OPTIMIZING THE EFFECTIVE USE OF RAP IN LOCAL ROADWAYS

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Outline

- Background
- Objectives
- Phase 1 - Laboratory Testing Program
- Results of Phase 1
- Field Test Sections
Background

- Though the benefits of using higher amount of RAP in new mixes are high, it presents a concern that resultant mixture may be prone to more cracking.
- Over the past two decades, numerous research studies have been conducted to address issues with using higher percentages of RAP in asphalt mixtures.
- Most of these studies have focused on developing mix design procedures and specifications for mixtures used on interstates and highway systems only.
Objectives

- Assess the current practices of using RAP in surface course mixtures for local roadways.
- Develop recommendations for a cost-effective method for designing well-performing and durable surface course mixtures with different RAP contents for use on local roadways.
- Evaluate the cost benefits of using different RAP contents in the surface course layer of local roadways.
- Provide recommendations for quality control methods of RAP used in the surface mixtures of local roadways.
Project Overview

- Conduct Literature Review
- Survey of Current State-of-the-Practice
- Develop Recommendations for Mix Design
- Develop Recommendations for Quality Control Methods of RAP
- Perform Benefit/Cost Analysis
- Provide Recommendations for Phase 2
- Prepare Interim Report – Phase 1
- Develop Field Testing Methodology
- Construction of Sections
- Evaluation of Test Sections
- Prepare Final Report
Phase 1 Overview

Conduct Literature Review

- Rejuvenator in RAP Mixes
- RAP Mixes

Survey of Current State-of-the-Practice

Develop Recommendations for Mix Design

- Fatigue Cracking
  - SCB & ITS
- Durability
  - AASHTO 283
- Rutting
  - APA

Develop Recommendations for Quality Control Methods of RAP

Perform Benefit/Cost Analysis

Provide Recommendations for Phase 2

Prepare Interim Report – Phase 1
Phase 1: Laboratory Testing Program

Select RAP Content

Select Binder PG

Select AC Content

Determine AC% based on Volumetric

Evaluate three AC contents

Adjust gradation of virgin to include RAP

AC content, Volumetric

Performance Evaluation

for mixtures Prepare mixture using AC% from volumetric @ 7% air void

Fatigue Cracking

Durability

Rutting

AE, ITS, FI

AER& TSR

APA

Meet Criteria?

No

Yes

Design AC%
Materials: RAP

- Limestone aggregates were obtained for the mixes considered in the testing program.
- RAP material was obtained from two different sources.
- A typical JMF for mixes to be used in resurfacing project for the City of Columbus during next construction was obtained.
- The virgin asphalt binder that was used in control and 20% RAP is PG 64-22.
- Softer virgin binder (64-28) was used based on this equation:

\[
T_{C(virgin)} = \frac{T_{C(need)} - (RBR \times T_{C(RAP \ binder)})}{1 - RBR}
\]
Two RAP materials with different rheological properties were obtained.

<table>
<thead>
<tr>
<th>RAP ID</th>
<th>Continuous High Temperature Grade, °C</th>
<th>Continuous Low Temperature Grade, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shelly 2017 Pile – A RAP-1</td>
<td>93.1</td>
<td>-14.3</td>
</tr>
<tr>
<td>IR 270 (RAP 2)</td>
<td>79.9</td>
<td>-21.1</td>
</tr>
</tbody>
</table>
Three types of recycling agents (RAs) were considered:

- Aromatic Extract: Hydrolene T90
- Tall Oils: Sylvaroad™ RP1000
- Triglycerides & Fatty Acids (WV Oil): Soybean Oil
## Materials: Recycling Agents (RA)

<table>
<thead>
<tr>
<th>Property</th>
<th>Sylvaroad</th>
<th>Hydrolene</th>
<th>Soybean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity (cm(^2)/s)</td>
<td>1.008 at 20 °C</td>
<td>0.162 at 100 °C</td>
<td>0.582-0.622</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>Not Available</td>
<td>0.98</td>
<td>0.916-0.922</td>
</tr>
<tr>
<td>Petroleum or Organic</td>
<td>Organic</td>
<td>Petroleum</td>
<td>Organic</td>
</tr>
<tr>
<td>Price per pound (USD)</td>
<td>1.5</td>
<td>0.2705</td>
<td>0.32</td>
</tr>
<tr>
<td>Source</td>
<td>KRATON</td>
<td>HollyFrontier LLC</td>
<td>-</td>
</tr>
</tbody>
</table>
Materials: Recycling Agents (RA)

- The optimum dosage for a specific RA was determined based on RA amount needed for the RAP-virgin asphalt binder blend to meet the target continuous temperature target virgin asphalt binder (PG 67.7-22.2).
- Three recycled blends prepared with PG 64-22 and three different RAs.
- 40% RAP was used in preparing blends.
- Then, generalized to 30% and 50% RAP mixes.
# Materials: Recycling Agents (RA)

<table>
<thead>
<tr>
<th>RA</th>
<th>Selected RA Dosage</th>
<th>PGL</th>
<th>PGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sylvaroad</td>
<td>8.0%</td>
<td>-25.7</td>
<td>67.7</td>
</tr>
<tr>
<td>Hydrolene</td>
<td>10.0%</td>
<td>-23.7</td>
<td>67.5</td>
</tr>
<tr>
<td>Soybean</td>
<td>9.5%</td>
<td>-25.1</td>
<td>67.6</td>
</tr>
</tbody>
</table>
## Mixtures Testing

<table>
<thead>
<tr>
<th>Mix</th>
<th>% RAP</th>
<th>Virgin Binder</th>
<th>Virgin AC%</th>
<th>RBR</th>
<th>$G_{mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>PG 64-22</td>
<td>6.3</td>
<td>0</td>
<td>2.429</td>
</tr>
<tr>
<td>20% RAP-1</td>
<td>20</td>
<td>PG 64-22</td>
<td>5.3</td>
<td>16%</td>
<td>2.428</td>
</tr>
<tr>
<td>30% RAP-1</td>
<td>30</td>
<td>PG 64-28</td>
<td>4.8</td>
<td>25%</td>
<td>2.440</td>
</tr>
<tr>
<td>40% RAP-1</td>
<td>40</td>
<td>PG 64-28</td>
<td>4.3</td>
<td>33%</td>
<td>2.448</td>
</tr>
<tr>
<td>50% RAP-1</td>
<td>50</td>
<td>PG 64-28</td>
<td>3.8</td>
<td>41%</td>
<td>2.455</td>
</tr>
<tr>
<td>30% RAP-1 -Hydrolene RA</td>
<td>30</td>
<td>PG 64-22</td>
<td>4.8</td>
<td>25%</td>
<td>2.439</td>
</tr>
<tr>
<td>40% RAP-1 -Hydrolene RA</td>
<td>40</td>
<td>PG 64-22</td>
<td>4.3</td>
<td>33%</td>
<td>2.439</td>
</tr>
<tr>
<td>50% RAP-1 -Hydrolene RA</td>
<td>50</td>
<td>PG 64-22</td>
<td>3.8</td>
<td>41%</td>
<td>2.435</td>
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<tr>
<td>30% RAP-1 -Sylvaroad RA</td>
<td>30</td>
<td>PG 64-22</td>
<td>4.8</td>
<td>25%</td>
<td>2.440</td>
</tr>
<tr>
<td>40% RAP-1 -Sylvaroad RA</td>
<td>40</td>
<td>PG 64-22</td>
<td>4.3</td>
<td>33%</td>
<td>2.447</td>
</tr>
<tr>
<td>50% RAP-1 -Sylvaroad RA</td>
<td>50</td>
<td>PG 64-22</td>
<td>3.8</td>
<td>41%</td>
<td>2.444</td>
</tr>
<tr>
<td>30% RAP-1 -Soybean RA</td>
<td>30</td>
<td>PG 64-22</td>
<td>4.8</td>
<td>25%</td>
<td>2.437</td>
</tr>
<tr>
<td>40% RAP-1 -Soybean RA</td>
<td>40</td>
<td>PG 64-22</td>
<td>4.3</td>
<td>33%</td>
<td>2.441</td>
</tr>
<tr>
<td>50% RAP-1 -Soybean RA</td>
<td>50</td>
<td>PG 64-22</td>
<td>3.8</td>
<td>41%</td>
<td>2.439</td>
</tr>
<tr>
<td>30% RAP-2</td>
<td>30</td>
<td>PG 64-28</td>
<td>4.8</td>
<td>25%</td>
<td>2.434</td>
</tr>
<tr>
<td>40% RAP-2</td>
<td>40</td>
<td>PG 64-28</td>
<td>4.3</td>
<td>32%</td>
<td>2.433</td>
</tr>
<tr>
<td>50% RAP-2</td>
<td>50</td>
<td>PG 64-28</td>
<td>3.8</td>
<td>40%</td>
<td>2.438</td>
</tr>
</tbody>
</table>
Mixtures Testing

Mix Testing

- Low Temp Cracking
  - ACCD

- Fatigue Cracking
  - SCB-IL

- Durability
  - IDT
  - AASHTO T283
RESULTS
\[ FI = A \times \frac{G_f}{\text{abs}(M)} \]

Where:

\( G_f \) = fracture energy in Joules/m², calculated from Work of Fracture \( (W_f) \)

\( M \) = slope of the post-peak curve at the inflection point in kN/mm

\( A \) = unit conversion factor and scaling coefficient \( (0.01) \).
SCB- Flexibility Index (FI)

Control  20% RAP  30% RAP  40% RAP  50% RAP

64-28  Sylvaroad-RA  Hydrolene-RA  Soybean-RA

FI
SCB-Normalized Fracture Energy

Normalized Fracture Energy (J/m²/kPa)

Control 20% RAP 30% RAP 40% RAP 50% RAP

- 64-28
- Sylvaroad-RA
- Hydrolene-RA
- Soybean-RA
AASHTO T283 Results-TSR
ACCD Results

![ACCD Results Graph](image-url)
APA Test Results

![Graph showing APA test results](image-url)

- 64-28
- Sylvaroad-RA
- Hydrolene-RA
- Soybean-RA

Rut Depth (mm)

- Control
- 20% RAP
- 30% RAP
- 40% RAP
- 50% RAP
Cost Analyses

<table>
<thead>
<tr>
<th>Item</th>
<th>Price ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 64-22</td>
<td>$345.83</td>
</tr>
<tr>
<td>PG 64-28</td>
<td>$450.00</td>
</tr>
<tr>
<td>RA-Hydrolene</td>
<td>$541.00</td>
</tr>
<tr>
<td>RA-Soybean</td>
<td>$640.00</td>
</tr>
<tr>
<td>RA-Sylvaroad</td>
<td>$3,000.00</td>
</tr>
</tbody>
</table>
## Cost Analyses - Cost Reduction

### Comparison to 20% RAP Mix

<table>
<thead>
<tr>
<th>RAP%</th>
<th>Hydrolene</th>
<th>Soybean</th>
<th>Sylvvaroad</th>
</tr>
</thead>
<tbody>
<tr>
<td>40%</td>
<td>22.1%</td>
<td>21.7%</td>
<td>10.2%</td>
</tr>
<tr>
<td>50%</td>
<td>26.8%</td>
<td>26.4%</td>
<td>13.7%</td>
</tr>
</tbody>
</table>

### Comparison to Virgin Mix

<table>
<thead>
<tr>
<th></th>
<th>Hydrolene</th>
<th>Soybean</th>
<th>Sylvvaroad</th>
</tr>
</thead>
<tbody>
<tr>
<td>40%</td>
<td>35.3%</td>
<td>35.0%</td>
<td>25.5%</td>
</tr>
<tr>
<td>50%</td>
<td>39.3%</td>
<td>38.9%</td>
<td>28.3%</td>
</tr>
</tbody>
</table>
Effect of RAP Source: SCB Results-FA
Effect of RAP Source: SCB Results-NFE

Control 20% RAP 30% RAP 40% RAP 50% RAP

Normalized Fracture Energy (J/m²/kPa)

RAP-1 RAP-2
Effect of RAP Source: IDT Results

- Control
- 20% RAP
- 30% RAP
- 40% RAP
- 50% RAP

ITS (psi)

[Bar chart showing the ITS (psi) for different RAP percentages (Control, 20%, 30%, 40%, 50%) with RAP-1 and RAP-2 categories. The chart indicates a comparison between RAP-1 and RAP-2 across different RAP percentages.]
Effect of RAP Source: AASHTO T 283

![Graph showing the effect of RAP source on TSR with RAP-1 and RAP-2 comparisons for different RAP percentages: Control, 20% RAP, 30% RAP, 40% RAP, and 50% RAP. The y-axis represents TSR, ranging from 0 to 1.2, and the x-axis represents the percentage of RAP used. The graph indicates the performance of different RAP sources at varying RAP percentages.]
Effect of RAP Source: ACCD Results

Cracking Temperature (°C)

Control  20% RAP  30% RAP  40% RAP  50% RAP

RAP-1  RAP-2
Phase 1- Findings

- Hydrolene (T90) Aromatic oil RA and Sylvaroad RA had significantly improved the cracking resistance of mixes with up to 50%.
- The Hydrolene RA was more effective than the Sylvaroad RA.
- RAP mixes with Soybean RA had better performance than those with softer binder (PG 64-28). However, was 40% and 50% mixes with Soybean RA had much lower resistance to fatigue cracking as compared to those with the other RAs.
Phase 1 - Findings

- Cost analyses showed that 50% RAP mix with Hydolene RA can be 26% less expensive than RAP mixes currently being used.
- Cost analyses showed that 50% RAP mix with Sylvaroad RA can be 13% less expensive than RAP mixes currently being used.
- The RAP source has a significant effect on the cracking resistance of high RAP asphalt mixes.
  - Particularly for mixes with more than 30% RAP.
- Therefore, it is very important to determine the performance grade of extracted and recovered RAP binder.
Recommended Mix Design

Select RAP Material Meeting Sampling Requirements

Select RAP Content

Determine Optimum AC% Based on Marshall Mix Design for Medium Traffic (use PG 64-22 with no recycling agent)

RBR<0.25

Select Binder Grade Based on

\[ T_{C(\text{new})} = \frac{T_{C(\text{need})} - (RBR \times T_{C(\text{RAP binder})})}{1 - RBR} \]

RBR>0.25

Select RA dosages based on procedure provided in Section E.1.4 & Figure E.2

Performance Evaluation

Prepare mixture using AC% with RA @ 7% ± 0.5 air void

Fatigue Cracking

Durability

Rutting

ITS, CTI, FI, NFE

TSR

APA

Meet Criteria?

No

Adjust AC% or RA dosage

Yes

Select Design AC%
# Recommended Criteria for RAP Mixes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FI (SCB)</th>
<th>NFE (SCB)</th>
<th>TSR (AAHTO T 283)</th>
<th>Rutting (APA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria</td>
<td>Minimum 2</td>
<td>Minimum 25 J/m²/kPa</td>
<td>Minimum 0.8</td>
<td>Maximum 5 mm</td>
</tr>
</tbody>
</table>

NFE: Normalized fracture Energy  
FI: Flexibility Index  
TSR: Tensile Strength Ration
PHASE 2
FIELD TEST
SECTIONS
Field Test Sections

- A total of eight test sections were constructed on Hall Road in the City of Columbus:
  - A control section
  - A section with 30% RAP and softer binder PG 64-28
  - Six sections with recycling agents: Three sections with 30%, 40%, and 50% RAP and the following recycling agents.
    - Sylvaroad™ RP1000
    - Hydrolene
- Construction started on 09/11/2018 and was completed 09/21/2018. One day was allocated for each section.
Field Test Sections

<table>
<thead>
<tr>
<th>Bledsoe Rd.</th>
<th>Norton Rd.</th>
<th>Train Rail</th>
<th>Georgesville Rd.</th>
</tr>
</thead>
<tbody>
<tr>
<td>30% RAP+SYL</td>
<td>40% RAP+SYL</td>
<td>50% RAP+SYL</td>
<td>Control</td>
</tr>
<tr>
<td>30% RAP+HYD</td>
<td>40% RAP+HYD</td>
<td>50% RAP+HUD</td>
<td>30% RAP PG64-28</td>
</tr>
</tbody>
</table>
Field Test Sections

<table>
<thead>
<tr>
<th>Location</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bledge Rd</td>
<td>30% RAP+SYL</td>
</tr>
<tr>
<td>Norton Rd</td>
<td>30% RAP+HYD</td>
</tr>
<tr>
<td>Norton Rd</td>
<td>40% RAP+SYL</td>
</tr>
<tr>
<td>Norton Rd</td>
<td>40% RAP+HYD</td>
</tr>
<tr>
<td>Bridge</td>
<td>50% RAP+SYL</td>
</tr>
<tr>
<td>Bridge</td>
<td>50% RAP+HUD</td>
</tr>
<tr>
<td>Control</td>
<td>30% RAP PG64-28</td>
</tr>
</tbody>
</table>
Sections Pre-Construction Evaluation

- Existing roadway was evaluated prior to milling and construction.
- Areas of distressed areas were identified.
- Core location were selected to avoid distressed areas.
Sections Pre-Construction Evaluation

LWD Modulus at 25C (MPa)

- Control
- 30% RAP-PG 64-28
- 50% RAP-SYL
- 50% RAP-HYD
- 40% RAP-HYD
- 40% RAP-SYL
- 30% RAP-SYL
- 30% RAP-HYD

Station 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
During construction, the research team monitored the placement and compaction of the control and RAP mixes. Pictures and videos were taken to document the construction process.
Construction of Sections
Construction of Sections
Testing of Sections
Questions??