first trial section of CIREAM on Highway 7, east of Perth in July 2003. Under the same contract, a 5-km trial section of CIREAM was constructed adjacent to 7-km of conventional CIR mix. The performance of these two sections has been monitored over the past 10 years, using the Ministry's Automated Road Analyzer (ARAN). The results indicate that CIREAM is performing in a similar fashion to conventional CIR. Both treatments are providing excellent long term performance and have been shown to significantly reduce or eliminate reflective cracking.

1.0 INTRODUCTION

In Ontario, Cold In-place Recycling (CIR) is an established pavement rehabilitation method typically selected to address older pavements with significant cracking. CIR is used to treat the top 100-125 mm of an existing Hot Mix Asphalt (HMA) pavement. The pavement is sized, additional asphalt cement is added, and the material is laid back down and compacted without the need for off-site hauling and processing. The added asphalt cement is typically an emulsified asphalt, a blend of water and asphalt cement droplets. The CIR material forms a binder course layer and a new HMA surface is placed after the emulsion has set, and moisture and compaction requirements have been met, typically within 14 to 30 days.

In 2003, a new development in CIR technology was introduced using expanded (foamed) asphalt, rather than emulsified asphalt to bind the mix. To foam the asphalt, asphalt cement is heated and pumped through an expansion chamber on the cold recycling unit, where a small amount of cold water is injected and immediately vaporizes, causing the asphalt cement to rapidly expand (foam). The expanded asphalt is then mixed with the reclaimed asphalt pavement. As with conventional CIR, the material is then profiled and compacted to form a binder course layer. This combination of CIR and expanded asphalt technologies was introduced as Cold In-Place Recycled Expanded Asphalt Mix (CIREAM).

With conventional CIR, the Ministry of Transportation Ontario (MTO) specifies a minimum 14-day curing period to allow the emulsion to set, and moisture and compaction requirements to be met. The advantage of CIREAM is that the asphalt cement does not need to break and cure, therefore a new HMA surface can be applied, if compaction requirements have been met, following a 3-day curing period.

MTO constructed its first CIREAM project on Highway 7, east of Perth in July 2003. A 5-km trial section of CIREAM was constructed adjacent to a 7-km section of conventional CIR mix, giving the Ministry an excellent opportunity to observe the performance of each mix. During construction, samples of both mixes were obtained and indirect tensile strength testing was carried out. For ten years, the long term performance of these two adjacent pavement sections has been evaluated in terms of pavement roughness and rutting using the Ministry’s Automated Road Analyzer (ARAN).

2.0 BACKGROUND

The CIR/ CIREAM demonstration project is located on Highway 7, from Innisville to the town of Perth, 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. 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 axle, six tire, single unit trucks (16%).

Figure 1. Contract 2002-4040 Limit on Highway 7 from Innisville to Town of Perth

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 (life cycle costing over a 30 year period), 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 bid the contract as conventional CIR, and 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.

3.0 CONSTRUCTION

Construction of the CIR and CIREAM began in early July 2003. Seven 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, with 10,500 m^2 on a single day being the best production rate.

Five km 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, with 16,387 m^2 on a single day being the best production rate. Figures 2 and 3 show the CIR and CIREAM equipment, while Figure 4 a) and b) show 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

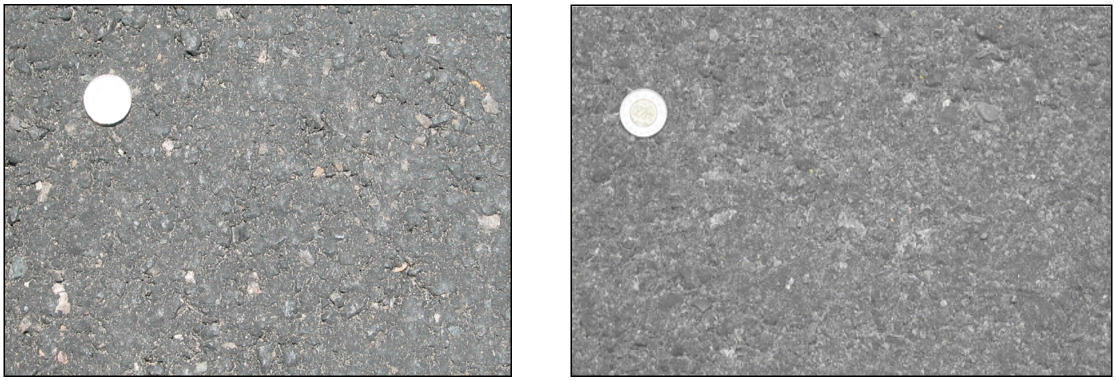

Figure 4. a) Finished Surface of CIR Mix b) Finished Surface of CIREAM Mix

4.0 INDIRECT TENSILE STRENGTH TESTING OF CIREAM DURING CONSTRUCTION

Testing of CIR for acceptance purposes on MTO contracts typically involves checking compaction and moisture content. However, testing of full depth reclamation (FDR) with expanded asphalt on MTO contracts involves indirect tensile strength testing. It was decided to follow the FDR specification and test the CIREAM mix to determine indirect tensile strength. For testing purposes, a lot consisted of a single day’s production of CIREAM. Each lot was divided into a minimum of 3 equal sublots, each 5000 m^2 or less. One random 15 kg sample of CIREAM was obtained from each sublot, and testing was carried out to determine dry tensile strength, wet tensile strength and tensile strength ratio in accordance with ASTM D4867/D4867M [1].

Acceptance criteria for tensile strength was based on the lot mean computed from quality assurance test results for each sublot. Dry tensile strength requirements for the lot were met when at least 90 percent of all dry tensile strength measurements were equal to or greater than a minimum requirement of 350 kPa. Wet tensile strength requirements for the lot were met when at least 90 percent of all wet tensile strength measurements were equal to or greater than a minimum requirement of 175 kPa. Tensile strength test results from the owner (Quality Assurance) and the Contractor (Quality Control) are summarized in Table 1 below.

Table 1. Indirect Tensile Strength Test Results for CIREAM

Quality Assurance Results				Quality Control Results		
Lot / Sublot	**Dry Tensile Strength (kPa)**	**Wet Tensile Strength (kPa)**	**Tensile Strength Ratio**	**Dry Tensile Strength (kPa)**	**Wet Tensile Strength (kPa)**	**Tensile Strength Ratio**
1-1	340	214	63%	425	300	71%
1-2	275	236	86%	333	242	73%
1-3	362	232	64%	475	317	67%
1-4	271	198	73%	555	333	60%
2-1	269	209	78%	413	343	83%
2-2	344	206	60%	620	382	63%
2-3	250	187	75%	573	348	61%
3-1	221	179	81%	560	417	75%
3-2	212	188	88%	552	355	64%
3-3	259	177	68%			
Mean	**280**	**202**	**73%**	**501**	**337**	**70%**
Stdev	51.74	20.69	9.7%	94.05	49.64	7.6%

An examination of the test data showed that the Quality Control (QC) test results for Dry Tensile Strength met the specification, while Quality Assurance (QA) test results did not. Discrepancies between QC and QA testing may be attributable to moisture conditioning of the samples and timing of testing. The specification for CIREAM states that samples must be modified by moisture conditioning prior to manufacture of the briquettes to ensure that the materials are properly lubricated and readily compacted. While the Contractor’s QC laboratory was able to carry out testing immediately upon receipt of the samples, the QA testing was delayed. Moisture loss may have occurred due to water condensing on the inside of the plastic sample bags and the samples may have hardened with time. The test method requires compaction of the lab sample (briquette) at the field moisture content. If the optimum moisture is not achieved, the result is a decrease in density and a lower tensile strength. A new test method LS-297 [2] has since been written to provide a clear testing procedure and reduce testing variability.

5.0 COMPACTION OF CIREAM

The target density of the CIREAM was determined based on the mix design with material reclaimed from the roadway. The specification required that each lot be compacted to a minimum of 96.0 percent of the target density established for the mix, with no result falling below 95.0 percent.

Prior to HMA overlay, the Contractor randomly obtained one slab sample from each sublot to test for compaction. The slab samples were dry cut 150 x 150 mm and removed intact from the roadway. Compaction of the slab samples was determined in the laboratory according to LS-306 [3]. Compaction results met the contract requirements for CIREAM (Table 2).

Table 2. Compaction Results for CIREAM

Lot / Sub lot	Bulk Relative Density (BRD)	% Compaction by sublot	Lot Average
1-1	2.181	97.9	96.4
1-2	2.180	97.9	
1-3	2.124	95.4	
1-4	2.101	94.3	
2-1	2.290	102.8	102.5
2-2	2.251	101.1	
2-3	2.307	103.6	
3-1	2.267	101.8	103.5
3-2	2.306	103.5	
3-3	2.327	104.5	
Average	2.233	100.3	

6.0 MOISTURE CONTENT OF CIR

The contract required that the mean moisture content of the CIR for each lot be less than 2.0 percent with no sublot moisture content exceeding 3.0 percent. The moisture content of the CIR was determined according to LS-291 [4] from slab samples taken from the roadway. Although the CIR placement occurred in early to mid July, by August 13, the 2 percent moisture criteria had not been met (Table 3), possibly due to wet weather conditions. The contractor asked permission to overlay, however, with several weeks of summer ahead, the Ministry preferred to wait for the moisture requirements to be met. HMA overlay of the CIR mix, placed July 2-15, was carried out August 18-22.

According to the contract, the CIREAM was only required to cure for a minimum of 2 calendar days prior to overlay. However, HMA overlay of the CIREAM was carried out July 31, August 6 and 8 for the CIREAM, which was placed July 7-9.

Table 3. Moisture Content Results for Cold In-Place Recycled (CIR) Mix

Lot / Sub lot	% Moisture	Lot / Sub lot	% Moisture
1 / 1	2.1	7 / 1	2.4
1 / 2	2.2	7 / 2	2.0
1 / 3	1.8	7 / 3	2.0
2 / 1	1.5	8 / 1	3.8
2 / 2	2.8	8 / 2	3.1
2 / 3	3.6	8 / 3	3.4
3 / 1	2.7	9 / 1	3.4
3 / 2	2.0	9 / 2	3.0
3 / 3	2.4	9 / 3	2.5
4 / 1	2.6		
4 / 2	3.1		
4 / 3	2.4		

7.0 POST-CONSTRUCTION TESTING AND EVALUATION

7.1 Indirect Tensile Strength Testing of Materials Obtained During Construction

The CIREAM trial on Highway 7 was the Ministry's first use of this new technology. To evaluate the material outside of the contract environment, both the CIR and CIREAM material were sampled and tested in-house to allow a comparison of the materials. During construction, three 15 kg samples of the CIR and three 15 kg samples of the CIREAM were randomly obtained from the beginning, middle and end of the work and shipped to the Ministry's Downsview Laboratory for testing. At a much later date, briquettes were made for dry tensile strength (DTS), wet tensile strength (WTS), and tensile strength ratio (TSR) according to LS-297 [2]. Results of this testing are presented in Table 4.

Table 4. Results of Indirect Tensile Strength Testing of CIREAM and CIR

	CIREAM			CIR		
	DTS (kPa)	**WTS (kPa)**	**TSR (%)**	**DTS (kPa)**	**WTS (kPa)**	**TSR (%)**
	707	567	80	193	52	27
	784	595	76	175	60	34
	693	511	74	191	62	33
	269	144	53	136	126	92
	298	131	44	143	109	76
	278	150	54	157	99	63
	421	254	60	262	113	43
	375	255	68	255	123	48
	424	266	63	269	135	50
Mean	**472**	**319**	**64**	**198**	**98**	**52**
Stdev	201	187	12	52	32	22

Note that the CIREAM tensile strength results, although quite variable, are significantly higher than the CIR results. A more detailed review of the test data show that the wet and dry tensile strength of both materials is directly related to the bulk relative density of the briquette. Briquettes for the testing were compacted in accordance with the test method, however, the CIREAM material was more readily compacted and the denser briquettes gave higher indirect tensile strengths (Figure 5).

These results indicate that the tensile strength of both materials is dependent on density. It was decided to look at the in-place density of the CIR and CIREAM pavements. Cores obtained 8 months after construction were tested to determine if there were any differences in compaction density between the CIR and CIREAM. Eight cores of CIR and 10 cores of CIREAM were obtained and the density of each core was measured. Results indicated that the mean density of the two materials was similar (Table 5).

The field density of the CIR and CIREAM (2.233-2.249 t/m^3) corresponded to the bulk relative density of the CIREAM briquettes with the highest tensile strengths (Figure 5). It is likely that, had the testing been carried out shortly after sampling, the briquettes would have been more readily compacted to the required density. Since testing was delayed for several months, the material had cured in the bag and was difficult to compact, resulting in low and variable densities, and in turn low and variable tensile strengths.

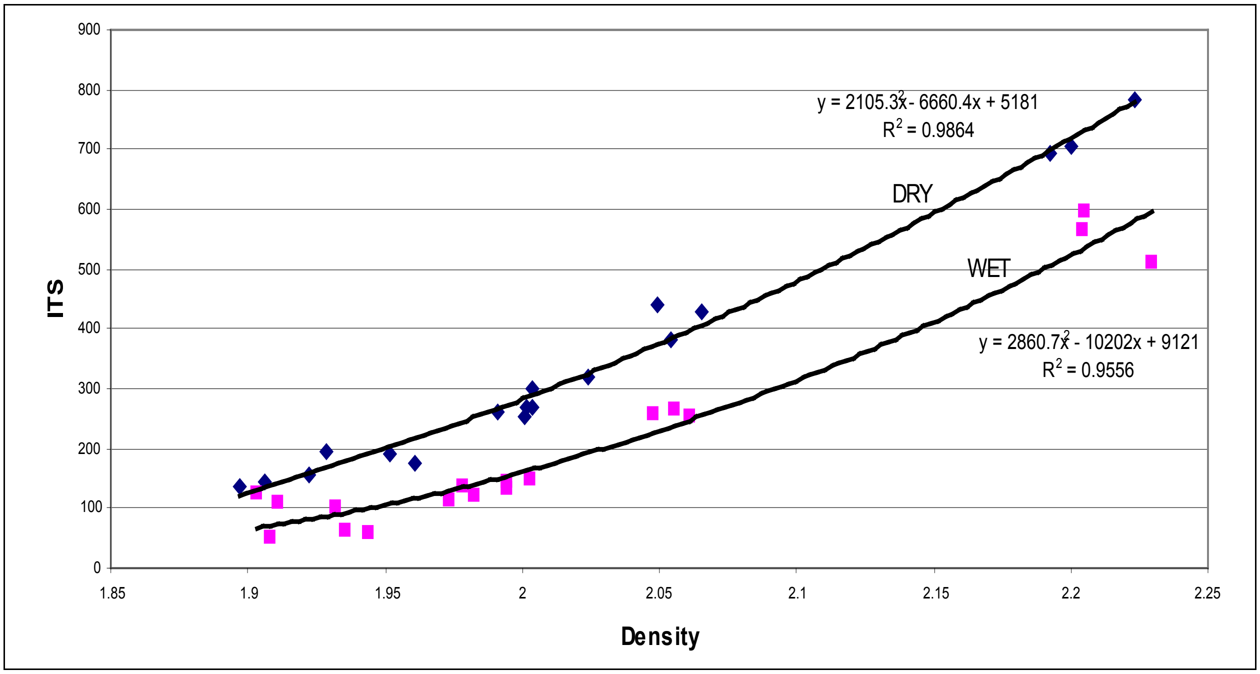

Figure 5. Indirect Tensile Strength (ITS) versus Briquette Density for CIR and CIREAM

Table 5. Density of Field Cores of CIR and CIREAM

	No. of Cores	Mean Density	Variance
CIR	8	2.233	0.0015
CIREAM	10	2.249	0.0016

7.2 Roughness and Rutting

Shortly after placing the HMA surface course, the Ministry carried out a survey of roughness and rutting using the Automated Road Analyser (ARAN).

The average International Roughness Index (IRI) was found to be 1.16 m/km for the CIREAM and 1.00 m/km for the CIR, indicative of a fairly smooth pavement. ANOVA analysis concluded that these results were statistically different, and the CIR was smoother than the CIREAM (F = 10.29 > Fcrit = 3.85). Note that the CIR was micro-milled to correct profile and cross-fall prior to surface course overlay, which likely improved the smoothness of the pavement. The average rut depth was found to be 2.6 mm for the CIREAM and 2.9 mm for the CIR. ANOVA analysis showed that the two sets of data were statistically different (F = 22.71 > Fcrit = 3.85). The CIREAM had slightly less rutting overall, but was more variable than the CIR.

ARAN measurements of roughness and rutting have been carried out every year since construction. The two sections have been performing similarly since 2004 and remain in very good condition after 10 years. In 2012, the average IRI was 1.2 m/km for both the CIR and CIREAM test sections (Figure 6). Similarly, rutting performance has been nearly identical for the two sections, with an average rut depth of 2.8 mm for CIR and 2.7 mm for CIREAM (Figure 7).

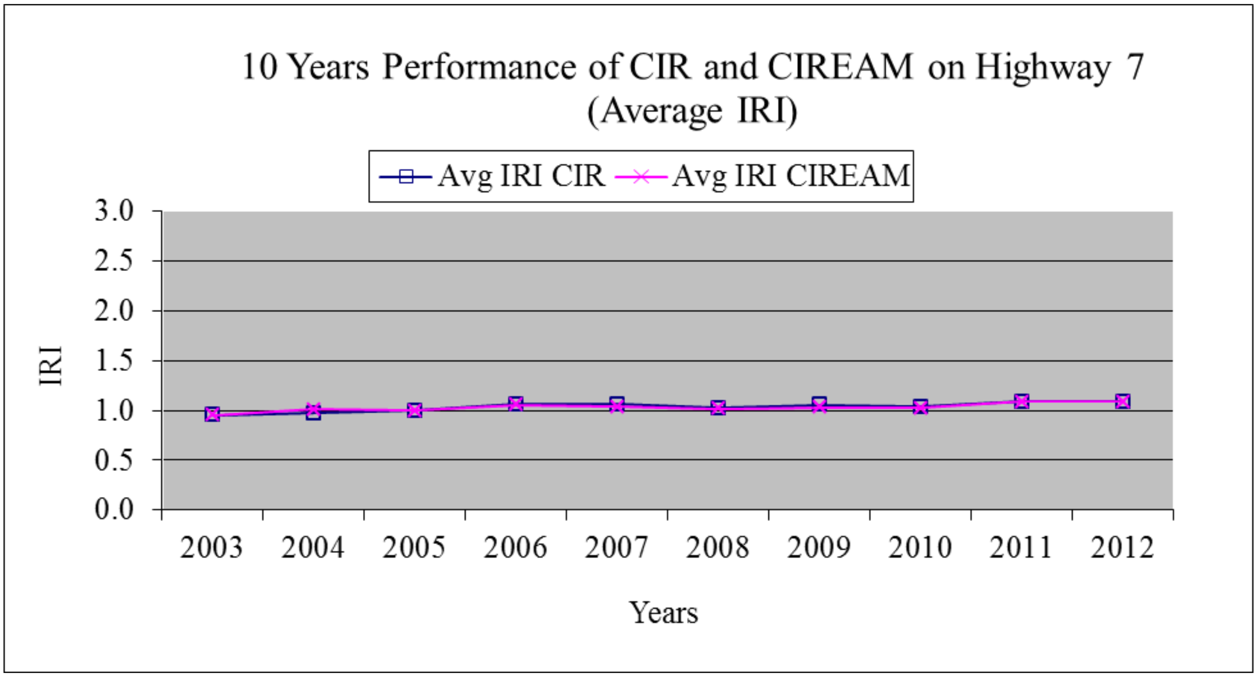

Figure 6. Ten Year Performance of CIR and CIREAM on Highway 7 in terms of Average International Roughness Index (IRI) in m/km

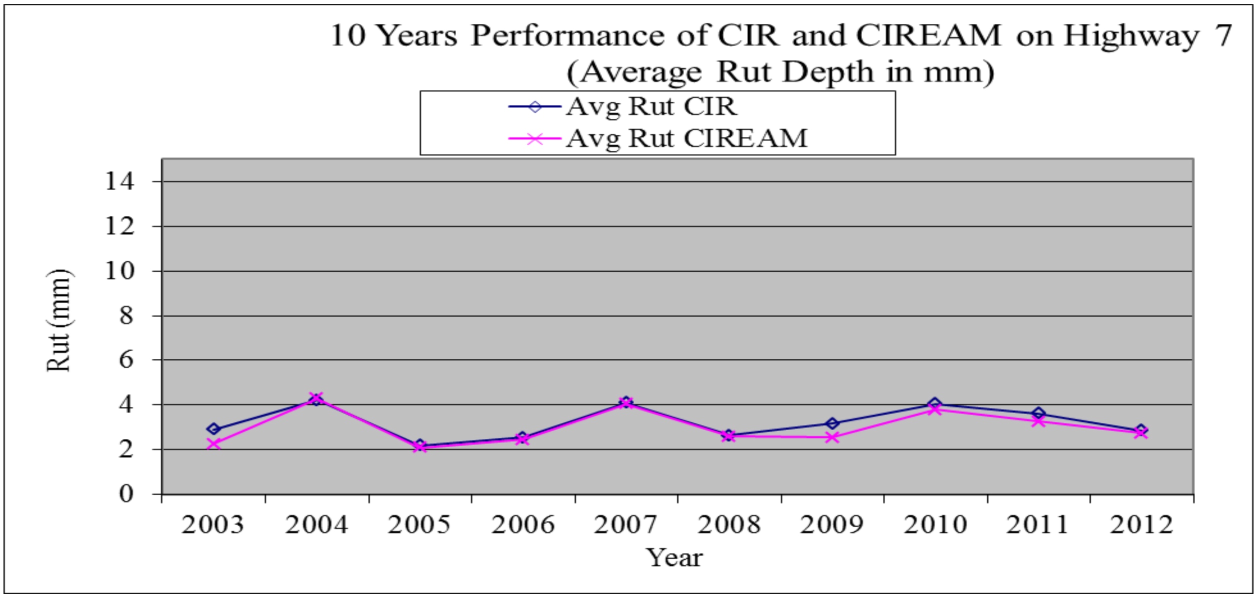

Figure 7. Ten Year Performance of CIR and CIREAM on Highway 7 (Average Rut Depth in mm)

Of interest is the performance of the adjacent section to the west on Highway 7, Perth to Wemyss, where a more conventional treatment of milling, full depth crack repair, and two lift overlay was carried out. This type of rehabilitation is more expensive, more time consuming, and more of an inconvenience to the travelling public due to construction delays. The treatment however, is considered to be more robust. A comparison of the adjacent pavement sections reveals that the CIR / CIREAM treatment has been very effective at crack mitigation (the pavement has remained smooth for ten years), while the section with milling, crack repair and two lift overlay starts rougher and deteriorates rapidly (Figure 8).

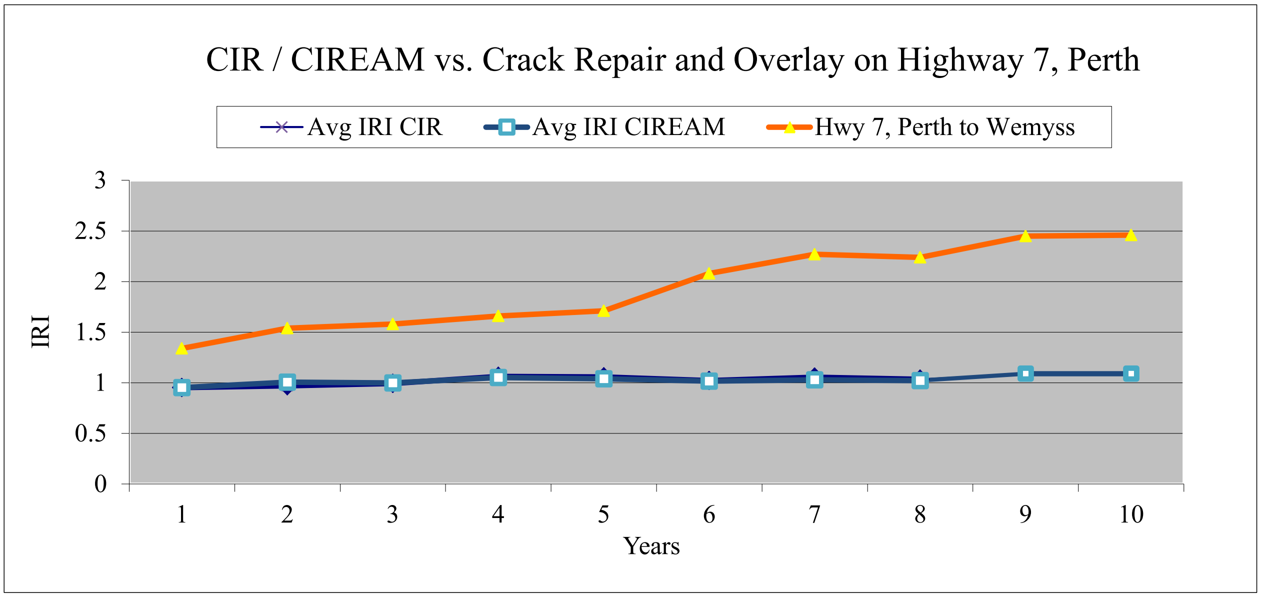

Figure 8. Comparing CIR/ CIREAM to Crack Repair and Overlay on Highway 7 (IRI)

7.3 Visual Distress Survey

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. After 10 years of service (2013 data), the entire pavement section is performing very well with the following distresses:

- Very slight, few coarse aggregates loss
- Very slight, few flushing
- Very slight, few distortion
- Very slight, few longitudinal wheel tracking cracking
- Very slight, intermittent centerline cracking
- Slight, frequent pavement edge cracking
- Slight, intermittent transverse cracking
- Slight, few mid-lane cracking

The visual distresses identified are slight in severity. This indicates the pavement distresses are minor with no significant performance issues on this section after 10 years of service.

In 2012, the pavement condition index (PCI) for this combined section is 88 with a distress manifestation index (DMI) of 9.16. 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. DMI is the subjective distress manifestation index, theoretically ranging from 0 to 10, where 0 indicates the worst condition and 10 represents an excellent condition. The pavement performance of the CIR and CIREAM sections with PCI = 88, DMI = 9.16 and IRI = 1.2 after 10 years of service is considered to be very good.

Figure 9. Highway 7 Pavement Condition (2013)

8.0 CONCLUSIONS

CIR has been found to be an effective pavement rehabilitation treatment with the benefit of mitigating reflective cracking, thereby extending pavement life. By reusing the existing hot mix asphalt pavement (aggregates and asphalt cement), CIR is both environmentally sustainable and cost-effective. The Ministry has successfully carried out over 75 CIR contracts since 1990. In 2003, CIREAM was introduced as an alternative to CIR with emulsion technology, that to date has been shown to perform equivalently to the conventional CIR method.

Ten 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 at a similar cost. Both treatments perform remarkably well in comparison to the milling, crack repair and two-lift overlay performed on the adjacent contract.

ARAN results from the Highway 7 demonstration project indicate that the CIR and CIREAM pavements are performing identically in terms of roughness and rutting. Pavement distresses are minor with no significant performance issues after 10 years of service.

REFERENCES

[1] ASTM D4867/D4867M-96. Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures, Annual Book of ASTM Standards, Vol.0403, p. 485-489 (1996).

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