A Performance Review of Cold-in-place Recycling in Canada

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1.0 INTRODUCTION

Large scale recycling of pavements started in the mid-seventies. The petroleum crisis of the seventies and the development of milling equipment for the road industry created a favourable environment for emerging large scale recycling technologies. The current concept of Cold In-place Recycling (CIR) of bituminous pavement was introduced in Eastern Canada in 1989. Over twenty-five millions square metres of pavement have been rehabilitated with this process since 1989 in Canada.

The experience with CIR in Canada is extensive and the benefits are significant when compared with traditional pavement rehabilitation methods. Cold In-place Recycling reduces the cost of pavement rehabilitation. Existing materials are reused allowing the preservation of aggregates and bitumen. The cold nature of the process reduces the impact on the environment and preserves energy.

The objective of this paper is to provide current information on how the CIR process is carried out in Canada. Project selection criteria and project design practices are presented. Information on CIR equipment and the current construction procedures are provided. Performance of CIR is discussed. Finally, experimental technologies associated with CIR are presented.

2.0 PROCESS DESCRIPTION

Cold In-place Recycling is based on the principle that the in-place bituminous pavement is a source of materials that may be used to build a new bituminous layer. The process reuses the in-place bituminous material to a depth of 65 to 125 mm. The process consists of several operations:

- reclamation of the existing bituminous concrete pavement
- transformation of the reclaimed pavement into a calibrated bituminous aggregate
- addition of a corrective aggregate, if required
- mixing of new binder with bituminous aggregate and corrective aggregate, if incorporated
- placement/aeration of the new mixture
- compaction of the mixture
- curing of the mixture
- application of a wearing course.

3.0 PROJECT SELECTION

Cold In-place Recycling may be considered wherever cracking, permanent deformation and/or loss of integrity in the existing bituminous pavement occurs. Structurally sound and well-drained pavements are the best candidates.

Rutting, shoving and flushing may be indicative of an excess of bitumen in the existing mixture. The addition of a corrective aggregate may be required to correct the gradation of the existing mixture and to reduce the ratio of total bitumen/mineral aggregate. Yet, when rutting, shoving or flushing is not present, the addition of a corrective aggregate is seldom required.

Non-traditional mixtures such as Sand Mix or others may be recycled using the CIR process. The process may also be used to treat stripping mixture or mixture that were produced with non-standard aggregate such as slag. The usage of specific corrective measures such as corrective aggregate, anti-stripping agent or/and special binder may be required in those situations.

When the pavement is severely deformed, CIR may require an additional corrective operation such as profiling the road with a milling machine before the CIR operation, adding an aggregate from an external source or/and using additional wearing course material.

4.0 BITUMINOUS MIXTURE DESIGN

Representative samples of the in-place bituminous material are extracted from the pavement and crushed in the laboratory to reproduce the field operation. The material testing is performed to determine the nature of the in-place bituminous aggregate. The testing results are used to decide if the addition of corrective aggregate is required and what type of emulsion should be selected. Samples are examined for evidence of stripping from the aggregate to determine if an anti-stripping agent may be required.

Corrective aggregate is required to strengthen the mineral skeleton of the mixture and/or to lower the binder content. The corrective aggregate is usually selected to adjust the existing gradation of the mineral aggregate to a shape similar to that of a dense graded material.

The selection of an emulsion is based on the following characteristics:

- softening ability of the old bitumen
- coating capability of both the bituminous aggregate and the added virgin aggregate
- cohesion build up and adhesion development at an early age
- insensitivity to small variations in emulsion content.

A sequence of tests is performed on trial specimen of bituminous aggregate with varying emulsion and water contents. When required, the trial mixtures also include a corrective aggregate. The trial specimens are produced using a modified version of the Marshall method of compaction. The testing provides the necessary information to select an emulsion and water content for proper mix density, adequate air voids and optimum stability. The evaluation of the moisture sensitivity of the selected mixture is also recommended. If the new mixture is sensitive to moisture, use of a different emulsion or an anti-stripping agent may be required. The typical emulsion content for standard CIR ranges from 1.5 to 2.2 % and the typical water content ranges from 2.3 to 3.0 %.

5.0 PAVEMENT DESIGN

The structural capacity of CIR recycled material is dependent on the nature of the in-place bituminous material, the added binder and the curing/fluxing time. The US road agencies assume AASHTO layer coefficients between 0.20 and 0.44 for cold recycled material. The most commonly used value for standard CIR work is 0.30 [1]. The various road agencies using the CIR process in the province of Ontario are assuming a gravel base equivalency (GBE) of 1.8 [2].

A minimum depth of CIR treatment is required to mitigate reflective cracking. As a rule of thumb, whenever the depth of the treatment is 100 mm or 70 % of the full depth of bituminous pavement, the potential occurrence of reflective cracking is greatly reduced [1]. Paved shoulders should also be recycled to prevent propagation of shoulder cracks into adjacent CIR treated lanes.

When CIR was first introduced many road agencies recommended not to use the process on high volume roads. The performance knowledge of recycled materials has greatly improved in the last decade and CIR projects have been successfully carried out on high volume roadways. Limits on traffic volume have been removed by most road agencies. An appropriate pavement design must be completed and it is still recommended to evaluate the rutting potential of the recycled mixture when the volume of heavy traffic is high [1,2].

The final operation of the CIR process is the placement of a surfacing course. The surfacing course provides sealing and, when required, pavement reinforcement. Hot bituminous surfacing is the most commonly selected surfacing material for CIR in Canada.

6.0 RECYCLING EQUIPMENT

A wide variety of recycling trains is available to perform CIR; they differ from one another by how the following operations are regrouped or separated:

- reclamation of the existing bituminous concrete pavement
- transformation of the reclaimed pavement into a calibrated bituminous aggregate
- addition of an emulsion and mixing of all the components
- placement of the new mixture.

Recycling trains grouping all of these operations into one single unit as well as multi-unit recycling trains are available.

7.0 CONSTRUCTION PROCEDURE

The intent of sizing of the reclaimed material is to separate the aggregate particles from one another. A maximum particle size of 37 mm for the bituminous aggregate is widely used. If segregation occurs, a reduction of the maximum particle size of the bituminous aggregate may be required [3].

To maximize surface smoothness, grade and slope control devices are required to control both the cutting drum and the paving screed. Material storage capabilities as well as a means of adding material in the process are required to regulate the flow of material to the paving operation.

The CIR mixtures are coarse and segregation is often difficult to control. Standard paving equipment is often the source of systematic segregation. The central gear unit that drives the augers creates a discontinuity in the flow of material and causes systematic segregation. Outboard driven auger systems are very effective in preventing segregation.

The addition of emulsion is controlled by weight and the mixing of the emulsion with the bituminous aggregate is performed in a twin shaft pugmill. Corrective aggregates are introduced ahead of the milling machine and mixed with the bituminous aggregate in the cutting drum.

Successful CIR is highly dependent on the compaction. Recycled mixtures require more compaction energy than do standard hot bituminous mixtures. The internal friction of recycled mixture is high. The use of one heavy pneumatic roller combined with one large vibrating roller is typically used. The minimum compaction requirement is 96 % of the density of the Marshall laboratory compacted specimen. The compacted mixture internal void content ranges between 12 and 15 % [4]. During the first few months of service, a decrease of the void content of up to 0.5 % may be anticipated [5].

Field adjustments are carried out on a continuous basis to account for the variability of the field conditions [1]. Field adjustments of the emulsion content and of the water content do not exceed ± 10% of the job mix formula. The adjustments are relatively minor, but they are very important to obtain uniform performance of the mat. The field adjustments of the water and of the emulsion content are based on the appearance of the mat after the initial rolling.

A certain time period is necessary to allow the recycled mixture to cure and build up cohesion. A time period of 14 days is typically specified. Moisture content is used as a criteria to evaluate the curing of the mixture. However, moisture alone may be misleading because the moisture may be increased by rain. The material may have built up adequate internal cohesion, but rainfalls may have raised the moisture content at a high level, incorrectly suggesting that the mixture has not sufficiently cured. As a rule of thumb, whenever a complete core can be extracted from the mat relatively easily, the material has built up enough internal cohesion to be covered.

Weather limitations for CIR are not as stringent as those of other emulsion applications. Light rain will not affect the process providing that the moisture content of the bituminous aggregate is monitored. Air temperature will affect the CIR process more than rain. Low air temperature will influence the breaking and the curing of the emulsion, and it also affects the viscosity of the aged bitumen contained in the bituminous aggregate. At lower air temperatures, the early cohesion of the recycled mixture may be insufficient resulting in excessive raveling.

8.0 REJUVENATING EFFECT OF THE EMULSION

The most commonly accepted understanding of the rejuvenating effect occurring in the recycled mixture is based on two opposing ideas proposed in the early development of CIR [1]. One concept was based on the assumption that the aged bitumen was inert and the bituminous aggregate was a black aggregate. The other concept assumed that the aged bitumen was still active and that the addition of a rejuvenating agent restored the aged bitumen to its original characteristics.

Field observations and laboratory work indicate that both processes are occurring. A portion of the aged bitumen remains inert and a portion is rejuvenated [6]. The rejuvenation of the aged bitumen depends on the gradation of the bituminous aggregate, the bitumen content, the softness of both the aged and the virgin bitumen, and the coating characteristics of the added emulsion.

The rejuvenating concept supports the observations, which indicate that the mechanical performance of recycled mixtures improves during the first few months of service. The first few months of service represent the time period during which the added bitumen is fluxing the aged bitumen [4,5].

9.0 EMULSION PERFORMANCE

The usage of polymer and non-polymer modified high float emulsions is common. The gel structure provided by the high float emulsion residue allows a to build thicker film of bitumen around the bituminous aggregate particles. The high float emulsion is added in small dosage and the coating is selective. The bitumen rich smaller particles of the bituminous aggregate are generally coated with a thick film of bitumen while the larger particles are partially or not coated. The added bitumen fluxes the aged bitumen of the bitumen rich small fraction of the bituminous aggregate creating a mortar like paste that binds the aggregate matrix together.

The usage of polymer and non-polymer cationic slow setting emulsions is not as common. The coating characteristics of cationic slow setting emulsion are significantly different than those of high float emulsion. The thickness of the coating is thinner than the coating obtained with high float emulsions, but a larger portion of the smaller fraction of the bituminous aggregate is coated at an equivalent emulsion dosage. As the added bitumen fluxes through the aged bitumen, a mortar like paste is also created. However, in this case, the mortar is produced with a larger portion of the smaller fraction of the bituminous aggregate and the mortar is not as bitumen rich as the mortar obtained with the high float emulsions.

10.0 MECHANICAL CHARACTERISTICS OF RECYCLED MIXTURES

Strength and fatigue life of recycled mixtures will increase during the first two to three years of service. The increase is the greatest in the first few months (3 to 5 months), after that period the strength and the fatigue life will still increase but at a reduced rate [5,7]. This phenomenon may be associated with the fluxing of the virgin bitumen with the aged bitumen as well as a decrease in air voids [7].

Resilient Modulus ranging from 3100 to 5500 MPa have been measured in the State of Oregon. The fatigue life measured after 48 months of service has reached values of up to 250,000 cycles [8]. These modulus and fatigue values were obtained in accordance with the diametral modulus and fatigue test (ASTM D4123). The tests were conducted at 23°C with a loading duration of 0.1 sec., a pulse frequency of 1 Hz and a pulse magnitude of 100 microstrain (με).

At similar air voids, CIR mixtures have significantly greater fatigue lives than standard hot bituminous mixtures. The creation of a mortar like paste with the bitumen rich smaller fraction of the bituminous aggregate appears to provide mechanical properties to the recycled mixture similar to those of virgin emulsion mixes rather than dense graded hot bituminous mixtures [8].

11.0 PAVEMENT CRACKING

Cold In-place Recycling is considered the most effective process to mitigate reflective cracking in a cold environment. The primary cause of pavement distress and failure in Ontario is thermal cracking. In the Municipality of Ottawa, a pavement usually requires rehabilitation when the cracking frequency is approximately 155 to 170 cracks per kilometre. Standard hot bituminous mixture overlay may reach a cracking frequency requiring rehabilitation after 10 years of service. Based on the same cracking frequency criteria, it is estimated that rehabilitation of a CIR pavement may not be required until after 14 years of service[9].

12.0 ECONOMICS

Cold In-place Recycling is a cost effective rehabilitation alternative to traditional methods. Based on the life cycle cost of pavement rehabilitation, the Municipality of Ottawa has reported that the annual cost of CIR projects may be as low as 80 % of a traditional method [9]. The Ministry of Transportation of Quebec has reported an annual cost of 70 % of the traditional method [10].

9.0 NEW TECHNOLOGIES

9.1 Single DrumVibratory Roller

Heavy double drum vibratory rollers are commonly used with Cold In-place Recycling. A large double drum vibratory roller can provide centrifugal force of up to 187 kN. Trials are currently carried out with modified single drum vibratory roller that can provide up to 250 kN of centrifugal force with the same static linear loading. The initial trials are also indicating that the static linear loading should not be drastically increased over 40 kg/cm. The exact size of a modified single drum vibratory roller remains to be determined, but it appears from the initial trials that this type of roller is better suited for Cold In-place Recycling.

9.2 High-Density Screeds

The smoothness of the CIR mat may be greatly improved if the pre-compaction of the recycled mixture behind the screed was increased. The differential settlement related to the compaction operation is reduced and the smoothness of the mat is increased. High-Density Screeds have been developed to provide greater pre-compaction. High-Density Screeds are fitted with tamper/pressure bars that push the material downwards while being smoothen through the screed. The usage of High-Density Screeds is particularly advantageous whenever the pavement is deformed and the thickness of the mat is greater than 65 mm. The usage of High-Density Screeds with CIR is very recent in North America and the results are very encouraging.

9.3 Usage of Cement or Lime with Bitumen Emulsion

Further improvements in recycled mixture properties are possible. The use of cement or lime in conjunction with bitumen emulsion provides higher early strengths and greater resistance to water damage [3]. Cement is used on CIR projects in the province of Quebec whenever the resistance to water damage is considered insufficient.

9.4 Solvent Rich Emulsion

The usage of solvent rich emulsion is relatively recent. The solvent rich emulsion may contain up to 12 % solvent in residual bitumen of the emulsion. The solvent appears to work as a fluxing agent. It accelerates the combination of the added virgin bitumen with the aged bitumen of the bituminous aggregate. The usage of this type of emulsion in cold weather is providing promising results.

10.0 CONCLUSION

Cold In-place Recycling is considered a well-proven pavement rehabilitation technology. It is a recognized viable engineering and economic alternative to traditional rehabilitation methods for a wide range of traffic and pavement distress situations.

Continual developments are being made in both the pavement engineering and the materials engineering fields to standardize and catalogue the various parameters designing, testing and constructing Cold In-place Recycled pavements.

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