Why not 100% RAP Recycling?

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ACKNOWLEDGEMENTS

• Mr. Rick Bradbury, Dale Peabody and Wade McClay of Maine DOT
• Mr. Jim Brownridge of TRICOR
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• Robert Frank, RAP Technologies
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• Introduction

• Tests on laboratory mixes

• Tests on field mixes

• Conclusions and recommendations
Introduction

• Use of RAP in construction of HMA pavement has been the subject of research for over five decades.

• State DOTs still limit the use of RAP to such a degree that the national average content is only 13 percent.

• Two reasons
  • Properties of RAP are assumed to be variable and hence RAP cannot be relied on for producing consistent materials;
  • Long term performance of recycled mix is questionable
Introduction

- Meanwhile Hot In-place Recycling (HIR) technology has been studied much less yet is experiencing consistent annual growth.
- New equipment designs and improved infrared heaters can heat, scarify, apply rejuvenators, and mix in one pass while correcting deficiencies in the surface layer.
- HIR success depends on a relatively simple mix design process that evaluates then corrects existing aggregate gradation and binder viscosity with addition of new aggregate and a rejuvenating agent.
- HIR design process and market growth has not been complicated by limits and restrictions that are commonly imposed on hot mix recycling.
- Obviously, the expectations from HIR mixes are also somewhat different than those from hot mixed recycled HMA.
Introduction

• Aside from different rule books, there is one striking difference between HMR and HIR.
• Hot Mix Recycling with partial RAP uses differing grades of asphalt cement to produce a mix with desired stiffness.
• In HIR, the objective is to use a rejuvenator to improve the properties of the age hardened asphalt binder in the existing mix, such that the mix regains its lost properties.
• No one expects HIR mix to be as good as a virgin mix, the goal is simply to give back some of the good properties that have been lost over the years.
• That HMR averages 13% recycled content while HIR succeeds regularly at 90+% is a conundrum that deserves examination and explanation.
Introduction

• The statement that 100% Hot Mix Recycling is not possible is commonly heard among pavement engineers due to issues with RAP consistency and actually producing such a mix without causing environmental hazards.

• With budget crises at every level of government, road conditions deteriorating faster than we can afford to repair, and natural resources such as asphalt cement being depleted at an alarming rate, perhaps it is time that the use of rejuvenators and the development of proper equipment for 100% recycling be given some serious thought.
Objectives

• Laboratory study on the use of rejuvenators in 100 % HMR

• Study of NYCDOT 100% Hot Mix Recycling demonstration project including analysis of field cores.
Rationale

• Follow-up of work that has been reported in a series of TRB publications (2007, 2008, 2009) in the last three years.
• Work started out of a need to improve the base/binder course of typical Maine DOT reconstruction projects.
• Pavements selected for reconstruction are generally in severely cracked condition that cannot be rectified by a spray application of a rejuvenator.
• A recycled base/binder course is generally produced by combining 100% RAP with MS2 emulsion in a pugmill (plant mixed RAP – PMRAP) and placed with a paver.
• Extensive laboratory and field investigations of the properties and long term performance of this layer have shown that there is a need for improvement in compaction/density and stiffness of this recycled base/binder course (TRB, 2006).
• Any improvement in the base layer will be of significant importance for the entire pavement structure.
RATIONALE

• There are two things that are to be noted here:
  • The RAP that is utilized is generally milled from the same pavement where it is put back (after being stockpiled along the road); and
  • The mix that is currently put back as PMRAP is in many cases 100% RAP.

• Previous studies have shown that
  • the use of Sasobit with asphalt binder at a mixing temperature of 125°C produced mixes with workabilities and compactibilities that are lower but close to those of a mix with neat asphalt binder, mixed at 150°C, and
  • It is possible to produce mixes with 75 percent RAP with similar air voids as virgin mixes at lower than conventional temperatures using 1.5% Sasobit.
SCOPE OF WORK

• Use a proven rejuvenator to recycle 100% RAP and produce a mix meeting the aggregate gradation requirement of MDOT, and evaluate its performance and structural design related high, moderate and low temperature properties and compare those against properties of conventional HMA.

• Use Sasobit as a stiffening agent in one of the mixes to offset early low stiffness, if any, and evaluate the Sasobit’s effect on high and low temperature stiffness through dynamic modulus, as well as through creep compliance.

• Side by side, evaluate construction procedures and properties of mixes, which have 100% RAP.
SCOPE OF WORK

• Try to answer the following questions:
  • Is a rejuvenating agent effective in (plant mix) recycling 100% RAP?
  • How different are the properties of 100% recycled mix from those with virgin mixes and low percentage RAP?
  • Are construction methods available to recycle 100% RAP and produce mix with good quality?
Materials for Laboratory Study

- Reclamite was selected as the rejuvenating agent to be used in the laboratory on the basis of its proven record of excellent performance. Reclamite is an asphalt rejuvenator which provides maltenes to restore the asphaltene/maltene ratio in RAP.
- The effectiveness of Reclamite has been reported in a number of reports, as summarized by Boyer (2000):
  - Air Force study in 1970
  - Navy study in 1970, 1973
  - US Army Corps of Engineers study in 1976
  - Several unreported studies from states and provinces such as Montana, British Columbia, summarized in reference (Brownridge, 2006)
What is an asphalt rejuvenator?

Asphalt consists of two main fractions: “asphaltenes” which are the hard brittle component, insoluble and not affected by oxidation and the highly reactive sub-fractions: “maltenes”. These maltenes are oily and resinous in appearance.

How does an asphalt rejuvenator work?

An asphalt rejuvenator is a manufactured product which has the ability to absorb or penetrate into the pavement and restore those reactive components that have been lost due to oxidation.

This relationship of maltene and asphaltene percentage becomes out of balance in the aging process. The component package hardens causing an imbalance with the asphaltenes.

This aging process can start as early as initial hot plant production and continues through the pavement life cycle – the effects of time, weather, sunlight, etc.
Materials for Laboratory Study

• RAP materials were obtained from a Maine DOT stockpile near Portland, ME. This RAP consists of 12.5 mm NMAS aggregate with PG 64-28/AC 20 binder.
• The asphalt content of the RAP was determined to be 5 %, and the washed gradation was determined.
• The RAP was then regraded to meet the gradation of a MDOT base course.
• Sasobit was obtained from Sasol Wax
• Reclamite was obtained from TRICOR refining, LLC, CA.
Reclamite content

- **Reclamite Content:** The Reclamite content was determined on the basis of the formula suggested by its manufacturer.

\[ P = \frac{(4R + 7S + 12F) \times 1.1}{100} \]

Where,
- \( P \) = asphalt content of RAP plus recycling agent (required) content
- \( R \) = percent retained on 2.36 mm sieve
- \( S \) = percent passing 2.36 mm sieve and retained on 0.075 mm sieve
- \( F \) = percent passing 0.075 mm sieve

The 1.1/1.2 factor compensates for base or soil contamination in the mix.
Reclamite content

• The asphalt content of the individual fraction was determined, and those were considered in conjunction with the percentage used in the total regraded RAP.

• This yielded an asphalt content of 4.66%. Hence, in this case, the percentage of Reclamite was determined to be 0.9%, as shown below.

\[
P = \frac{(4 \times 43 + 7 \times 35.8 + 12 \times 7.2) \times 1.1}{100}
\]

= 5.59 %

Hence, Reclamite content = 5.59 – 4.66 = 0.9 %
TEST PLAN

• Three different mixes were used - one with RAP only, one with RAP plus Reclamite, and a third with RAP plus Reclamite and Sasobit.
• Sasobit was premixed with the RAP at 125°C.
• The Reclamite was mixed with the RAP, with and without Sasobit, and compacted immediately at 60°-70°C to a target air void content of 6-8%.
• Following compaction of 150 mm diameter samples, 100 mm diameter, and approximately 150 mm tall samples were cored out and tested for dynamic modulus at three temperatures and four frequencies.
• The samples were then kept at 60°C oven for 5 weeks to facilitate the action of the rejuvenating agent and tested for dynamic modulus at the end of each week.
• After the last dynamic modulus test, samples were cut from the dynamic modulus samples and tested for indirect tensile (IDT) creep compliance and indirect tensile strength at -10°C.
RESULTS AND ANALYSIS

• Laboratory Prepared Mixes
  • The addition of Reclamite helped in compaction of the mixes and the Sasobit made the mix stiffer.
  • Compactions for the mixes with Reclamite and Reclamite plus Sasobit were done at 60-70°C, whereas those for the RAP only were done at 150°C.
<table>
<thead>
<tr>
<th>Type</th>
<th>Average Voids of samples, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP only</td>
<td>6.6</td>
</tr>
<tr>
<td>RAP + Reclamite</td>
<td>6.5</td>
</tr>
<tr>
<td>RAP + Reclamite + Sasobit</td>
<td>6.8</td>
</tr>
</tbody>
</table>

![Graph showing the relationship between Number of gyration and Air Voids, %](image-url)
Dynamic Modulus
<table>
<thead>
<tr>
<th>Type of Mix</th>
<th>Frequency, Hz</th>
<th>Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-10.00</td>
<td>4.40</td>
</tr>
<tr>
<td>RAP</td>
<td>10</td>
<td>28,932</td>
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<tr>
<td>RAP+Reclamite</td>
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<td>14,727</td>
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<tr>
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<td>24,369</td>
</tr>
<tr>
<td>RAP</td>
<td>5</td>
<td>32,447</td>
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<tr>
<td>RAP+Reclamite</td>
<td></td>
<td>15,635</td>
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<tr>
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<td>25,077</td>
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<tr>
<td>RAP</td>
<td>1</td>
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<tr>
<td>RAP</td>
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<tr>
<td>RAP+Reclamite</td>
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<td>10,757</td>
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<tr>
<td>RAP+Reclamite+Sasobit</td>
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<td>19,924</td>
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Creep Compliance
Comparison with VA Mixes Reported by Loulizi et al, 2006
Comparison with LA Mixes with PG 64-22-76-22 Reported by Mohammed et al, 2007
Comparison with TN Mixes with PG 64-22-76-22
Reported by Huang et al, 2008 LO
Comparison with TN Mixes with PG 64-22-76-22
Reported by Huang et al, 2008 HI
Comparison with 0% RAP-CT-PG 64-28 Mixes, Reported by Daniel, 2009

- 0.1 Hz-CT
- 1 Hz-CT
- 5 Hz-CT
- 10 Hz-CT
- 0.1 Hz-Reclamite
- 1 Hz-Reclamite
- 5 Hz-Reclamite
- 10 Hz-Reclamite
- 0.1 Hz RAP Only
- 1 Hz RAP Only
- 5 Hz RAP Only
- 10 Hz RAP Only

E*, MPa vs Temperature, C
Comparison with 25% RAP-CT-PG 64-28 Mixes, Reported by Daniel, 2009

- 0.1 Hz-CT
- 1 Hz-CT
- 5 Hz-CT
- 10 Hz-CT
- 0.1 Hz-Reclamate
- 1 Hz-Reclamate
- 5 Hz-Reclamate
- 10 Hz-Reclamate

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<thead>
<tr>
<th>[E^*], MPa</th>
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<tr>
<td>35,000</td>
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<tr>
<td>30,000</td>
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<tr>
<td>25,000</td>
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<tr>
<td>20,000</td>
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<tr>
<td>15,000</td>
</tr>
<tr>
<td>10,000</td>
</tr>
<tr>
<td>5,000</td>
</tr>
<tr>
<td>0</td>
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</table>

Temperature, °C

-20  -10  0  10  20  30  40  50  60
Comparison with 40% RAP-CT-PG 64-28 Mixes, Reported by Daniel, 2009

- 0.1 Hz-CT
- 1 Hz-CT
- 5 Hz-CT
- 10 Hz-CT
- 0.1 Hz-Reclamite
- 1 Hz-Reclamite
- 5 Hz-Reclamite
- 10 Hz-Reclamite

|E*|, MPa vs Temperature, °C

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>30</th>
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<td>5 Hz-CT</td>
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<td>10 Hz-CT</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>0.1 Hz-Reclamite</td>
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<tr>
<td>1 Hz-Reclamite</td>
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<tr>
<td>5 Hz-Reclamite</td>
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<tr>
<td>10 Hz-Reclamite</td>
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</table>
Comparison with 15% RAP-NH-PG 64-28 Mixes, Reported by Daniel, 2009
Comparison with 25% RAP-NH-PG 64-28 Mixes, Reported by Daniel, 2009

$|F^*|$, MPa

Temperature, °C
Comparison with 40% RAP-NH-PG 64-28 Mixes, Reported by Daniel, 2009
PROPERTIES OF 100% RECYCLED FIELD MIXES
• RAP millings delivered by truck:
  • Mechanical sizing: Stockpiled millings are run through a diesel powered Powerscreen Chieftain 800 screening plant; Fed by a rubber tired loader into the Hopper; Conveyed to a double deck screen to make a fine and sized aggregate; Oversize material is conveyed to an electric powered impact crusher; Debris and tramp material is scalped from the crusher discharge by a small in line scalping screen; Debris is stacked for offsite disposal. Reduced material is returned to the main conveyor for screening. Fines and sized material are stockpiled in yard for use in manufacturing

• Manufacturing
  – Cold Feed: Fines and sized materials are feed by loader to feed hoppers and metered into a rotary shell dryer for heating to 300 F.
  – Rotary Dryer: Dryer is fired with #2 fuel oil; Produces 150 to 200 tons finished product per hour
  – Material is heated then discharged to a drag slat conveyor for surge storage
  – A rejuvenator is sprayed onto the material as it leaves the dryer.
  – Dryer is maintained at a slight negative pressure to vent combustion gases and fugitive emissions to the air pollution control device.
  – Surge Storage: Finish product is stored in an insulated silo for load out into conventional dump trucks. Silo is equipped with weigh hopper rather than truck scale to provide certified tickets for legal sale.

• Air Pollution Control Baghouse: Removes airborne particulate and aerosol mist
  – Cyclonic separator is use to drop out coarse fines that are manually removed and mixed with screened fines to be reintroduced
  – Water spray provides adiabatic cooling to 160 F
  – Disposable fiberglass pocket filters remove micron size particulate
  – Fiberbed filters remove aerosol mist
  – Scrubber liquor is pumped periodically and stored in a hold and haul tank
  – Exhaust gases comply with 0.04 grains per SCF and 10% opacity at 40 CFR 60; Air flow approximately 30,000 ACFM at 30% moisture
<table>
<thead>
<tr>
<th>SIEVE SIZE</th>
<th>RAP</th>
<th>Blend</th>
<th>Mix Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>2&quot; (50.0mm)</td>
<td>100.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 1/2&quot; (37.5mm)</td>
<td>100.0</td>
<td>100.0</td>
<td>90 100</td>
</tr>
<tr>
<td>1&quot; (25.0mm)</td>
<td>100.0</td>
<td>99.4</td>
<td>90 100</td>
</tr>
<tr>
<td>3/4&quot; (19.0mm)</td>
<td>100.0</td>
<td>100.0</td>
<td>90</td>
</tr>
<tr>
<td>1/2&quot; (12.5mm)</td>
<td>98.4</td>
<td>93.9</td>
<td>90 100</td>
</tr>
<tr>
<td>3/8&quot; (9.5mm)</td>
<td>94.1</td>
<td>75.2</td>
<td></td>
</tr>
<tr>
<td>No.4 (4.75mm)</td>
<td>60.6</td>
<td>44.4</td>
<td></td>
</tr>
<tr>
<td>No.8 (2.36mm)</td>
<td>39.7</td>
<td>32.4</td>
<td>28.0 58.0</td>
</tr>
<tr>
<td>No.16 (1.18mm)</td>
<td>31.0</td>
<td>22.0</td>
<td></td>
</tr>
<tr>
<td>No.30 (600um)</td>
<td>24.5</td>
<td>15.8</td>
<td></td>
</tr>
<tr>
<td>No.50 (300um)</td>
<td>15.0</td>
<td>11.8</td>
<td></td>
</tr>
<tr>
<td>No.100 (150um)</td>
<td>8.4</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>No.200 (75um)</td>
<td>5.3</td>
<td>4.8</td>
<td>2.0 10.0</td>
</tr>
</tbody>
</table>
# Recycling Agent - Renoil

<table>
<thead>
<tr>
<th>Property</th>
<th>Specifications</th>
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<tr>
<td>Viscosity SUS @100 °F, 494</td>
<td>Pour Point F (C), -10 (-23)</td>
</tr>
<tr>
<td>Viscosity SUS @210 °F, 51</td>
<td>Flash Point F (C), COC420 min (216)</td>
</tr>
<tr>
<td>Viscosity cSt @40 °C, 92.2</td>
<td>Sulfur wt %, 4.3</td>
</tr>
<tr>
<td>Viscosity cSt @100 °C, 7.4</td>
<td>Aniline Point F (C), 55 (13)</td>
</tr>
<tr>
<td>Specific Gravity@ 60 °F, 0.966</td>
<td>Clay Gel Analysis</td>
</tr>
<tr>
<td></td>
<td>Asphaltenes %, 0; Polars %, 7; Aromatics %, 65; Saturates %, 28</td>
</tr>
<tr>
<td>Density lb/gallon @60 °F, 8.04</td>
<td>Carbon Analysis %</td>
</tr>
<tr>
<td></td>
<td>Aromatic %, 30; Naphthenic, %15; Paraffinic %, 55; Refractive Index, 1.5218</td>
</tr>
</tbody>
</table>
Test plan for field mixes/cores

- Loose regraded RAP and seven year old field cores, consisting of 100% recycled mix (with rejuvenator), and 15% recycled mix (conventional mix with PG 64-22) were obtained.
- The loose RAP was compacted as it is at 150°C to obtain samples with 6 - 8% air voids.
- These samples, along with the cores, were tested for bulk specific gravity, resilient modulus at three temperatures, 5, 25 and 40°C, and creep compliance at -10°C.
- Resilient modulus was selected over dynamic modulus because of the height of the field cores.
Some parting thoughts...

- In the case of hot mix recycling with 10-40% RAP, guidelines exist that recommend the use of a softer grade asphalt binder. These guidelines mingle hard old and soft new asphalts and aim at achieving a mix with a binder of the same grade as required for that specific mix/climate.
- Unfortunately the consequence of this approach has been to limit allowed recycled content in HMA mixes country wide rather than to facilitate increased use of RAP.
- How then do we get to 40 - 100% recycling?
- There aren’t readily available binders soft enough to improve the age hardened binder, restore the balance of chemical components, and produce a mix that has performance related properties that are similar to those of accepted mixes (with virgin materials or low RAP content).
- Even if the binders were available, producers don’t have storage tanks to hold the numerous binder grades that would be required by blending charts.
• Aggregates depleted at alarming rate

• 1,300 million tons of virgin aggregates are used in the US every year for pavement construction

• Landfills are largest source of methane caused by humans – many of the landfills will reach permitted capacity and shut down in the next 10 years
CONCLUSIONS

• The addition of rejuvenating agent is effective in lowering the stiffness of RAP, and providing mixes with dynamic modulus values that are similar to mixes that are regularly used in the US.

• The addition of rejuvenating agent is also effective in increasing low-temperature creep compliance, and probably improving low-temperature performance of mixture with 100% RAP content, which has been a major concern for all RAP mixes used in northern latitudes.

• 100% recycled mixes with good performance can be produced with existing quality control procedures in a suitable plant.
RECOMMENDATIONS

• For regions with abundant high quality RAP, it is recommended that demonstration projects be sponsored using rejuvenators for 25+% RAP mixes.

• Plants with required equipment, for both production and environmental control are available, and their increased use should be encouraged.
Thank you!