TEN YEAR PERFORMANCE REVIEW OF IN-SITU HOT MIX RECYCLING IN ONTARIO

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ABSTRACT

In today's climate of environmental and economic constraints coupled with a diminishing aggregate supply, in-situ hot mix recycling provides an important alternative to conventional pavement rehabilitation. In-situ hot mix recycling, including hot in-place recycling (HIR) and cold in-place recycling (CIR), is proving to be an economical rehabilitation technique that conserves granular materials, energy, and results in zero waste.

The Ministry of Transportation (MTO) and the Regional Municipality of Ottawa-Carleton (RMOC) have rehabilitated in excess of 80 projects utilizing in-situ hot mix recycling techniques since 1987. The HIR process is suitable for roadways exhibiting a variety of surficial non-structural distresses. CIR is suitable for roadways with moderate to severe distresses where reflection cracking is a concern.

This article provides an overview on the design, construction procedures, test results and pavement performance to date of in-situ recycling. Ten years performance monitoring of the in-situ recycling projects has resulted in the evolution of design strategies and performance specifications.

INTRODUCTION

As we become more conscious of the need for construction techniques that not only rehabilitate to acceptable standards but are also environmentally acceptable, in-situ hot mix recycling, including hot in-place recycling (HIR) and cold in-place recycling (CIR), has proven to be an economical rehabilitation technique that conserves granular materials, energy, and results in zero waste.

The HIR process is suitable for highways exhibiting a variety of surficial and slight to moderate non-structural distresses. The HIR process involves heating the existing pavement surface, scarifying the heated pavement surface, adding rejuvenator, fine aggregates and/or an admixture (beneficiating hot mix) as required, mixing, reprofiling, and compacting this hot mixture in a continuous operation.

CIR is suitable for highways exhibiting moderate to severe distresses. CIR involves milling the existing pavement, screening for oversize, the addition of an asphalt emulsion (high float or polymer modified) and mixing, then placement of this cold renewed material on the roadway in one continuous operation. The processed material is then spread and reprofiled with a conventional paver and compaction equipment.

The performance evaluation and recommendations from the monitoring of contracts utilizing these two processes are discussed within this article.

HOT IN-PLACE RECYCLING

HIR Projects

MTO has completed 31 contracts since first utilizing the HIR process in 1987 to rehabilitate asphaltic concrete pavements. The majority of these projects included the placement of a thin conventional hot mix surface (thin integral overlay), placed over the uncompacted HIR mat; the two layers compacted as one integral layer. Most of these projects added rejuvenator and fine aggregate to the HIR mix and one project included an admixture.

Interest has been expressed by many in regard to the rehabilitation potential of this process, as well as their concerns with the smoke generated and the large range in test results for both recovered penetration (PEN) and air voids.

Suitability Criteria for HIR Process

When determining if a pavement is suitable for HIR, factors such as pavement depths and types, traffic, previous maintenance work, and the pavement's existing condition must all be considered; the following are the main points to consider:

- The process is suitable for pavements exhibiting only surficial distresses, i.e., ravelling, coarse aggregate loss, and slight to moderate cracking. The process does not mitigate reflection cracking or instability rutting.

- HIR will not add to the structural strength of a pavement or correct any structural fatigue distresses.
- Process treats existing pavement to a maximum depth of 50 mm.
- Corrects up to ± 1.3% crossfall deficiency, when HIR for a depth of 40 mm and placing a 25 mm integral overlay.
- Traffic volumes are not a limiting factor.
- Process allows for a thin integral overlay (25 mm) of conventional hot mix.
- Pavements with large quantities of cold mix patches, spray patching and/or extensive crack sealant are unsuitable and/or require removal of this material.
- Hot mix with steel slag aggregates appears unsuitable for HIR due to the aggregates poor heat transfer and absorptive characteristics resulting in excess smoke generation and rapid cool down of the mix.

Construction

Basic Equipment and Operation Options Available

The equipment predominately used in Ontario for HIR projects is a single-stage process. This equipment shown in Photo 1 consists of two or three infrared preheaters, a reformer unit that scarifies the hot asphalt pavement, mixes in a rejuvenator, fine aggregate and/or admixture as required. The reformer unit has both a strike off and a separate screed at its back end. The strike off places the heated rejuvenated (recycled) material. The screed is used to place a thin integral overlay of conventional hot mix if required over the hot uncompacted recycled material.

Multi-stage process trains from outside the province have also been used in Ontario. The train depicted in Photo 2 consists of a preheater followed by two infrared heater-milling units, a mixing auger/pugmill, and conventional paver. This train recycles in two stages of 20 mm, rather than removing the full 40 mm depth in one pass. Most of the multi-stage equipment has been unable to provide the thin integral overlay. Newer equipment utilizes low intensity infrared heat and high velocity hot air which literature indicates heats the pavement effectively without the overheating and resultant oxidation of the existing pavements asphalt cement.
The efficiency of the various equipment trains vary as follows:

- Radiant heat produced by infrared heaters is more desirable than open flame heaters since a more uniform heat is produced with less opportunity for oxidation of the surface hot mix.
- For scarifying/milling a combination of spring mounted scarifying tines, and a downward rotating

milling head, are desirable to minimize fracturing of the existing aggregate.
- To provide a homogenous lift of hot mix, free of segregation, flushing, and uncoated aggregates; proper mixing is required. A separate mixing unit (pugmill) is recommended particularly when an admixture is being added to the HIR mix.
- Newer equipment reduces in instances of flare-up and the accompanying generation of excess smoke when processing pavement surfaces with crack sealants and surface treatments.

Productivity

Productivity is governed by depth recycled, ambient temperature, rain, moisture in the existing pavement, wind, addition of fine aggregate, delays in delivery of hot mix, lane tapers, paving around obstacles and equipment mobilization concerns. The process slows down considerably in colder weather and when curves, widenings, tapers, or rain are encountered. Tight curves such as intersections are difficult for the long HIR equipment trains to manoeuvre around.

The productivity tends to range from 2 to 5 m/minute with productivity increasing when more efficient heating systems and/or multi-stage systems are used.

Acceptance Testing

Penetration of Asphalt Cement

Rejuvenators consist of commercially available base stock light oils, an intermediate refinery product produced to specification incorporating aromatic content. These rejuvenators are used to increase the recovered penetration (PEN) of the existing asphalt cement in the reclaimed material. An admixture is added when a rejuvenator and/or fine aggregate will not provide a HIR mix conforming to the mix requirements specified. The admixture can range from a pre-coated fine aggregate to a high or low asphalt cement content coarse aggregate hot mix depending on the existing mix deficiencies. The admixture is specifically designed to assist the final HIR mix to conform to mix specifications.

Comparison of the recovered PEN values for the material before and after HIR indicates that for the first five years of HIR in Ontario the rejuvenator, on average, raised the PEN values by 18 penetration units. During the past five years, the average increase in recovered penetration units was double that of the first five years with an average increase of up to 45 units obtained on recent projects.

Recent recovered PEN test results for HIR mix averaged 61 units with a standard deviation of 13 are comparable to these produced for conventionally recycled hot mix at an average of 65 units and a standard deviation of 9.

Air Voids

Adding a rejuvenator to the reclaimed material decreases air voids. Fine aggregate (or an admixture) can be added to increase the air voids. Air void requirements of 3% to 5% are specified for the HIR mix as well as for conventional hot mixes. Contractors seem to have varying degrees of success in meeting these requirements. Air void test results have, however, improved over time; from less than a third of the results within the specified range during the first five years of utilizing the technique to as many as three quarters of the test results within the required specifications during the past five years.

Pavement Performance

Pavement Evaluation

The performance to date of the HIR pavements has been comparable to conventionally rehabilitated pavements. The following pavement distresses were noted within the early life of the HIR pavements placed in conjunction with thin integral overlays:

- Half of the pavement edge, transverse, and mid-lane cracks reflected through within the first year (slight in severity). This is also typical for pavements conventionally rehabilitated using thin overlays.
- The majority of longitudinal and centreline cracks have not reflected through. This may be due to all HIR joints being formed hot, eliminating cold joints and allowing for additional compaction at the longitudinal joint.

Roughness

All HIR projects have been evaluated for pavement ride quality (roughness) using the Portable Universal Roughness Device (PURD). The PURD is an accelerometer-based device, which uses the root mean square vertical acceleration of a trailer axle to measure roughness. The data is converted into a ride condition rating (RCR) on a scale from 0 for very poor to 10 for excellent as follows:

$$RCR = 26.64 - 7.38*\log_{10}(PURD)$$

Typically RCR values for the HIR contracts have increased by 2.6 units to between 8.2 and 9.5. These RCR values are in the smooth and pleasant range, which is a typical roughness value on other conventionally rehabilitated projects. The RCR values have not shown any significant decrease in the years following rehabilitation.

Performance-Based Warranty Specification

Prior to 1996, all HIR contracts in Ontario utilized an end result specification with specific equipment requirements. Based on the past performance of the HIR technique which has been monitored regularly since it was first used to rehabilitate flexible pavements in 1987, a performance based specification utilizing a three year warranty period was established.

The warranty specification still contains elements of the existing end-result requirements but most of the method specification components were eliminated. Repair requirements include:

- milling the surface course and replacing it with a minimum of 40 mm of appropriate hot mix surface course;
- milling 2 lifts and replacing with appropriate hot mix binder and hot mix surface course; or
- HIR 50 mm and placing an integral overlay with appropriate hot mix surface course depending on the distress type present.

COLD IN-PLACE RECYCLING

CIR Projects

RMOC and MTO have completed 36 contracts since first utilizing the CIR process in 1989 to rehabilitate asphaltic concrete pavements. All of these projects have included a separate overlay as a wearing surface. Most of the projects utilized high float emulsion as the stabilization additive with more recent trial sections including the use of quicklime and cement slurry in the emulsion.

The use of CIR has only recently become more widely accepted by road agencies in Ontario. The volume of CIR work carried out in Ontario since 1989 was about 300,000 m^2 per year, but was noted to have increased to about 2,000,000 m^2 in 1997.

The main advantage of this process over conventional hot mix rehabilitation method is the improved reflective crack mitigation provided by the CIR materials. Two research programs are currently being undertaken; the first by the RMOC with assistance from Carleton University, and the second by Miller Construction Ltd. with National Research Council (NRC), RMOC and MTO participation. These studies will provide field assessment of the CIR pavement performance and on the material properties, which account for CIR materials' superior mitigation of reflective cracking.

Design Considerations for CIR

CIR may be carried out on a wide range of deteriorating pavements. Selection of a suitable CIR candidate requires consideration of the work site, pavement surface distress condition, and pavement base and subbase data.

Site constraints such as curb height, presence of significant iron works and lack of good local aggregates are some factors to be considered.

Pavement surface distress analysis is used to determine the type, extent and severity of the pavement distress in road sections under consideration. CIR may be considered to rehabilitate pavement with the following categories of pavement distress:

- Pavement cracking due to aging, thermal cracking, fatigue cracking, reflective cracking
- Pavement deformation such as rutting due to mixture instability, shoving, rough pavement
- Loss of pavement integrity such as raveling, flushing and loss of bond between the layers

Conventional CIR by itself may not be able to correct problems such as rutting, shoving and flushing. These distresses may be indicative of excessive bitumen in the mix; hence addition of more bituminous binder, a requirement in conventional CIR, may aggravate the situation. The addition of corrective aggregate is needed to improve the gradation of the existing mixture and to reduce the ratio of total bitumen/mineral aggregate.

Pavements with substandard pavement strength, extensive base and/or subgrade problems are not good candidates for CIR. Pavement strengthening using two or more lifts of a hot mix overlay on CIR pavement may be considered under some circumstances.

Mix Design

The mix design used for CIR process is similar to the Marshall method developed for conventional hot bituminous mix. Instead of optimizing just the asphalt binder content to satisfy the volumetric requirements of the Marshall mix design, the CIR mix design optimizes the emulsion and water content to achieve the desired mix density, air void and stability. Typical emulsion content ranges from 1.5 to 2.2 % with water content ranging from 3.5 to 4.5%.

For pavements experiencing rutting, shoving or flushing, the use of a corrective aggregate may be required.

The CIR mix design process should be used for selection of initial job mix formula with final mixture adjustments being carried out in the field with consideration given to workability, coating, plasticity and ease of compaction of the mix. The current mix design process takes into consideration the improvement of CIR mix performance with time.

CIR Construction

A wide variety of equipment is available to perform CIR; they differ from one another by how the various components of the recycling train are grouped or separated. These components include:

- Reclamation of the existing asphaltic concrete pavement (milling unit)

- Transformation of reclaimed pavement to a calibrated RAP aggregate (processing unit)
- Addition of an emulsion or stabilizing slurry additives and mixing (pugmill mixer)
- Laydown of the new mixture (paving unit)

The various combinations of recycling equipment systems used can be grouped into single train or multi-unit recycling train. The single unit recycling equipment (Photo 3) reclaims, sizes and mixes in the additives in the cutting drum while the laydown operation is performed with a standard screed attached to the back of the unit. In the multi-unit recycling train (Photo 4), the reclamation of the existing bituminous pavement is performed by a standard milling machine, the sizing is accomplished by a mobile screen/crusher unit, mixing is done with a mobile pugmill and the laydown is performed with a conventional paver.

Other variations include a mix-paver instead of a mobile pugmill and standard paver. A down cut milling machine may be used to replace a standard up cut milling machine with mobile screen/crusher.

The CIR recycled mat upon laydown is left in place for 15 to 30 minutes prior to compaction to allow for the emulsion to break and aeration of the mix. Aeration is required in emulsion based CIR process if the mix water required is in excess of the optimal water content for field compaction. The optimum moisture content for compaction of CIR mix is about 3.5 to 4.5%. A successful CIR operation requires more compaction energy than that of a conventional hot bituminous mixture. The use of one heavy pneumatic roller combined with one double drum, vibrating roller is generally sufficient to achieve the desired compaction. Double vibrating drum rollers were found to provide high compaction levels in the CIR mix when carried out at high amplitude and low frequency.

Minimum compaction requirement is generally 96% Marshall density using field specimens. The compacted CIR mix generally has an air void content of 12 to 15%.

Productivity

The productivity of cold in-place recycling process is about 4 to 6 m/minute when weather and equipment conditions are favourable.

The weather limitations for CIR are similar to those of other emulsion applications. When rain is imminent, the CIR operation must be stopped. Air temperature affects not only the breaking and curing of the emulsion, but also the viscosity of the aged bitumen contained in the bituminous aggregate.

The CIR recycling train is long and, hence, is subject to similar space and maneuverability constraints as the HIR process. CIR around iron work, lane widening, lane tapers and tight curves with the current technology and equipment is still a challenge.

Unlike conventional hot mix paving and HIR, a curing period is required for the CIR recycled mixture to develop enough internal cohesion prior to being overlaid with a wearing course. Typically 14 days of curing is specified, however, as a rule of thumb, if a completely intact core can be obtained for the recycled mat then it is ready for placement of the wearing surface.

Pavement Performance

Crack Mitigation

Results from a study done by RMOC indicated thermal cracking manifested, as transverse cracking is the principal cause of reduced effective pavement life and reduced pavement performance for structurally adequate roads. The results are based on about 800 km of one lane wide pavement consisting of 95 km of new and reconstructed candidates, 190 km of CIR candidates, and 505 km of resurfaced roadways. Data was obtained using an automated multi-purpose data collection vehicle equipped with a distance measuring device, multiple high resolution video camera, ultrasonic profile bar and accelerometers for vehicle response measurements.

Results from the study indicated that some initial cracking is expected for resurfaced candidates after the first year of rehabilitation because of reflective cracking. Few to no cracks were observed for CIR, new, and reconstructed candidates in the first year. The rate of transverse crack propagation after rehabilitation was noted to be highest for resurfaced roadways, followed by new or reconstructed roadways, with CIR candidates showing the lowest rate of crack propagation with time. These results indicate that the CIR process is superior in crack mitigation compared to resurfaced or even new construction using conventional 85/100 binder.

Pavement Deflection Analysis

As part of RMOC pavement management system, the structural adequacy of the pavements in the network are determined using a Dynaflect Deflectometer. It is a trailer-mounted system that measures deflections produced by impulses generated by a pair of unbalanced flywheels rotating in opposite directions. Load pulses are transmitted to the pavement through a pair of rigid wheels spaced 50.8 cm apart at a frequency of 8 Hz. A series of geophones at predetermined locations measures the pavement surface deflection under a harmonic constant load level of about 4kN. The deflection basin is largest at the point of load application and reduces in magnitude away from the source of loading. The deflection is measured by five geophones located between the two rigid wheels with the first sensor located at their point of contact with the pavement, and the remaining four sensors spaced 30.5 cm from the preceding sensor.

The CIR projects in this study generally consist of CIR 100 mm of the existing pavement using high float polymer emulsion and overlaying the CIR mat with an additional 40 mm hot mix asphalt.

Readings taken after the CIR process but before the hot mix overlay, generally indicate an increase in the deflection reading, indicating less structural strength. Progressive reduction in pavement deflections with time were measured for the CIR mat indicating strength gain in the CIR mixture as curing progressed before overlaying the CIR mat with the hot mix surface course. After an overlay of about 40 mm of hot mix asphalt, the deflection measurements are observed to be lower than readings obtained on the CIR mat and generally achieved similar or slightly lower deflection values than the original pavement deflection. Similar Falling Weight Deflectometer deflection results were obtained on an MTO CIR project.

Roughness

The Ride Comfort Rating (RCR) criteria of pavements selected for CIR is generally lower than 5.0. The two main factors influencing selection of the CIR rehabilitation process are a RCR value of less than 5.0, and a frequency of transverse cracking in excess of 170 cracks/km. CIR must also be the best strategy in terms of life cycle costs.

Figure 1 indicates the relationship between RCR with age for CIR candidates in this study. Restoration of RCR value above 9.5 is generally anticipated for CIR projects.

Rutting

A network-wide rut depth survey was conducted on RMOC roadways in 1997 using a vehicle-mounted ultrasonic rut bar. Rut depth measurements taken in 1997 of CIR, and new or reconstructed road projects with AADT of less than 7,000 and no more than 6% trucks were compared. This comparison showed that the magnitude of rut from the CIR candidate with 50 mm conventional hot mix overlay is similar or marginally higher than new or reconstructed roads for the above-mentioned traffic loading condition. Most roadways in the Ottawa-Carleton region generally experienced only slight rutting with the exception of the transit-way (bus only roadway). This acceptable performance is primarily attributed to the use of good quality 100% crushed quarried aggregate.

DISCUSSION

The advantages of in-situ recycling are in the conservation of aggregates, asphalt cement and energy. In-situ recycling uses 100% of the reclaimed material, where as conventional central plant recycling uses a maximum of 50%. Traffic disruptions are minimized with in-situ recycling. Vehicles can drive on the recycled mat immediately after compaction and need only to be detoured around the in-situ recycling train and the uncured CIR mat as it proceeds down the highway.

As with all rehabilitation techniques, there are also some constraints to in-situ recycling:

- They must be carried out in warm, dry weather, particularly CIR. Highest productivity for construction is therefore achieved during the summer months.

- The HIR process can generate smoke when the train passes over crack sealant and various types of patching material depending on the types of equipment used.
- The CIR mix is susceptible to moisture intrusion and abrasion and requires a separate sealing/wearing surface such as a hot mix overlay or surface treatment.
- Since CIR is a relatively new technique, there is no widely accepted mix design or thickness design methodology.

CONCLUSIONS

Based on Ontario's experience with in-situ recycling, the following conclusions appear warranted.

1. HIR is an acceptable rehabilitation technique for pavements exhibiting moderate surficial pavement distresses that are not associated with structural deficiencies.

2. Contractors can and are achieving the recovered PEN values specified for the HIR process provided adequate attention is paid to the existing pavement condition and properties.

3. Pavements with steel slag aggregates should not be HIR due to their porous and insulative properties.

4. Excessive quantities of temporary maintenance treatment materials (sand seals and cold mix) and rubberized asphalt sealant should be removed before HIR.

5. CIR is a viable alternative for use in Ontario on pavements exhibiting a variety of distress manifestations and provides reflection crack mitigation benefits.

6. On the basis of deflection results, the strength characteristics of CIR pavement improves with time as the mix cures.

7. In-situ recycling should be carried out during the warmer, drier months since the efficiency of the operations are dependent on it - the HIR process to ensure uniform heat penetration is achieved, and the CIR for curing purposes.

Overall the performance to date of the in-situ recycling processes has been comparable to pavements rehabilitated conventionally. In-situ recycling that uses 100% of the reclaimed asphalt product, shows potential to address the concerns of future zero waste environmentally conscious roadway rehabilitation contracts. Ongoing refinements in equipment and rejuvenator technology, evolution of mix design/specification requirements, incorporation of emission control systems, and improvements in field operations will ensure the long term performance of pavements rehabilitated using in-situ recycling technology.

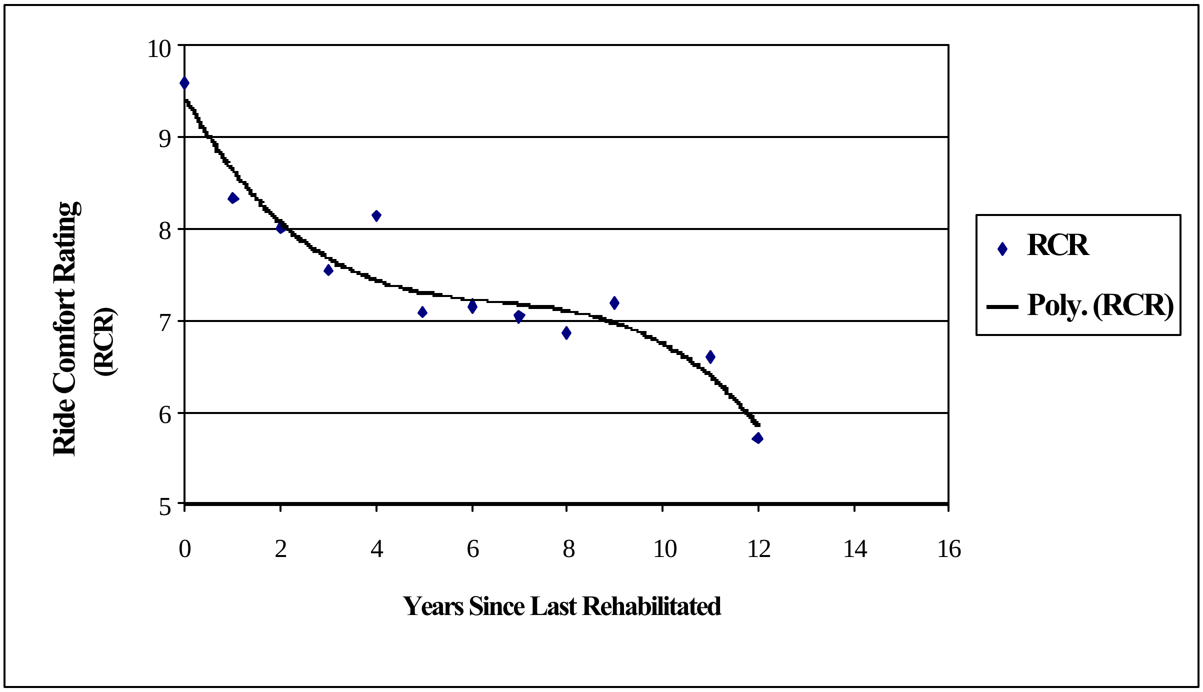

FIGURE 1 RIDE COMFORT RATING VS PAVEMENT AGE

ILLUSTRATION CAPTIONS

PHOTO 1: Single Stage Hot-In-Place Recycling Process Equipment

PHOTO 2: Multi-stage Hot-In-Place Recycling Process Equipment

PHOTO 3: Single unit Cold-In-Place Recycling Train

PHOTO 4: Multi-unit Cold-In-Place Recycling Train