Design Factors
For Using RAP
In Hot Mix Asphalt

Greater Iowa Asphalt Conference
March 2006
What is RAP?

Recycled Asphalt Pavement

Asphalt pavement removed from the roadway, typically by milling.
Why Use RAP in HMA?

**Economics**

Components of RAP have value

- High quality aggregate
- Asphalt binder
- No (or low) hauling cost

20% RAP = 20% Savings in new asphalt binder
(at $250/ton and 5% binder = $2.50/ton mix)
RAP in HMA

Material Factors

Variability in the pavement materials
- multiple layers
- different mix designs

Age of the hot mix asphalt

Storage & management of RAP
- Classified RAP (known materials)
- Unclassified RAP (unknown materials from multiple projects stored in same stockpile)
### RAP in HMA

**Binder Grade Selection**

**>> Iowa Specification <<**

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<tr>
<th>ACTION</th>
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<td>&gt;20 - 30%</td>
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<tr>
<td>Use Blending Charts</td>
<td>&gt;30%</td>
</tr>
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RAP in HMA

Critical RAP Properties

Low RAP (up to 30% RAP)
- Asphalt Content of RAP
- Aggregate Gradation of RAP
- RAP Specific Gravity
- Consensus Aggregate Properties

High RAP (more than 30% RAP)
- All of the above - PLUS >>
- Asphalt binder physical properties
Extraction and Recovery Procedures

- **Extraction**
  - Determine asphalt content of RAP
  - Determine RAP aggregate gradation
  - Necessary for mix design

- **Recovery**
  - Determine asphalt binder physical properties
  - Necessary for blending charts
  - Required for RAP content greater than 30%
RAP in HMA

The Black Rock Question

Does RAP act like a black rock in the mixture?

When a chunk of RAP is added to the mix does the asphalt binder in the RAP interact (blend) with the virgin AC?
Black Rock Research

- **Case A** = black rock = virgin binder with virgin aggregate plus extracted RAP aggregate.
- **Case B** = standard practice = virgin binder with virgin aggregate plus RAP.
- **Case C** = total blending = virgin binder physically blended with recovered RAP binder, then added to aggregate.

If no blending: **Case A = Case B**
If partial blending: **Case A < Case B < Case C**
10% RAP

Cycles

Plastic Shear Strain

A

B

C
Black Rock Research

40% RAP

Plastic Shear Strain

Cycles

Case A

Case B

Case C

Black Rock Research
Indirect Tensile Testing
Creep Stiffness at -20°C

Case A  Case B  Case C

PG 52-34  PG 64-22

Black Rock Research
Blending occurs at higher RAP contents. At low RAP contents, effects are not significant.

Results from all phases support concept of a tiered system.
RAP mixtures should be able to perform at least as well as virgin mixes.

RAP aggregates need to be included in consensus properties and gradations. Watch changes in aggregates due to extraction.

Exception: sand equivalent value.
Extraction and Recovery

- **Solvent Extraction**
  - ASTM D2172 -- Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
    - Method A (Centrifuge) - most common
    - Method B (Reflux) - completely contained
    - Method E (Vacuum)

- **Ignition Oven**
Reflux Extraction

Obtain mix sample, determine weight, and place into two conical containers (with filters)
Reflux Extraction

- Place conical containers in cylinder
- Place cylinder with solvent on hot plate
- Seal top of cylinder with condenser unit
- Begin reflux extraction and continue until the effluent from the lower cone is a light straw color
Component Analysis of RAP

- After Extraction Procedure...
  - Determine the final mass of the sample and the amount of asphalt binder extracted

  Asphalt Content

  - Use extracted aggregate for further testing

  Gradation
Recovery

To Determine the Physical Properties of RAP Binder

- Conducted after extraction procedure
- ASTM 1856 - Recovery of Asphalt from Solution by Abson Method
- ASTM D5404 - Recovery of Asphalt from Solution Using the Rotavapor Apparatus
- AASHTO TP2 - Quantitative Extraction and Recovery of Asphalt Binder from Hot Mix Asphalt (HMA)
# RAP in HMA

## Binder Grade Selection

<table>
<thead>
<tr>
<th>Blending Method</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder Grade Required by the Project</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Recovered RAP Binder Properties</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Percentage of RAP in Mixture</td>
<td>✓</td>
<td>?</td>
</tr>
<tr>
<td>Virgin Binder Properties/Grade</td>
<td>?</td>
<td>✓</td>
</tr>
</tbody>
</table>
RAP in HMA

Blending -- Method A

Blending at a Known RAP Percentage
(Virgin Binder Grade Unknown)

\[ T_{\text{virgin}} = \frac{T_{\text{blend}} - (%\text{RAP} \times T_{\text{RAP}})}{1 - %\text{RAP}} \]

- \( T(\text{virgin}) = \) Tc of virgin binder
- \( T(\text{blend}) = \) Tc of blended binder (desired)
- \( T(\text{RAP}) = \) Tc of recovered RAP binder
- \( %\text{RAP} = \) percentage of RAP (expressed as a decimal)
**Example**

Desired Final Binder Grade: PG 64-22

RAP Percentage: 30%

RAP Binder Properties:

<table>
<thead>
<tr>
<th>Aging</th>
<th>Property</th>
<th>Critical Temperature, C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>DSR $G^*/\sin d$</td>
<td>High 86.6</td>
</tr>
<tr>
<td>RTFO</td>
<td>DSR $G^*/\sin d$</td>
<td>High 88.7</td>
</tr>
<tr>
<td></td>
<td>DSR $G^*\sin d$</td>
<td>Intermediate 30.5</td>
</tr>
<tr>
<td></td>
<td>BBR S</td>
<td>Low - 4.5</td>
</tr>
<tr>
<td></td>
<td>BBR m-value</td>
<td>Low - 1.7</td>
</tr>
<tr>
<td>PG</td>
<td>Actual</td>
<td>PG 86-11</td>
</tr>
<tr>
<td></td>
<td>MP1</td>
<td>PG 82-10</td>
</tr>
</tbody>
</table>
Example
Desired Final Binder Grade: PG 64-22
RAP Percentage: 30%

\[ T_{\text{virgin}} = \frac{T_{\text{blend}} - (%\text{RAP} \times T_{\text{RAP}})}{1 - %\text{RAP}} \]

\[ T_{\text{virgin (High)}} = \frac{64.0 - (0.30 \times 86.6)}{(1 - 0.30)} = 54.3 \]
RAP in HMA

Blending Charts - Method A

$T_{\text{critical}, C}$

Percentage of RAP

$T_{\text{critical}, C}$ = 54.3
RAP in HMA

Blending Chart - Method A

![Blending Chart](image)

**T_{critical}, C**

- 22.6

**Percentage of RAP**

0% 20% 40% 60% 80% 100%

- 0%
- 20%
- 40%
- 60%
- 80%
- 100%

- 19
- 22
- 25
- 28
- 31
- 34
RAP in HMA

Blending Chart - Method A

$T_{\text{critical}}$, $C$

Percentage of RAP

0% 20% 40% 60% 80% 100%

0 0% 20% 40% 60% 80% 100%

-24 -18 -12 -6 0

-16.4
### RAP in HMA

### Blending - Method A

#### Virgin Binder Properties Required:

<table>
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<th>Property</th>
<th>Critical Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>DSR G*/sin</td>
<td>High</td>
</tr>
<tr>
<td>RTFO</td>
<td>DSR G*/sin</td>
<td>High</td>
</tr>
<tr>
<td>PAV</td>
<td>DSR G*sin</td>
<td>Intermediate</td>
</tr>
<tr>
<td></td>
<td>BBR s</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>BBR m-value</td>
<td>Low</td>
</tr>
</tbody>
</table>

**Actual Grade**: PG 54-26  
**MP1 Grade**: PG 58-28
RAP in HMA
Blending - Method A

- From the Example:
  - To achieve a final asphalt binder grade of PG 64-22...
    - Recovered RAP Binder Grade = PG 82-10
    - 30% RAP used in mixture
  - ...the virgin asphalt binder needs to be PG 54-26 (PG 58-28)
Blending with a Known Virgin Binder Grade
(RAP Percentage Unknown)

\[
\% \text{RAP} = \frac{T_{\text{blend}} - T_{\text{virgin}}}{T_{\text{RAP}} - T_{\text{virgin}}}
\]

- \( T(\text{virgin}) \) = Tc of virgin binder
- \( T(\text{blend}) \) = Tc of blended binder (desired)
- \( T(\text{RAP}) \) = Tc of recovered RAP binder
- \( \% \text{RAP} \) = percentage of RAP expressed as a decimal
### RAP in HMA

**Blending - Method B**

**Example**

**Desired Final Binder Grade:** PG 64-22

**Virgin and RAP Binder Properties:**

<table>
<thead>
<tr>
<th>Aging</th>
<th>Property</th>
<th>Critical Temperature, $C$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Temp.</td>
</tr>
<tr>
<td>Original</td>
<td>DSR $G*/\sin\delta$</td>
<td>High</td>
</tr>
<tr>
<td>RTFO</td>
<td>DSR $G*/\sin\delta$</td>
<td>High</td>
</tr>
<tr>
<td>PAV</td>
<td>DSR $G*\sin\delta$</td>
<td>Intermediate</td>
</tr>
<tr>
<td></td>
<td>BBR $S$</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>BBR $m$-value</td>
<td>Low</td>
</tr>
<tr>
<td>PG</td>
<td></td>
<td>Actual</td>
</tr>
<tr>
<td>MP1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Example**

**Desired Final Binder Grade:** PG 64-22

**Known Virgin and RAP Binder Properties**

\[
\%\text{RAP} = \frac{T_{\text{blend}} - T_{\text{virgin}}}{T_{\text{RAP}} - T_{\text{virgin}}}
\]

\[
\%\text{RAP (High)} = \frac{64.0 - 60.5}{86.6 - 60.5} = 13.4\%
\]
RAP in HMA

Blending - Method B

Percentage of RAP

T_{critical}, C

0% 20% 40% 60% 80% 100%

13% 36%

52 58 64 70 76 82 88

0% 20% 40% 60% 80% 100%
RAP in HMA

Blending - Method B

Percentage of RAP

$T_{critical}, C$

66%
RAP in HMA

Blending - Method B

Percentage of RAP

$T_{\text{critical}}$ in °C

-24  -18  -12  -6  0

0%  20%  40%  60%  80%  100%

5%  40%
### RAP in HMA

#### Blending - Method B

**Percent RAP Required to Achieve Final Blend:**

<table>
<thead>
<tr>
<th>Aging</th>
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<th>PG 6422</th>
<th>PG 7028</th>
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<tbody>
<tr>
<td>Original</td>
<td>DSR $G^*/\sin\delta$</td>
<td>High</td>
<td>13.4%</td>
<td>36.4%</td>
</tr>
<tr>
<td>RTFO</td>
<td>DSR $G^*/\sin\delta$</td>
<td>High</td>
<td>10.8%</td>
<td>32.5%</td>
</tr>
<tr>
<td>PAV</td>
<td>DSR $G^*\sin\delta$</td>
<td>Intermediate</td>
<td>66.3%</td>
<td>---</td>
</tr>
<tr>
<td>BBR S</td>
<td></td>
<td>Low</td>
<td>57.6%</td>
<td>23.7%</td>
</tr>
<tr>
<td>BBR m-value</td>
<td></td>
<td>Low</td>
<td>40.5%</td>
<td>5.8%</td>
</tr>
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</table>
RAP in HMA

Blending - Method B

- From the Example:
  - To achieve a final asphalt binder grade of PG 64-22...
    - Recovered RAP Binder Grade = PG 86 -11
    - Virgin Binder Grade = PG 60-29 (PG 58 -28)
  - ...the allowable RAP percentage is between 14% and 40%.
# RAP in HMA

## Binder Grade Selection

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Handling RAP During the Mix Design Process

- RAP Heating Procedure
  - 110 °C (230 °F) for 2 hours (max)
  - Suitable for 1-2 kg batches
  - Higher temperature or longer time may affect properties of some RAP

- Virgin Aggregate Heating Procedure
  - Heat to 10 °C above mixing temperature
  - (typically 275 + 20 = 295 °F)
Mixtures with 10 to 15% RAP may become more common.

At high RAP contents, gradation and properties of RAP aggregate may limit amount of RAP used.
  - Processing or screening RAP?
RAP variability must be controlled to meet production tolerances.

Binder blending methods are used for high RAP contents.

Designs with modified binder require special attention.
RAP in HMA