# 2005 INTERNATIONAL SYMPOSIUM ON PAVEMENT RECYCLING

**SÃO PAULO – SP – BRAZIL - MARCH 14 – 16**


# MARTEC'S APPROACH TO ROAD MAINTENANCE FOR SUSTAINABLE PAVEMENTS THROUGH HOT IN-PLACE RECYCLING TECHNOLOGY


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## ABSTRACT

The sustainable life-cycle performance and cost effective preservation of the world's road networks is an increasing challenge with aging infrastructure, insufficient funding of maintenance, and increasing growth of heavy vehicle traffic. Hot in-place recycling (HIR) of functionally deteriorated, but still structurally sound, asphalt pavements is a very cost-competitive alternative process, of equivalent quality and performance, with less road-user disruption, to the common hot-mix asphalt overlay and milling/hot-mix asphalt filling processes. The Martec AR2000 Super Recycler HIR process is based on a recirculating forced hot-air with low-level radiant heating, processing (hot milling), post heating, drying, mixing, paving, and compaction system. This Martec AR2000 Super Recycler third generation HIR system effectively deals with the recycling depth, heater efficiency and effectiveness, speed and productivity, emissions, and processing uniformity problems associated with previous second generation HIR systems. The Martec self-propelled, diesel-fuelled, one-pass, continuous equipment (traveling asphalt recycling plant), which minimizes emissions without overheating the recycled asphalt concrete or degradation of the aggregate, has been shown to be cost-effective, time-saving, and environment-friendly (emission control, total reuse of old asphalt concrete, and reduced trucking) for a wide range of projects and asphalt surface course types (conventional, Superpave and open friction courses) from local roads to expressways. Monitoring of Martec HIR projects, particularly the very busy Ontario Highway 401, has shown good performance, better than second generation HIR, microsurfacing, and milling/filling with new or recycled hot-mix asphalt. With the use of more long-life ('perpetual') asphalt pavements, and the recent recognition of top-down cracking surface distress, HIR should have an increasing role in asphalt pavement renewal. This will also involve associated asphalt technology advances such as Superpave, polymer modification, rejuvenator characterization and selection, and performance evaluation of the mix, in an overall systems approach to optimized HIR.

## KEY WORDS

Hot, in-place, asphalt, recycling, equipment, performance

## INTRODUCTION

There are several major challenges to the world's road networks that require a clear focus on enhanced pavement design, construction, management, preservation, and performance through the development of longer-lasting, lower-maintenance pavements: aging infrastructure; costly urban congestion; increasing growth in heavy vehicle traffic; and insufficient funding for systematic maintenance (1,2,3). This global situation has recently become more acute with the spike in crude oil prices and associated sustainability concerns with non-renewable construction material resources (4). Within this milieu, enhanced asphalt reclaiming and recycling, such as hot in-place recycling, has a key role in asphalt pavement preservation, a planned system of treating asphalt pavements at the optimum time to maximize their functional life thus enhancing pavement longevity at the lowest cost (3). The advent of asset management-based accounting for highway agencies encourages systematic pavement management and preservation. Even with these driving forces, there is still a tendency to use conventional hot-mix asphalt overlays and milling/hot-mix asphalt filling (5), rather than the very cost-competitive alternative of equivalent quality and performance, with less road-user disruption, of hot in-place recycling (HIR). This may be based on a lack of appreciation of the current state of HIR technology and the HIR asphalt pavement renewal quality that can be achieved. With the increasing use of long-life (perpetual) asphalt pavements, the use of technically-sound, cost-effective, environment-friendly HIR for renewable asphalt surface courses is particularly relevant.

The 1994 NCHRP Synthesis 193 "Hot In-Place Recycling of Asphalt Concrete" concluded that HIR can provide high quality renewed asphalt surfaces, with reduced natural resource requirements (aggregates, asphalt cement, and fuels) and environmental impacts, and less road user disruption (6). However, some key objectives for improved, third generation, HIR equipment were also identified: recycling to a greater depth with less overheating of the asphalt concrete and degradation of the recycled aggregate; more efficient and effective heater technology with reduced emissions from the heating and processing equipment; and more uniform processing of the reheated old asphalt mix and any added rejuvenator, aggregate, or new mix. In addition, significant asphalt technology needs were identified: long-term performance characterization of the HIR mix as compared to new asphalt concrete (rutting and cracking resistance, moisture susceptibility, and interface bond); selection, incorporation and long-term behaviour of rejuvenators; use of up-to-date recycled and new hot-mix design technology (AAMAS and early SHRP at the time); implementation of comprehensive HIR design guidelines and specifications (recommendations based on Canadian experience (7) provided in Synthesis); and evaluating the effects of rubber on recycling (crumb rubber modifier (CRM) popular at the time).

Since 1995, the Canadian company Martec Recycling Corporation (Martec) has developed a third generation HIR process (AR2000 Super Recycler), based on a recirculating forced hot-air with low-level radiant heating, processing (hot milling), post heating, drying, mixing, paving, and compaction system, that has dealt with the recycling depth, heater efficiency and effectiveness, emissions, and processing uniformity problems with previous HIR systems. This has been demonstrated on many HIR projects from municipal roads to expressways, including the 1999 Ontario Highway 401 trial sections where the Martec AR2000 HIR section is still performing the 'best', even compared to new dense friction course (2002 evaluation (8) and recent 2005 visual evaluation). A joint Marini-Martec HIR expressway project in Italy has shown the effective recycling of polymer modified porous asphalt (9). From an asphalt technology viewpoint, a Martec AR2000 interstate HIR project in Mississippi has shown the feasibility of effectively re-recycling a previous poor (second generation technology) HIR project and was also designed to (rejuvenator and additional new hot-mix) Superpave mix requirements, including checking potential performance with an Asphalt Pavement Analyzer (APA)(10).

## HOT IN-PLACE RECYCLING PROCESSES

The objective of hot in-place recycling (HIR) of structurally sound asphalt pavements is to restore (renew) the existing aged, cracked, worn, or rutted asphalt surface course to the same quality (or better) as a new hot-mix asphalt overlay, in a cost-effective manner (6,7). Current HIR processes have evolved through continuous technical and quality improvements, particularly with respect to heating and mixing systems such as Martec's AR2000 (Figures 1 to 7). There are three basic HIR process options:

1. Reform (heater - scarification) – heating to a depth of 20 to 25 mm, rejuvenation (optional), mixing, leveling, reprofiling, and compaction (Figure 3);
2. Repave (partial recycling) – heating to a depth of 25 to 50 mm, hot milling, rejuvenation (optional), mixing, leveling, reprofiling, and adding a new thin overlay of hot-mix asphalt (Figure 4); and
3. Remix (full recycling) – heating to a depth of up to 75 mm, hot milling, rejuvenation/new aggregate/new mix (optional – designed), mixing, reprofiling/placing with paver screed, and compaction (Figure 5).

The HIR remix process option is particularly attractive in terms of the recycling (renewal) depth achieved and full recycling of the old asphalt concrete (recovery of aggregate and asphalt cement). It is very important that a systematic HIR process selection, design, construction and quality approach is adopted such as outlined in Table 1 (6,7).

## MARTEC AR2000 SUPER RECYCLER

Most of the first generation asphalt paving equipment used open flame burners that damaged the old asphalt concrete and resulted in poor air quality (Figure 2). While second generation HIR equipment with infrared heaters has largely addressed the proper heating of the old asphalt concrete with controlled emissions (particularly since the late 1980s), there are still remix process concerns with: recycling to greater depths without overheating the old asphalt concrete or degrading the recycled aggregate; reducing emissions with strict environmental requirements; and more uniform processing with reduced mechanical and thermal segregation of the renewed asphalt concrete mat (11 to 15). The Martec AR2000 Super Recycler addresses these concerns.

FIGURE 1  Steam Asphalt Pavement Heater Working at Queen and Duncan Streets, Toronto, 1916.  (City of Toronto Archives)

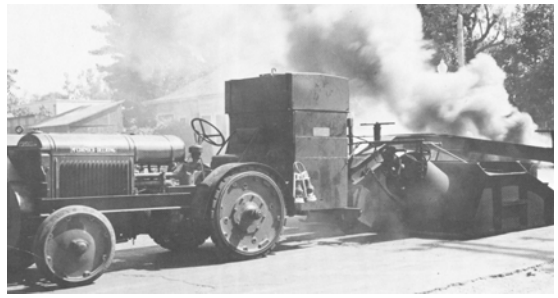

FIGURE 2  Recycling an Asphalt Pavement Which is 'Burned' in the Process of Street Resurfacing, 1936.  (APWA Archives)

FIGURE 3  First Generation HIR Heater. Scarification of Old Asphalt Pavement Prior to Placing Overlay, Toronto, Early 1980s.

FIGURE 4  Second Generation HIR. Remix Process (No Rejuvenation), B.C. Highway 1 Near Langley, late 1988 (7).


FIGURE 5  Third Generation HIR.  Martec AR2000 Full Remix Option, Interstate 85, North Carolina, Open Friction Course, 2001.

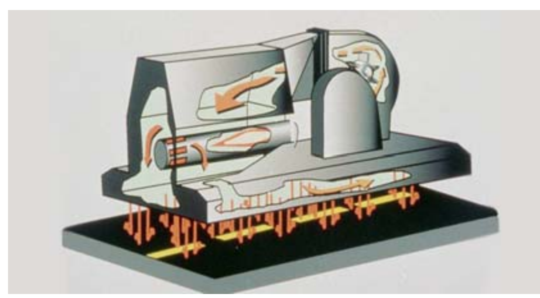

FIGURE 6  Martec AR2000 Heater With Combined Forced Hot-Air and Low-Level Radiant Heat, and Recirculation System.

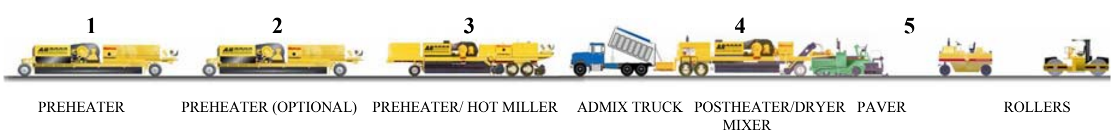


FIGURE 7  Martec AR2000 HIR Process, a Travelling Asphalt Recycling Plant (15)

TABLE 1 General Steps in a Hot In-Place Recycling (HIR) Project (7)

| STEP | COMMENTS |
|---|---|
| 1. PRELIMINARY PAVEMENT EVALUATION | MAINLY TO DETERMINE IF THE ASPHALT PAVEMENT STRUCTURE IS ADEQUATE (FWD FOR INSTANCE). |
| 2. APPLICABILITY OF HOT IN-PLACE RECYCLING? Yes ↓ No ⟶ | IF HOT IN-PLACE RECYCLING IS NOT APPLICABLE, DEVELOP ALTERNATE REHABILITATION OR RECONSTRUCTION METHOD(S). |
| 3. DETAILED ASPHALT PAVEMENT EVALUATION | MAINLY QUALITY AND PROPERTIES OF THE EXISTING ASPHALT PAVEMENT SURFACE COURSE. |
| 4. SELECTION OF HOT IN-PLACE RECYCLING OPTION | HEATER-SCARIFY, REPAVE, OR REMIX. |
| 5. A. REPAVE-SPECIFY NEW HOT-MIX ASPHALT OVERLAY REQUIREMENTS<br>B. REMIX-SELECT REJUVENATOR (TYPE AND APPLICATION RATE), CORRECTIVE AGGREGATE (TYPE AND AMOUNT) AND/OR DESIGN CORRECTIVE NEW HOT-MIX ASPHALT TO BE ADDED (REMIXED) (TYPE, MIX PROPERTIES AND AMOUNT) | MAJOR ASPHALT TECHNOLOGY ASPECTS IN CONJUNCTION WITH STEP 3. |
| 6. COMPLETION OF HOT IN-PLACE RECYCLING OPTION | CONTRACTOR QUALITY CONTROL IMPORTANT, WITH AGENCY OVERVIEW QUALITY ASSURANCE. |

NOTE: It is assumed that the appropriate specification preparation, tendering, and quality control have been incorporated in the steps, as required.

As shown in Figures 5, 6 and 7, the Martec AR2000 Super Recycler (travelling continuous asphalt recycling plant) HIR process involves up to four units:

1 and 2. Preheaters – these units 'gently' heat and soften the deteriorated old asphalt concrete using a combined hot-air/low-level radiant heating system (also incorporated in heater/hot-miller and postheater/dryer/mixer units, Figure 7). The air in the diesel-fueled combustion chamber (Figure 6) is heated to about 600°C and blown on the pavement through holes in the manifold, with the spent hot air recuperated and reheated. The softened old asphalt concrete is not damaged ('burned') and emission levels are very low (Table 2);

3. Preheater/Hot Miller – this unit applies additional heat which enables its hot milling heads (processing) to loosen and remove the softened asphalt pavement without degrading the old asphalt mix. Any rejuvenator is added into the windrow to ensure uniform incorporation. The unit has automatic depth control and the hot milling heads (processing) can be adjusted to working widths of 3.2 to 4.0 metres; and

4. Postheater/Dryer/Mixer – this unit uniformly heats/dries and thoroughly mixes the loosened old asphalt mix with any new corrective aggregate or hot-mix asphalt added into the process (if required) and then transfers this recycled old asphalt mix to its pugmill for final mixing. The fully mixed renewed hot-mix asphalt is then transferred to a conventional paver for laydown followed by compaction (Figure 7).

When recycling to a depth of 50 mm, the Martec AR2000 work speed may vary from 2 to 6 metres/minute, with an average production rate up to 10,000 square metres of HIR typically completed per 10 hour working shift.

TABLE 2 Comparison of Emission Factors in Kilograms/Tonne for Two Types of Hot In-Place Recycling Trains Compared With Average Emissions from 400 Conventional Asphalt Plants in The United States (11 to 14)

| POLLUTANT | | MARTEC AR2000 SUPER RECYCLER | TYPICAL INFRA-RED RECYCLER | ASPHALT PLANT STACK EMISSIONS (1990) |
|---|---|---|---|---|
| **CO** | **kg/t** | **.0085** | **.290** | **.019** |
| **$NO_x$** | **kg/t** | **.0014** | **.015** | **.018** |
| **$SO_X$** | **kg/t** | **.0017** | **---** | **.146** |
| **Particulates** | **kg/t** | **.0009** | **.002** | **---** |
| **Total Hydrocarbons** | **kg/t** | **.0007** | **.013** | **.014** |

## TYPICAL MARTEC AR2000 PROJECTS, AND QUALITY ACHIEVED

Representative world wide Martec AR2000 Super Recycler HIR process projects (Figure 8) are summarized in Figures 9 to 13, with notes on specific HIR features involved. The Ontario Highway 401 Demonstration Project is particularly important as its performance is being monitored. These Martec AR2000 HIR process projects have clearly demonstrated the wide range of renewed asphalt surface courses that can be achieved, with little disruption to traffic, minimized emissions, and energy savings, while reusing the old asphalt pavement contributes to sustainability (8 to 15).

The monitoring of the 1999 Ontario Highway 401 Demonstration Sections, as summarized in Figures 14 to 23 and Tables 3 and 4, is particularly important to advancing HIR technology. Such independent, documented, comparative monitoring of HIR process sections with other recycling processes, surfacing (microsurfacing for instance), and conventional asphalt overlays is unfortunately not common, and must be encouraged in the quest for enhanced pavement preservation technology (8). A review of those Highway 401 Demonstration Sections Figures and Tables (particularly February 2005 by JEGEL) clearly supports the Ontario Ministry of Transportation 2002 findings, for this highly trafficked route, that the Martec AR2000 HIR Section is in excellent condition and performing the best of all the Sections (8).


FIGURE 8  Representative World Wide Martec AR2000 Super Recycler HIR Process Projects Completed From 1998 to 2004.


FIGURE 9  United States – 1998, Mississippi Interstate 55, 49.5 lane-km 180,600 m$^2$, Re-recycling of Previous Second Generation HIR to Superpave Requirements (10).

FIGURE 10  Canada – 1999, Ontario Highway 401 Demonstration Project, 5.6 lane-km HIR Section as Part of Five Rehabilitation Strategies Comparison.

FIGURE 11  Italy – 2003, Livorno – Cecina Section of A12/E80, Combination of Martec AR2000 and Marini ART220 Recycling, Polymer Modified Porous Asphalt (9).

FIGURE 12  Costa Rica – 2004 North Section of PanAmerica Highway, 185 lane-km, to AASHTO 19 mm Surface Course Requirements.

FIGURE 13  China – 2004 Heibei Province Shi-An Expressway Demonstration Project, 10 lane-km.  Technology Transfer Completed to Chinese National Standards.

FIGURE 14 Martec AR2000 HIR Equipment (Figure 7) Working at Night With Traffic on the Ontario Highway 401 Demonstration Project, September 1999.

FIGURE 15 The Martec AR2000 HIR Section Involved Two Lanes (5.6 lane-km) With Processing Depth of 35 mm and Compacted Remixed Premium Mix Depth of 50 mm (8).


FIGURE 16 Completed Martec AR2000 HIR Section in September 1999 with Typical Highway 401 Truck Traffic on this US-Canada NAFTA Route.


FIGURE 17 Current Condition of the Martec AR2000 HIR Section in February 2005 Showing the Excellent Condition of the Two Lanes Involved.

TABLE 3 Roughness Monitoring Test Results for the Highway 401 Demonstration Project Sections (8)

| DEMONSTRATION SECTION | RCR [a.] | | | IRI [b.] | |
|---|---|---|---|---|---|
| | BEFORE 1999 | AFTER 1999 | ONE YEAR 2000 | TWO YEARS 2001 | THREE YEARS 2002 |
| SECOND GENERATION HIR | 8.1 | 8.5 | 8.8 | 1.33 | 1.29 |
| NEW DENSE FRICTION COURSE (DFC) | 8.6 | 8.2 | 8.2 | 1.13 | 1.12 |
| MARTEC AR2000 HIR | 8.3 | 8.5 | 8.7 | 1.02 | 0.98 |
| RECYCLED HOT-MIX DFC | 8.5 | 8.0 | 8.0 | 0.98 | 0.98 |
| MICROSURFACING - 2000 | 8.4 | 8.6 (Before) | 8.2 | 0.92 | 0.90 |
| MICROSURFACING - 1999 | 8.7 | 8.0 | 8.4 | 0.78 | 0.78 |

NOTES:

a. RCR is the Ride Comfort Rating, scale of 0 to 10 with 10 being the smoothest ride, from MTO PURD Equipment.

b. IRI is the International Roughness Index, scale of 0 to 16 with 0 being absolute smoothness, from MTO ARAN Equipment.

FIGURE 18  Martec AR2000 HIR Section, 2005.  Very Good Ride Quality and Good Surface Condition.


FIGURE 19  Closeup of Martec AR2000 HIR Section.  Uniform Surface Texture With No Apparent Deterioration.

FIGURE 20  Second Generation HIR Section, 2005.  Fair to Good Ride Quality With Considerable Ravelling.

FIGURE 21  Mill and Fill With DFC Section, 2005.  Good Ride Quality With Occasional Ravelling and Potholing.

FIGURE 22  Mill and Fill with RHM Section, 2005.  Very Good Ride Quality With Some Low Severity Deterioration.

FIGURE 23  Microsurfaced Section, 2005. Good Ride Quality With Very Coarse and Open Texture.

TABLE 4 Rutting and Friction Monitoring Test Results for the Highway 401 Demonstration Project Section (8)

| DEMONSTRATION SECTION | AVERAGE RUTTING (mm) | | | FRICTION (ASTM BRAKE TRAILER SKID NUMBERS) | | | |
|---|---|---|---|---|---|---|---|
| | ONE YEAR 2000[a.] | TWO YEARS 2001[b.] | THREE YEARS 2002[b.] | BEFORE 1999 | AFTER 1999 | ONE YEAR 2000 | THREE YEARS 2002 |
| SECOND GENERATION HIR | 3.1 | 5.2 | 4.2 | 41 | 43 | 39 | 44 |
| NEW DENSE FRICTION COURSE (DFC) | 2.8 | 4.3 | 2.9 | 41 | 41 | 41 | 44 |
| MARTEC AR2000 HIR | 2.8 | 4.3 | 2.3 | 41 | 41 | 43 | 47 |
| RECYCLED HOT-MIX DFC | 2.9 | 4.4 | 2.6 | 42 | 40 | 40 | 46 |
| MICROSURFACING - 2000 | | 6.0 | 4.2 | 49 | NOT PLACED | 44 | 44 |
| MICROSURFACING - 1999 | 4.0 | 5.2 | 4.6 | 45 | 42 | 37 | 41 |

NOTES:

a. Average value for Lanes 2 and 3.

b. Average value for Lane 3.

## SUSTAINABILITY

An acute issue for the transportation industry is to think beyond the pavement and to consider environmental harmony and sustainability (1). The recycling of old asphalt concrete makes a significant contribution to sustainability (reduction in aggregates, asphalt cement and fuel use with less trucking for instance), as clearly demonstrated for the HIR remix option (Martec AR2000 process for instance) in Figure 24 and Table 5. It is clear that all old asphalt concrete must be renewed, in the most resource efficient method, and that HIR process technology meets this challenge.

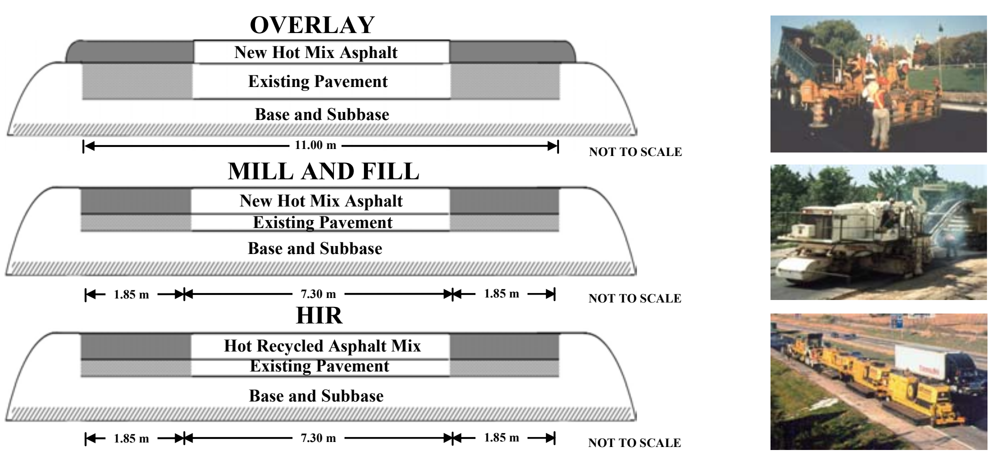


FIGURE 24 Basis for Non-Renewable Resources Consumption Comparison Typical Pavement Cross Sections For a Standard Two Lane Road.

TABLE 5 Non-Renewable Resources and Trucking Round Trips Required Per One Kilometre of a Typical Standard Two-lane Road Rehabilitation Project Using the Asphalt Overlay, Mill and Fill, and HIR Processes

| PROCESS | WIDTH metres | NON-RENEWABLE RESOURCE CONSUMPTION [a.] | | | | TRUCKING ROUND TRIPS [b.] |
|---|---|---|---|---|---|---|
| | | AGGREGATES tonnes | ASPHALT CEMENT tonnes | REJUVENATOR litres | DIESEL FUEL [c.] litres | |
| **ASPHALT OVERLAY 60 mm [d.]** | **11.0** | **1442 (89%) [f.]** | **76 (89%) [f.]** | **–** | **52,345 (72%) [f.]** | **252 (89%) [f.]** |
| **MILL 60 mm/ FILL 60 mm [d.]** | **7.3** | **957 (83%) [f.]** | **50 (84%) [f.]** | **–** | **41,572 (64%) [f.]** | **251 (89%) [f.]** |
| **HIR 60 mm [d.,e.]** | **7.3** | **160** | **8** | **2190** | **14,784** | **29** |

NOTES

a. Hot-mix asphalt is assumed to be 95% aggregate and 5% asphalt cement.

b. Trucking round trips include transportation of: aggregates to asphalt plant; milled asphalt pavement from project site to a hot-mix plant or fill; hot-mix asphalt from asphalt plant to project site; and asphalt cement, fuel and rejuvenator from supplier to asphalt plant or project site.

c. Diesel fuel requirement is for asphalt plant, transportation trucks and all project equipment, assuming average distance for aggregates of 70 km and asphalt plant to project site of 70 km.

d. Incorporating reclaimed asphalt pavement (RAP) in the hot-mix asphalt (RHM) will reduce the resource consumption and trucking round trips and should be encouraged for cost-effectiveness and sustainability.

e. The HIR process includes 20% corrective hot-mix asphalt. This, and rejuvenator use, will vary from HIR project to project depending on the old asphalt concrete's properties and the renewed asphalt pavement requirements. Some HIR projects may not require corrective hot-mix asphalt or rejuvenator.

f. Martec HIR process potential savings compared to the asphalt overlay and mill and fill processes.

## ASPHALT TECHNOLOGY FOR HOT IN-PLACE RECYCLING

It is important that asphalt technology advances complement developments in HIR technology. The growing use of long-life asphalt pavements (Figure 25) and recognition of extensive world-wide top-down cracking (TDC) problems (Figure 26) requires the use of cost-effective renewal of premium asphalt surface course mixes such as stone mastic asphalt (SMA) and polymer modified open friction course (OFC). Associated asphalt technology work, summarized in Figures 25 to 28, has focused on the selection and incorporation of low viscosity rejuvenators based on rubber extender (process) oils, and replacing the Abson recovery/viscosity blending approach (Figure 27) with asphalt concrete stiffness (indirect binder stiffness) testing (resilient modulus in the Nottingham Asphalt Tester (NAT)) to determine rejuvenator addition rates and influence on the actual asphalt concrete stiffness (Figure 28). This has been complemented by full recycled asphalt concrete laboratory performance characterization in the APA (Figure 28).

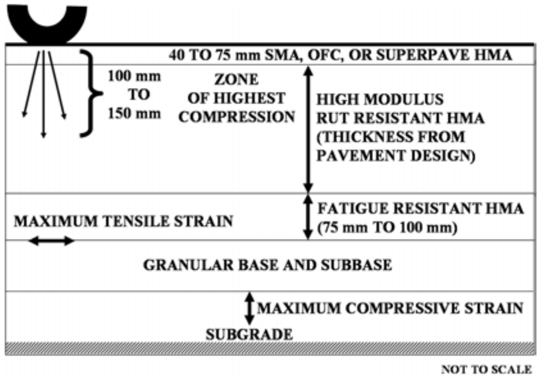


FIGURE 25 Schematic of a Long-Life Asphalt Pavement (Asphalt Pavement Alliance Perpetual Pavement) Showing the Renewable SMA, OFC, or Superpave Surface Course.

FIGURE 26 Typical Top-Down Cracking (TDC) in Wheelpath, With Some Transverse Thermal Cracking, of Relatively New Expressway Near Hohhot, Inner Mongolia, China.

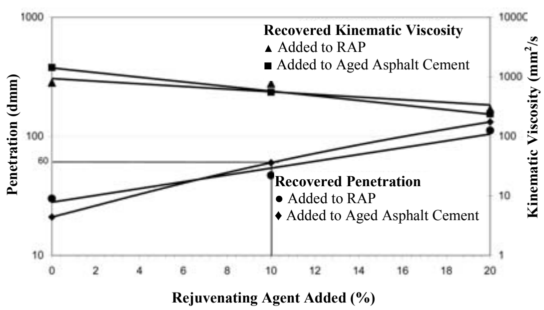


FIGURE 27 Typical Recovered Penetration and Kinematic Viscosity Blend Chart for a Low Viscosity Rejuvenator (Recycling Agent) Added to Aged Asphalt Binder or Reclaimed Asphalt Pavement.


FIGURE 28 Nottingham Asphalt Tester (NAT) Used to Determine Resilient Modulus ($M_r$) and Asphalt Pavement Analyzer (APA) Used to Determine Rutting Resistance, Fatigue Endurance, and Moisture Damage.

## CONCLUSION

The Martec AR2000 Super Recycler HIR process demonstrated the ability to consistently and cost effectively renew and enhance premium asphalt surface course mixes. This Martec third generation AR2000 Super Recycler HIR process will assist the asphalt paving industry in meeting the critical challenge of providing long-life, lower-maintenance, renewable asphalt pavement surfaces in an environmentally responsible manner, with materials, energy, and cost savings, worldwide.

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