100% Recycled Asphalt Paving, Our Experience

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ABSTRACT

Every year, Hot Mix Asphalt (HMA) roadways are rehabilitated by milling and replacing with new HMA. As a result of this practice, a tremendous amount of Reclaimed Asphalt Pavement (RAP) is created.

The Ministry of Transportation Ontario (MTO) currently allows RAP to be recycled into new HMA, but with restriction on percentage. On average, an individual asphalt pavement in Ontario will contain 17 percent of RAP. In an effort for Ontario to have the greenest roads in North America, MTO increased allowable RAP to 20 percent in surface courses and up to 40 percent in binder courses.

Recycling helps road agencies to achieve their goal of a sustainable “green” road transport system by reducing waste and resource consumption yielding environmental and economic benefits.

McAsphalt Industries has found that specifically-engineered emulsions can provide robust 100 percent RAP materials targeted for secondary highways to yield significant economic and environmental benefits. Specifically, the use of rejuvenated 100 percent RAP as paving material on a secondary road in Northern Ontario, without the need of an HMA overlay, was investigated. This paper presents our findings examining properties and performance of 100 percent RAP mixtures from both the laboratory and field perspective.

RÉSUMÉ

Chaque année, des chaussées souples sont réhabilitées par fraisage et remplacées par de nouvelles couches d’enrobés. En raison de cette pratique, une grande quantité de granulats bitumineux récupérés (GBR) est générée.

Le ministère des Transports de l'Ontario (MTO) permet actuellement au GBR d’être recyclé en de nouveaux enrobés, mais avec une restriction quant au pourcentage. En moyenne, une couche typique d’enrobé en Ontario contiendra 17% de GBR. Dans un effort pour que les routes de l'Ontario deviennent les plus vertes en Amérique du Nord, le MTO a augmenté le pourcentage de GBR admissible à 20% dans les couches de surface et jusqu'à 40% pour les autres couches d’enrobés.

Le recyclage permet aux agences routières d’atteindre leur objectif d'un système de transport durable et "vert" en réduisant les déchets et la consommation de ressources procurant ainsi des avantages environnementaux et économiques.

McAsphalt Industries a constaté que des émulsions spécifiquement conçus peuvent fournir des matériaux robustes contenant 100% de GBR visant les routes secondaires et obtenant des avantages économiques et environnementaux importants. Plus précisément, une étude a été faite sur l'utilisation d’un enrobé utilisant 100% de GBR ajouté d’un agent de réjuvénation comme revêtement sur une route secondaire dans le Nord de l'Ontario, sans avoir besoin d'une superposition d’enrobé neuf. Ce document présente les conclusions de l’examen des propriétés et des performances des mélanges avec 100% GBR à la fois dans le laboratoire et sur le terrain.

1.0 BACKGROUND

1.1 Introduction

Pavement recycling is not a new concept. In the 1970s, interest in pavement recycling was fueled by an oil embargo, which drove asphalt prices higher. Major advances in the development of heavy duty equipment and construction procedures have been part of the recycling evolution. Powerful milling equipment was developed so that contractors could reclaim materials from distressed asphalt pavements and combine it with virgin aggregates and asphalt cement. Hot mix asphalt plants were modified to handle Reclaimed Asphalt Pavement (RAP). Mix design, structural design and construction practices were altered where needed to accommodate the use of RAP.

Interest was rekindled in the early 2000s in pavement recycling as the hot mix asphalt industry was once again hit by rapidly rising asphalt costs along with diminishing supplies of high quality aggregate. Among the factors which make pavement recycling attractive are cost effectiveness, materials conservation and economical considerations. The use of RAP in asphalt helps reduce cost, conserve asphalt and aggregate resources and limits the amount of waste materials going into the landfills [1].

The search for better quality of life led society to exploit the planet in the past few decades in an uncontrolled way. It resulted in a rapid reduction of natural resources, leading the society to search for new sustainable alternatives. In the field of asphalt paving technology, the recycling of pavements can be seen as a sustainable option, as it is a production process with environmental and economic benefits. The use of high RAP ratio in asphalt mixes reduces the amount of new aggregate and asphalt cement extracted from the environment thus being an effective sustainable technology.

Research in asphalt recycling has led us to an innovative technique that uses 100 percent RAP in paving mixtures. This process utilizes rejuvenators to reactivate aged asphalt binder in RAP materials to an acceptable state. In the production of hot recycled asphalt, it is necessary to over-heat the virgin aggregates in order to provide indirect heat to the RAP. The main focus of this project is to formulate an emulsion for use in cold mix pavements suitable for paving secondary roads using 100 percent RAP materials [2].

The use of 100 percent RAP will lead to a significant reduction of energy consumption and emissions in comparison to the current use of about 15 to 30 percent RAP in hot mix. This would pave the way towards achieving sustainable pavement construction in addition to reducing the overall construction cost while still providing a structurally sound pavement.

1.2 Objectives

Considerable efforts have been made with regard to controlling large-scale pollution and improving working conditions in recent years. A great deal of attention has been given to limiting the consumption of natural resources but efforts have been concentrated on the increase of the greenhouse effect, which is the most worrying problem in the field of sustainable development [3].

The need to limit the emission of green house gases leaves the asphalt paving industry with the next available option of exploring cold mix technology in order to maximize the use RAP materials.

The main objectives of our research were to study the performance of recycled mixtures with 100 percent RAP in order to evaluate their efficiency and to formulate a rejuvenating emulsion with an optimal blend of asphalt cement and a rejuvenator. This emulsion should be suitable for use in 100 percent RAP mixtures and to provide a structurally durable and smooth pavement wearing surface for secondary roads without the need for an overlay. This will in turn increase the value of our RAP materials and provide an asphalt concrete pavement surface mix with improved properties and versatility through the use of asphalt emulsions and rejuvenators.

In order to confirm the whole production process and encourage its field application, we carried out extensive laboratory studies characterizing the RAP materials and its aged binder, produced and analyzed several 100 percent RAP mixtures using different percentages of selected rejuvenators and asphalt emulsion in order to select the optimum blend. In a later stage, the workability/compactability of the mixtures was studied at different temperatures in order to select their production conditions.

2.0 RAP COLD MIX

Cold mix is a mixture of unheated aggregate and emulsion or cutback asphalt cement and filler. The main difference between cold mix and hot mix asphalt is that the aggregate and emulsion or cutback are mixed at ambient temperature (10 to 30°C) whereas in the case of hot mix the aggregate and binder are mixed at high temperature (138 to 160°C). Dense-graded cold mixes have far lower permeability and good resistance to deformation. Open-graded mixtures are storable and semi dense mixtures have good adhesion and lower permeability.

When used as paving mix, cold mix can offer the following advantages:

- Elimination of aggregate and binder heating;
- Conservation of energy and environmentally friendly. Cold mix pavements can provide energy savings of over 50 percent [4] compared with hot mix asphalt, so it qualifies as green asphalt pavement mix for rural road construction;
- Can easily be prepared using a small set up on the jobsite. It can be produced manually for a small scale job. Laying of hot mix asphalt for rural road construction sometimes is not economical because of setting up of a hot mix plant for a small job increases project cost;
- This paving mix is particularly suited for construction of roads in remote and isolated areas of a country where plant produced hot mix may have lost temperature required to achieve compaction at paving site because of the long haul;
- It is economical due to its use of local resources and its low investment; and
- These mixes can sometimes be formulated to be stockpiled and laid during wet or cold periods.

The use of RAP in cold mix has been around since the development of the grinding process and hot mix recycling. Highway agencies throughout the country have stockpiles of RAP. There is a cost associated with these stockpiles and the use of RAP cold mix can gradually reduce these piles. During the 1970s, RAP cold mix paving was tried in a number of jurisdictions. The first trials have been produced using cutback asphalt, with a subsequent shift to using emulsified asphalts. The RAP mix has been placed using various asphalt emulsion products such as High Floats, SS-1, CSS-1, and CMS-2. The quantity added to the mix is determined through laboratory design and typically varies between 1 and 2 percent depending on the properties of the RAP materials being used. The properties of the RAP that are important are the asphalt cement, the recovered penetration of the asphalt cement, the gradation of the RAP itself, as well as the aggregate extracted from the RAP (Figure 1).

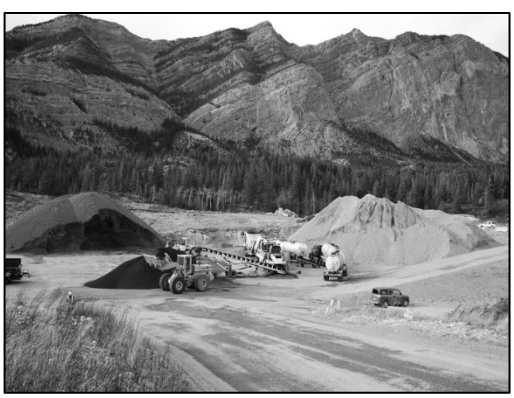
1a. RAP Mix Placement

1b. Finished Mat – RAP Cold Mix

Figure 1. Reclaimed Asphalt Pavement (RAP) Cold Mix in Nova Scotia

An asphalt emulsion can be developed to work with most RAP materials depending on its properties. If for example, the RAP penetration is high (say >50 dmm), then an emulsion which has harder base asphalt cement, may have to be used to ensure that the finished mixture does not experience rutting or pushing in the pavement structure. The current trend in RAP cold mix is using a rejuvenator in combination with an asphalt emulsion.

The concept of asphalt rejuvenation has been around for many years and has become a more important tool after the development of the hot mix recycling industry. The use of recycling agents and softer grades of asphalt cement as the rejuvenators were investigated [4]. In the area of cold mixes and especially the cold mixes containing RAP, the idea of using rejuvenators as part of the new binder in the mix has been investigated and successfully used (see Figure 2).



2a. Pugmill Operation

2b. Placement and Compaction

Figure 2. Rejuvenator/Emulsion Cold Mix in Alberta (Exshaw)

Asphalt cement is made up of two fractions; asphaltenes and maltenes. The asphaltenes are the solid components and maltenes are the oily components of the asphalt cement. Each asphalt cement has its own unique maltenes to asphaltenes ratio and as the asphalt cement ages this ratio decreases. As the asphalt cement ages the maltenes gradually turn into low-end asphaltenes and the asphalt cement hardens.

A rejuvenator emulsion is comprised of water, emulsifier, and maltene oils. When rejuvenating RAP, a rejuvenator returns the maltenes to asphaltenes ratio back into balance and restores the asphalt cement to its original state, or as close as possible. In cold mixes there are two ways to use rejuvenator products; the use of a straight rejuvenator in the mix, or a blend of a rejuvenator and an asphalt emulsion [5].

3.0 LABORATORY MIXTURE DESIGN

3.1 Materials

The intent of the experimental work is to closely examine the locally available RAP materials and evaluate the suitability for 100 percent RAP mixtures for paving secondary roads. In a previous (unpublished) study by McAsphalt, different emulsions were tested for volumetric properties, moisture susceptibility and resistance to rutting. Based on the study, a special Rejuvenating Emulsion (RE) was selected as most suitable for use in 100 percent RAP mix.

In this study, RAP materials were used as the main component of the mixtures. However, since the binder in the materials was already aged, they required rejuvenation to improve properties. The RAP used in this study was obtained from Miller Paving's Markham plant stockpile. The RAP materials were evaluated by performing the gradation on the aggregates and percent binder content by solvent extraction. A number of samples were tested and the results showed low variation, which confirmed good homogeneity of the RAP materials.

Rejuvenating asphalt cement binder is simple in principle; consisting of replacement of oils lost during aging process and on the rebalancing of the binder composition so it no longer becomes brittle. However, this is not generally possible as it requires sophisticated extraction, testing and remodelling of the binder in the road pavement. For practical purposes, rejuvenating emulsions are normally used, containing oils that reduce the viscosity of aged asphalt cement binder thus improving adhesion and cohesion properties, as well as flexibility of the binder.

The next step was to determine the optimum content of the rejuvenator required for producing the blended Rejuvenating Emulsion (RE). This was addressed by studying the resistance of RAP binder blended with different portions of rejuvenating agents to low temperature cracking, fatigue cracking and rutting. The standard Superpave™ Performance Graded (PG) tests such as the Dynamic Shear Rheometer (DSR), and Bending Beam Rheometer (BBR) were used to assess the resistance of the blended RAP binder to different modes of failures. In this study, the binder from Miller's Markham plant RAP source was extracted and recovered according to AASHTO TP2-01 procedures. Different percentages of rejuvenating oil were blended with the RAP asphalt and the PG tests were run on the blends.

3.2 Mixture Design

Properties of the 100 percent RAP cold mix may vary depending on many parameters such as source of RAP, curing condition, and time to mention a few. Keeping in mind that there is no universally accepted mix design method for cold mixes, the Marshall Method is popularly utilized to design emulsified mixes. The Marshall Method for emulsified asphalt design is based on the research conducted at the University of Illinois. This method is applicable to base course mixtures for low to medium traffic volume roads.

An opportunity became available to test the formulation work done in the laboratory. Miller Paving obtained a contract to pave a residential street in the City of North Bay using 100 percent RAP. The City had been doing this process for a number of years using RAP and a standard asphalt emulsion as the binder. Permission was obtained to substitute the standard emulsion with the new rejuvenator/asphalt emulsion.

Based on the laboratory study, a specially designed rejuvenating type emulsion named RE-I, comprising fractions of asphalt cement and rejuvenating oil, was formulated initially to supplement the residual asphalt cement in the RAP as well as to reactivate the existing aged RAP binder. This oil fraction is carefully designed to maximize penetration into the RAP asphalt cement and restore its pre-aged properties, by reconstituting the chemical compositions of the aged oxidized binders. In addition, the oil fraction is derived from renewable resources, is fully non-toxic and environmentally friendly. The decision based on engineering judgment was made to formulate an emulsion to meet the PGAC 58-34 performance requirement that is needed in the North Bay area of the province.

A set of test specimens were prepared over a range of residual asphalt contents. Test mixtures were prepared in increments of 0.5 percent residual asphalt content; using the previously determined optimum water content for mixing and compaction. Specimens were then tested for bulk specific gravity, air voids, Marshall Stability and Flow using the Marshall Test apparatus.

Consequently, a RAP mix was produced in the laboratory by mixing RE-I and the RAP material from North Bay. The modified Marshall mix design procedure was followed to determine the optimum RE-I content. The volumetric properties of the RE-I RAP mix are shown in Column 2 of Table 1. The design binder content of 1.8 percent was selected to meet the acceptable level of air voids, flow and stability.

Table 1. Reclaimed Asphalt Pavement (RAP) Mix Design with RE-I and RE-II

Material Type	RE-I	RE-II
City of North Bay RAP, %	98.2%	98.0%
Emulsion, %	1.8%	2.0%
Added Water, %	2.7%	2.5%
Volumetric Properties		
Total Residual Asphalt in Mix, %	4.95	5.07
Depth of Grinding, mm	100	100
Stability (Newtons @ 22 °C) - Unsoaked	18857	17793
Flow Index (0.25 mm) - Unsoaked	13.5	15.3
Stability (Newtons @ 22 °C) - Soaked	13381	12881
Flow Index (0.25 mm) - Soaked	14.3	14.8
Retained Stability (Soaked/Unsoaked), %	71	72.4
Bulk Relative Density, tonne/m^3	2.237	2.224
Maximum Relative Density, tonne/m^3	2.501	2.487
Air Voids, %	10.56	9.93

In further review of the test results with RE-I, it was felt that more residual asphalt was needed with lower air voids to tighten up the surface texture. As a result, the initial formulation of RE-I was revised and the new emulsion was named RE-II. The mix design was repeated using RE-II and the results are shown in Column 3 of Table 1.

4.0 FIELD PLACEMENT

4.1 Trial Section Paving

Following the laboratory study, a 100 percent RAP cold mix field trial section was built on Cedar Heights Road in the City of North Bay on July 24, 2012. The cold mix paving operation involved blending of newly designed cationic emulsion (RE-II) and crushed 100 percent City of North Bay RAP aggregates supplied by the City. The Midland paver was used for the mixing and placement of the 100 percent RAP mix as shown in Figures 3 and 4. This unit was equipped with distributing augers capable of spreading the material evenly in front of the vibratory screed and placing the blended 100 percent cold RAP mix uniformly across the width of the road.

Figure 3. Midland Paver with 100% Reclaimed Asphalt Pavement (RAP) Mix

Figure 4: Lay Down of 100% Reclaimed Asphalt Pavement (RAP) Cold Mix

The initial layer thickness of the material placed was 100 to 105 mm before compaction to achieve 75 mm after compaction. Double steel drum and rubber tire rollers were used for compaction. There were no pick up issues (Figure 5). The emulsion supply system was equipped with a flow and total delivery meters and switches to regulate the supply of emulsion. This section will be monitored periodically to assess the performance (Figure 6).

The original mix design suggested the use of 2.0 percent RE-II. However, a short test section was built with 2.2 percent RE-II as part of the ongoing study to observe the performance of RAP mixes with two different binder contents. The mix placed with 2.2 percent emulsion was noticeably darker. Good compaction was achieved without any issues. Table 2 contains the volumetric properties on a field sample compared to the laboratory prepared design.

Figure 5. Compaction with Double Steel Drum Roller

Figure 6. Finished Pavement Surface After One Month

Table 2. Field and Laboratory Data on 100% Reclaimed Asphalt Pavement (RAP) Mix

Sieve	Field	Design
19.00 mm	100.0	
16.00 mm	98.5	100.0
13.2 mm	93.7	89.9
9.50 mm	85.2	79.8
4.75 mm	69.5	64.1
2.36 mm	58.9	54.2
1.18 mm	47.7	43.9
0.600 mm	35.3	32.5
0.300 mm	22.1	20.3
0.150 mm	12.2	11.4
0.075 mm	6.7	6.3
Total Residual Asphalt in Mix, %	5.16	5.07
Volumetric Properties		
Stability (Newtons @ 22 °C) - Unsoaked	23495	17793
Flow Index (0.25 mm) - Unsoaked	14.0	15.3
Stability (Newtons @ 22 °C) - Soaked	-	12881
Flow Index (0.25 mm) - Soaked	-	14.8
Retained Stability (Soaked/Unsoaked), %	-	72.4
Bulk Relative Density, tonne/m^3	2.259	2.224
Maximum Relative Density, tonne/m^3	2.488	2.487
Air Voids, %	9.24	9.93

4.2 Field Data Analysis

The RAP binder from the Marshal briquettes prepared and used for the mix design, as well as from the field samples, were recovered through extraction and the Superpave binder performance grade tests were carried out (see Table 3).

The results indicate that the binders recovered from the lab and field samples are essentially the same. Low temperature cracking may most likely occur if the temperature drops to only -27^{o}C as opposed to -34^{o}C, which was the target value in the study. The fact that the mixes are designed with higher air voids may help to alleviate the concern of low temperature cracking. The use of higher air voids such as seen in open graded pavements are known to slow down the onset of low temperature cracking.

Table 3. Laboratory Results of Recovered Asphalt Cement

	Field Sample	Lab Sample	Specification
Original AC			
G*/sin δ, kPa @ 70°C @ 76°C	 1.91 0.898	 1.15 0.562	1.0 min
RTFO Residue			
G*/sin δ, kPa @ 70°C @ 76°C		 3.63 1.75	2.2 min
PAV Residue			
(G*).sin δ @ 25°C, kPa	1940		5000 max
Creep Stiffness, MPa @ -18°C @ -24°C	 240 500	 249 487	300 max
Slope m-value @ -18°C @ - 24°C	 0.287 0.235	 0.295 0.242	0.30 min
PGAC Temp Range	**75.1-26.5**	**71.2-27.4**	

Note: AC is Asphalt Cement.
RTFO is Rolling Thin Film Oven.
PAV is Pressure Aging Vessel.
PGAC is Performance Graded Asphalt Cement.

5.0 CONCLUSION

This product development creates opportunities to build 100% RAP roads using specially designed emulsions on secondary roads without the need for an overlay. The concept of the greenest roads in Canada can be promoted extensively with this new product as the aggregate portion of the mix is completely comprised of recycled material and the new binder rate is much less than typical surface layers. Therefore, the dependence on non-renewable resources is significantly reduced.

A noteworthy conclusion is that an emulsion consisting of fractions of asphalt cement as well as rejuvenating oil has been formulated for use in the design and construction of a 100% RAP asphalt mix. A laboratory method to determine the proper formulation has also been developed and verified in the field. A trial section using this product, RE-II, with 100 % RAP aggregates, has been successfully built on Cedar Heights Road in the City of North Bay. The initial results look very promising. The test section will be monitored closely over the next few years to assess the field performance and modify the emulsion formulation as necessary to achieve optimum results.

REFERENCES

[1] Santuchi, L. "Recycling Asphalt Pavements – A Strategy Revisited", Tech Topic Number 8, Technology Transfer Program, Institute of Transportation Studies, University of California Berkley, Richmond, 1 -12 (2007).

[2] Silva HMRD, Oliveira JRM, Jesus MG. "Are Totally Recycled Hot Mix Asphalt A Sustainable Alternative For Road Paving", Resource, Conservation and Recycling, Journal, 60, 38-48 (2012).

[3] Choudhary R, Mondal A, and Kaulgud HS. "Use of Cold Mixes for Rural Road Construction", Proceedings, International Conference on Emerging Frontiers in Technology for Rural Area (EFITRA), 4, 21-25 (2012).

[4] Gannon CR, et al. "Recycling Conventional and Rubberized Bituminous Concrete Pavements Using Recycling Agents and Virgin Asphalt as Modifiers", Proceedings, Association of Asphalt Paving Technologists, 49, 95-122 (1980).

[5] Davidson JK. "Progress in Cold Mix Process in Canada", Proceedings, Canadian Technical Asphalt Association, 50, 138 – 157 (2005).