Recycled Asphalt Pavement

What’s Going On In There?

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RAP Use

Use Increasing

20.4% (2014)
AASHTO STANDARD

- M323
  Superpave
  Volumetric
  Mix Design
- Changes
  - Dec 2014
M323 Terminology

- Percent RAP
  - Reclaimed Asphalt Pavement Binder Ratio (RAPBR)

\[ RAPBR = \frac{Pb_{RAP} \times PRAP}{Pb_{total}} \]
Indiana DOT

- Virgin Binder Graded Based on Asphalt Binder Replacement (RAP or Shingles)
  - 0 to 25%
  - 25 to 40%

- Based on properties of
  - RAP binder
  - New binder
Properties of RAP

- Sample RAP Stockpiles
  - Measure Grade
- Recover Asphalt Binder
  - Measure Grade
- Sample New Asphalt Binder
  - Measure Grade
    - PG 64-22
    - PG58-28
Location of RAP Stockpiles Sampled

33 RAP Stockpiles
RAP

High Temperature Properties

![Bar chart showing frequency of high temperature properties with mean = 90 and s² = 5.0]
RAP
Low Temperature Properties

![Graph showing frequency distribution of low temperatures. The mean is -11 and the standard deviation squared (s^2) is 3.1.](image)
PG64-22
Low Temperature Properties

Frequency

0 10 20 30 40

-20 -22 -24 -26 -28

-25.1
PG58-28
Low Temperature Properties
Maximum RAP (PG64-22)

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

\[ = \frac{-22.0 - (-25.1)}{-11.1 - (-25.1)} \]

\[ = 23\% \]
Maximum RAP (PG58-28)

\[
\%\text{RAP} = \frac{\text{Tblend} - \text{Tvirgin}}{\text{Trap} - \text{Tvirgin}}
\]

\[
= \frac{-22.0 - (-28.7)}{-11.1 - (-28.7)} = 38\%
\]
## INDOT Binder Grade Selection

### Virgin Binder Grade

<table>
<thead>
<tr>
<th>Change in Grade</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Change in Grade</td>
<td>&lt; 25%</td>
</tr>
<tr>
<td>One Grade Softer</td>
<td>&gt;= 25%</td>
</tr>
</tbody>
</table>

### Mixing

- Should the binder grade be mixed?
Diffusion

Virgin asphalt acts as a ‘lubricant’

Pavel Kriz
Esso Canada
Diffusion

• Happens with Time

\[ \eta^*, \text{ Pa.s}\]

\[ \text{Diffusion Time, s}\]

RAP

50/50 Blend

Virgin

Pavel Kriz

Esso Canada
Effect of Temperature on Diffusion

Lower Temperature Slower Blending

Time to equilibrium

- 210°F: 2 hours
- 260°F: 25 hours
- 260°F: 6 hours

Pavel Kriz
Esso Canada
TU Delft Research

- Looking at Blending Zone

Diagram:
- RAP-binder
- Virgin bitumen
- 12mm distance
- 130°C, 40 secs
- RAP-binder
- Virgin bitumen
- Blended bitumen
Mixing

- Occurs by Diffusion
Diffusion In Practice

Pavel Kriz
Esso Canada

Blending

Time, days

100 days

Mix
Silo
Transport
Paving
Service

10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4}

0.5 0.6 0.7 0.8 0.9 1

HMA
WMA
Investigation of Low and High Temperature Properties of Plant-Produced RAP Mixtures

North Central Superpave Center
# Design and Produce Mix

<table>
<thead>
<tr>
<th>Binder Grade</th>
<th>RAP</th>
<th>0%</th>
<th>15%</th>
<th>25%</th>
<th>40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 64-22</td>
<td>Mix A</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Mix B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mix C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mix D</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG 58-28</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mix E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mix F</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mix Stiffness (PG 64-22)
Mix Stiffness (PG 64-22)

- Mix4-A (0% RAP)
- Mix4-B (15% RAP)
- Mix4-C (25% RAP)
- Mix4-D (40% RAP)
Same Mix (PG58-28)

Control versus PG58-28

Log $|E^*|$, MPa

Log Reduced Frequency, Hz

MixA (0% RAP)
MixE (25% RAP)
MixF (40% RAP)
Same Mix (PG58-28)

Control versus PG58-28

Log $|E^*|$, MPa

Log Reduced Frequency, Hz

MixA (0% RAP)

MixE (25% RAP)

MixF (40% RAP)
Cracking Temperature
Example 1

Axis Title

Strength  Temperature

Cracking Temperature, °C

PB-A  PB-B  PB-C  PB-D  PB-E  PB-F

-28  -22  -16  -10  -16  -22  -28

2500  3000  3500  4000
Cracking Temperature
Example 2


Strength
Temperature

Cracking Temperature, °C

2000 2500 3000 3500

-28 -22 -16 -10

JH-A JH-B JH-C JH-D JH-E JH-F
Where is the Limit?

- **Hot recycling**
  - How much can be put through a plant?

- **Issues**
  - Virgin Aggregate temperature
  - Drum temperature
  - Baghouse temperature
Asphalt Binder Replacement

\[
\% \text{Asphalt binder replacement} = \frac{\text{recycled binder}}{\text{total binder}}
\]

- RAP
- Coarse RAP
- Fine RAP
- Shingles
Typical Asphalt Binder Content

- RAP: 4 – 5%
- Fine RAP: 5 – 7%
- Coarse RAP: 2 – 3%
- Manufacturer Scrap: 18 – 22%
- Post Consumer: 22 – 25%
Mix Experiment

- Counterflow drum mix plant
  - With mixing drum
- 19 mm NMPS
  - 25 mm crushed gravel
  - 12.5 mm crushed limestone
  - 12.5 mm pea gravel
  - Natural sand
Recycled Materials

- Fine RAP
- Coarse RAP
- Post Consumer Shingles
Post Consumer Shingles
Coarse RAP (1/2 to 1 inch)
Fine RAP (minus 1/2 inch)
Recycled Components

![Bar Chart]

- Mix 9: 64-22
- Mix 10: 52-28
- Mix 11: 52-28
- Mix 12: 52-28
- Mix 13: 64-22

The chart shows the recycled components with different mixes and their corresponding recycled percentages.
Asphalt Binder Replacement

Mix 9  64-22
Mix 10  52-28
Mix 11  52-28
Mix 12  52-28
Mix 13  64-22
Volumetric Properties

Asphalt Content
Air Voids

Percentage

Mix 9
64-22
Mix 10
52-28
Mix 11
52-28
Mix 12
52-28
Mix 13
64-22
Asphalt Binder Grade

Mix 9   64-22
Mix 10  52-28
Mix 11  52-28
Mix 12  52-28
Mix 13  64-22
New Aggregate Temperature

<table>
<thead>
<tr>
<th>Aggregate Temperature, F</th>
<th>60%</th>
<th>50%</th>
<th>50%</th>
<th>50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp F</td>
<td>840</td>
<td>705</td>
<td>710</td>
<td>712</td>
</tr>
</tbody>
</table>
Drum Temperature

Drum Shell Temperature, °C

- 60%
- 60%
- 50%
- 50%
- 50%
Drum Mix Plant Limits

- Maximum 50% RAP
- Drum Shell Temperature
  - max 800 F
- Aggregate Temperature
  - max 700 F
- Exhaust Temperature
  - min 220 F
  - max 400 F
Dutch Experience

Sustainability high on the political agenda

- Small but densely populated country
- We are a prosperous country
- Competition between nature, agriculture, housing, transport, recreation, industry, excavation, landfill et cetera for scarce area of land
- Recycling, sustainable development encouraged by society
- Recycling is being made economic feasible
Contractor Visits

 Trials at 90%
RAP entry point into weigh hopper

U.S. Direct Addition
RAP Use in Indiana

Percent limits based on

- Laboratory research
- Properties of Plant mix
- Properties of new asphalt binder
- Properties of reclaimed asphalt binder
- Percent reclaimed asphalt binder
So That’s What’s Going On In There

RAP

Thank You