Utilization of Post-Consumer Recycled Asphalt Shingles (RAS) and Fractionated RAP in HMA

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R. Christopher Williams
Debra Haugen
Acknowledgements

- Illinois Tollway Authority- Steve Gillen
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- STATE Testing- Jay Benhke
- University of Illinois U-C- Bill Buttlar
- Iowa DOT- Scott Schram
Introduction

- Illinois Tollway Authority undertaking unprecedented rehabilitation/expansion program
- Looking to new technologies to solve financial challenges
- Tollway sponsored 2007 study on increasing the percentage of RAP in HMA shoulders (FRAP)
- New 2009 research to study use of post-consumer RAS in HMA shoulders
Field demonstration conducted in July 2009
Mixes containing RAS and FRAP were placed in the shoulder
Iowa State obtained field samples for laboratory testing
Objectives

1. Characterize performance of HMA with RAS and varying percentages of FRAP

2. Can 5% RAS replace 5% FRAP in Tollway mixtures and maintain quality?

3. Performance difference between laboratory and field samples
Mix Design Experimental Plan

- Base mix designed at lower air voids to reduce permeability
- Binder mix designed as a “rich bottom layer” mix
- One grade bump in the high temperature Performance Grade

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>NMAS (mm)</th>
<th>Design Air Voids</th>
<th>N_{des}</th>
<th>Performance Grade</th>
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<td>Base</td>
<td>19.0</td>
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<tr>
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## Mix Design Experimental Plan

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<tr>
<th>ID</th>
<th>Mix Type</th>
<th>FRAP</th>
<th>RAS</th>
<th>Experiment ID</th>
<th>Field Sample</th>
<th>Lab Sample</th>
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<td>RAS Shoulder Surface</td>
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<td>20%</td>
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<tr>
<td>RAS Subbase</td>
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<tr>
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Laboratory Testing Plan

- **Binder Characterization**
  - Dynamic Shear Rheometer - Rutting
  - Bending Beam Rheometer - Thermal Cracking

- **Mixture Characterization**
  - Dynamic Modulus - Rutting
  - Flow Number - Rutting
  - Tensile Strength Ratio - Freeze Thaw Damage
  - Flexural Beam Test - Fatigue Life
  - Fracture Energy* - Thermal Cracking
  *By University of Illinois Urbana-Champaign

- **Master Curves** - Viscoelastic Behavior
Field Samples
Laboratory Samples

- Samples Prepared by STATE Testing
- Aggregate heated to 325°F
- RAP heated separately until 300°F
- RAS carefully heated but no standard protocol
- Agg, RAP, and RAS added to mixing bucket individually
- No curing time
- Reheated in oven for 4-6 hours
RAS & FRAP Binder Contribution

![Graph showing the relationship between percent binder replacement and percentage of recycled materials. The graph includes two lines with correlation coefficients of R² = 0.9883 and R² = 0.9878. One line represents materials containing 5% RAS, and the other represents materials containing 0% RAS.](image-url)
Field Binders - High Temperature Grades

- 25% FRAP / 0% RAS
  - Surface

- 20% FRAP / 5% RAS
  - Surface

- 25% FRAP / 5% RAS
  - Binder

- 35% FRAP / 5% RAS
  - Binder

- 35% FRAP / 5% RAS
  - Base

- 45% FRAP / 5% RAS
  - Base

- 50% FRAP / 0% RAS
  - Base
Lab Binders – High Temperature Grades

<table>
<thead>
<tr>
<th>Performance Grade</th>
<th>20% FRAP / 5% RAS</th>
<th>25% FRAP / 5% RAS</th>
<th>35% FRAP / 5% RAS</th>
<th>40% FRAP / 0% RAS</th>
<th>45% FRAP / 5% RAS</th>
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</thead>
<tbody>
<tr>
<td>Base</td>
<td>Surface</td>
<td>Base</td>
<td>Base</td>
<td>Binder</td>
<td>Base</td>
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<td>58</td>
<td>64</td>
<td>70</td>
<td>76</td>
<td>82</td>
<td>88</td>
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<tr>
<td>FRAP / RAS</td>
<td>20%</td>
<td>25%</td>
<td>35%</td>
<td>40%</td>
<td>45%</td>
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<table>
<thead>
<tr>
<th>FRAP / RAS</th>
<th>45%</th>
<th>40%</th>
<th>35%</th>
<th>25%</th>
<th>20%</th>
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<td>5%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
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Field Binders – Low Temperature Grades

- 25% FRAP / 0% RAS: Surface
- 20% FRAP / 5% RAS: Surface
- 25% FRAP / 5% RAS: Binder
- 35% FRAP / 5% RAS: Binder
- 35% FRAP / 5% RAS: Base
- 45% FRAP / 5% RAS: Base
- 50% FRAP / 0% RAS: Base

Performance Grade Range: -28 to 2
Lab Binders – Low Temperature Grades

<table>
<thead>
<tr>
<th>FRAP (%)</th>
<th>RAS (%)</th>
<th>Surface</th>
<th>Base</th>
<th>Binder</th>
<th>Base</th>
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<tr>
<td>20</td>
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<td>25</td>
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<td>Binder</td>
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<tr>
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<td>Base</td>
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<td>Binder</td>
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<td>45</td>
<td>5</td>
<td>Base</td>
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</table>
Binder Master Curves

- Describes Shear Modulus $G^*$ as a function of temperature and rate of loading
- Frequency Sweeps in linear viscoelastic range in the DSR and BBR
- Converted Creep Stiffness to Shear Modulus values
- Frequency curves shifted horizontally with respect to 28°C
- CAM Model used to construction master curves

$$|G^*(\omega)| = G_g \left[ 1 + \left( \frac{\omega_c}{\omega} \right)^v \right]^{\frac{w}{v}}$$
Surface Course

- Complex Modulus, $G^*$ (Pa)
- Frequency, radians/second

- 20% FRAP, 5% RAS
- 25% FRAP, 0% RAS
Dynamic Modulus, $E^*$

- Five Replicate Samples
- 4” dia. by 6” height
- Axial Cyclical Load
- Constant Strain Mode
- Strain measured with three LVDTs
- Nine Frequencies
- 4, 21, and 37°C
HMA Mixture Master Curves

- Describes Dynamic Modulus $E^*$ as a function of temperature and rate of loading
- Used for Mechanistic-Empirical Pavement Designs
- Frequency curves shifted horizontally with respect to 21°C
- Sigmoidal function used to construct master curves

$$\log|E^*| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \log(t_r)}}$$
Dynamic Modulus Master Curve

|Frequency, Hz| |E*|, kPa|

37°C at Low Freq (Rutting)

21°C at Med Freq (fatigue)

4°C at High Freq (thermal cracking)
What effect does FRAP have on the Base Mix?

- High Temp/Low Freq $E^*$
- 25 to 35% is Significant

- Low Temp/High Freq $E^*$
- No Significant Diff.
What effect does RAS have on the Dynamic Modulus?

- **High Temp/Low Freq E***
  - RAS increases E*
  - No Significant Diff.

- **Med Temp/Med Freq E***
  - Significant but no trend

- **Low Temp/High Freq E***
  - RAS decreases E*
  - Significant in the Base Course
Flow Number

- Uses Dynamic Modulus Samples
- Test Temperature 37°C
- Constant Stress
- Cyclic Repeated load
- 0.1s pulse and 0.9s rest
- Measured Accumulated Strain after 10,000 load cycles
- Indication of Rutting Resistance
Accumulated Strain in Flow Number Test

% strain

\[ p\text{-value} = 0.6462 \]
\[ p\text{-value} = 0.0162^* \]
\[ p\text{-value} = 0.0048^* \]
Beam Fatigue

- Repeated traffic loading
- Haversine loading at 10Hz
- Linear Kneading Compactor
- Six beams for each sample tested at a different constant strain level
- Test Temperature 20°C
- Test is complete after a 50% reduction in flexural stiffness
- K2 indicates damage accumulation rate
- Above 3.5 is acceptable

\[ N_f = K_1 \left( \frac{1}{\varepsilon_0} \right)^{K_2} \]
Base Course Mixes

Load Cycles (N) vs. % micro strain graph showing the relationship between load cycles and micro strain for different base course mixes. The graph includes two lines:
- 45% FRAP / 5% RAS (solid line) with an R² value of 0.9716
- 50% FRAP / 0% RAS (dashed line) with an R² value of 0.803

The graph shows data points and trend lines for each mix type.
Binder Course Mixes

Load Cycles (N)

% micro strain

R² = 0.9762
R² = 0.9134

35% FRAP / 5% RAS
40% FRAP / 0% RAS
<table>
<thead>
<tr>
<th>K2 Coefficients</th>
<th>Field Mixes</th>
<th>Lab Mixes</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% FRAP, 0% RAS, surface</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>20% FRAP, 5% RAS, surface</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>25% FRAP, 5% RAS, base</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>35% FRAP, 5% RAS, base</td>
<td>9.0</td>
<td>9.0</td>
</tr>
<tr>
<td>35% FRAP, 5% RAS, binder</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>40% FRAP, 5% RAS, binder</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>45% FRAP, 5% RAS, base</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>50% FRAP, 0% RAS, base</td>
<td>6.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Compact Disk Tension

- Conducted by Univ. of Illinois Urbana-Champ.
- Test Temperature $-12^\circ C$
- 4 Specimens 120mm in height by 150mm in dia.
- Measures Fracture Energy
- Minimum recommended value is 350J/m$^2$
Average Fracture Energy by % recycled materials

- 25%: 388
- 30%: 363.1
- 40%: 357.7
- 50%: 299.9
Fracture Energy Comparison

50% Recycled Base

- NO RAS: 391.0
- RAS: 386.5

40% Recycled Binder

- NO RAS: 388.3
- RAS: 319.0

25% Recycled Surface

- RAS: 338.3
- NO RAS: 278.0
Conclusions

- Tollway mixes exhibit good resistance to rutting
- 5% RAS is not detrimental to the fatigue performance of the Tollway mixes
- Mixtures may see some cracking due to lower fracture energies and higher low performance grade temperatures
Illinois Tollway Conclusions

- Mixes with greater than 40% recycled will likely see the greatest amount of cracking.
- Their performance may be improved by grade bumping the virgin binder from 58-22 to 58-28.
- Fibers could be contributing to the performance of the mixtures.
- Tollway mixes exhibit satisfactory freeze-thaw durability.
- Laboratory RAS mix design procedures may need to be reevaluated.
MNDOT MIXES

![Graph showing modulus versus frequency for Mix #1, #2, and #3 with different labels: Mix #1 5% Mfr RAS, Mix #2 5% Tear-offs RAS, Mix #3 30% RAP.](image-url)
INDOT MIXES

- Mix #11: HMA - 15% RAP
- Mix #12: HMA - 3% RAS
- Mix #13: WMA - 3% RAS
Iowa DOT: WMA+RAP+RAS

- Muscatine County (Hwy 61 Shoulders)
- Evotherm 3G (Plant Temp = 250F)
- 3 Test Sections
  - 20% RAP/0% RAS
    - 20% Binder Replacement
    - 4.6% Design AC
  - 15% RAP/5% RAS
    - 30% Binder Replacement
    - 5.0% Design AC
  - 8% RAP/7% RAS
    - 30% Binder Replacement
    - 5.5% Design AC
WMA + 5% RAS + 15% RAP

5% RAS (5.0% AC)

Lab Voids (%) vs. Plant Temperature (°F)

- 34% Replacement
- 30% Replacement

4.7% AC

5.2% AC
WMA + 7% RAS + 8% RAP
WMA Control + 20% RAP

0% RAS (4.6% AC)

Lab Voids (%) vs. Plant Temperature (°F)

5.0% AC
WMA with RAS

- RAS contains much stiffer binder
- Not all RAS is activated
- 15-40% Acts like black rock = Requires more AC to coat
- May need to add oil
- May need to raise temperature
- HIGH RAS STOCKPILE MOISTURE
  - Reduce production rate
  - Increase plant temperature
Additional Demonstration Projects

- Iowa- 4%, 5%, 6% RAS
- Missouri- Coarse vs. Fine Grind
- Colorado- to be determined!
- Wisconsin- to be determined.
- California- to be determined.
Items Considered Best Practices

• Minimize water usage during grinding
• Store ground shingles under a covered roof
• Use multiple recycled cold feed bins- one that is dedicated to shingles
• Use a 2^{nd} recycle bin on drum plants closer to the hot zone for adding shingles
Thank You! & Questions?