Evaluating RAP Binder Rheological Properties

[How to account for them in Recycled HMA]

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P3- Warm Mix and Recycled Asphalt Pavements
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Outline

- Background
  - Properties of binders in RAP:
    - Changes in rheological and failure properties due to aging
    - Blending Charts for determination of properties of blended bitumen
  - Development of new BBR protocol for evaluating RAP binders without solvent extraction
- Concluding Remarks
Bitumen Aging and Recycling

- Bitumen is known to oxidize and age-harden; yet its recycling is widely accepted.
- Bitumen aging is a chemical process that is known to be source-specific; some bitumens age faster and become harder than others.

- When aged and fresh bitumens are blended, the properties of the blend can be balanced and brought back to acceptable service.
- For proper recycling there is a need to characterize aged properties.
Surface Mixes –
Average RAP Used Less than allowed!

Source: RAP Expert Task Group, By Mr. C. Jones, NC State DOT
Specification Barriers

- Quality Concerns
  - Consistency of RAP
  - Ability to Meet Volumetric Requirements
  - Durability of Mixes
- Stiffness of Binder
- Use with Polymer Modified Binders

Source: RAP Expert Task Group, By Mr. C. Jones, NC State DOT
Research Needs

- Performance of High RAP Mixes
  - Modulus of RAP Mixes
  - Fatigue Concerns
- How to Better Control RAP - Fractionating
- Binder Issues
  - Final Effective Binder Grade
  - Need to Bump Binder Grade

Source: RAP Expert Task Group, By Mr. C. Jones, NC State DOT
**Typical Examples of Limits of RAP Used in the USA**

<table>
<thead>
<tr>
<th>State</th>
<th>Batch Plant</th>
<th>Drum Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maine</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Mixes</td>
<td>15% (same PG)</td>
<td>Same as batch plant</td>
</tr>
<tr>
<td></td>
<td>25% (PG change)</td>
<td></td>
</tr>
<tr>
<td>Intermediate Mixes</td>
<td>Same as base above</td>
<td>Same as batch plant</td>
</tr>
<tr>
<td>Surface Mixes</td>
<td>15% max</td>
<td>15% max</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Virginia</strong></th>
<th>Batch Plant</th>
<th>Drum Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Mixes</td>
<td>25 % before grade bumping is required.</td>
<td>25 % before grade bumping is required.</td>
</tr>
<tr>
<td>Intermediate Mixes</td>
<td>20 % before grade bumping is required.</td>
<td>20 % before grade bumping is required.</td>
</tr>
<tr>
<td>Surface Mixes</td>
<td>20 % before grade bumping is required.</td>
<td>20 % before grade bumping is required.</td>
</tr>
</tbody>
</table>

Virginia is allowing up to 30% in surface and intermediate mixes without grade bumping on several county maintenance projects this year.
High Variability in Penetration Retained with Age

1. Bitumen specific (wide range in one location)
2. Climate is very significant
3. Pen can reduce to 10% in 5-10 years

Figure 1. Penetration retained for a number of asphalts used in test sections in the United States.
Rheology of Bitumen Measured with Shear Rheometers

Asphalt

Applied Stress or Strain

Oscillating Plate

Fixed Plate

Test at Pavement Temperature

Asphalt

G* = \frac{\tau_{\max}}{\gamma_{\max}}

\delta = \text{time lag/w}

Measures hardness

Measures elasticity

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Figure 5. Effect of oxidative aging in the PAV on rheological master curves of a typical asphalt. (a) complex modulus, (b) phase angle.
Effect of Aging on Rheological Properties of Bitumen

- All asphalts become harder, more elastic, and possibly more brittle.
  - $G^*$ increase
  - Phase angle ($\delta$) decrease
  - These changes can result in more fatigue and low temperature cracking after age.

- Low and intermediate temperature properties are more relevant
Direct Tension Testing

Load

Elongation at failure

Length before test

Load

Failure stress = Load at break / area

Failure strain = \( \frac{\text{Elongation}}{\text{Length before test}} \)
Effect of Aging on Failure Strain
Blending of Fresh Bitumen with Aged Bitumen in RAP

Recycled Asphalt Mixture
Illustration of G* Rheology master curve for Bitumen
Effect of aging on Rheology
Appears to be simple

Changes in $R$, and $F_c$
How to include RAP Effects on PG Grade

Thermal Cracking  Fatigue Cracking  Permanent Deformation  Mixing & compaction

Pavement Temperature, C
-20 20 60 135

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Concept of Limiting Temperatures

- **S** = 300 MPa
- \( m > 0.3 \)
- \( G* \sin \delta = 5 \text{ MPa} \)
- **PAV-aged**
- **RTFO**
- \( G*/\sin \delta = 0.001, 0.0022 \text{ MPa} \)
- **Unaged**

**Limiting Temperatures**

- LT (S), LT(m)
- LT (G*.sind)
- LT (G*/sind)
Example for Blending of RAP Binder with Virgin Binder

\[ G^* \sin d \]

Limiting Temperature, C

24 C

30.0

20.0

10.0

0.0

-10.0

-20.0

-30.0

-40.0

0%

20%

40%

60%

80%

100%

RAP Bitumen

S(6), m(60)

RAP PG (xx- 04)

PG (xx-28)

Fresh Bitumen

(% Fresh Bitumen) 100 %
What is needed to reduce barriers?

- A method to measure / estimate $S(60)$ and $m(60)$ without extraction and recovery.
- Method should represent mixing of fresh binders with binder in RAP, without extraction.
- **ARC work element: E2b**
- **One of the best alternatives:**
  - Test RAP mortars
Aim of the study

Develop testing protocol

- high temperature
- low temperature

RAP aggregates (-#8)
+ virgin binder

BBR

RAP mortar
Development of RAP Mortar Testing Protocol

✓ Modify BBR testing procedure:
  ➢ molds
  ➢ testing parameters

✓ Set up experimental plan

✓ Data acquisition
  ➢ RAP mixture
  ➢ virgin binder

✓ Blending charts → influence of binder on RAP
BBR test modification

Modified mold (12.7 mm x 12.7 mm cross section)

Allow for at least 4 times maximum aggregate size
BBR test modification

Modified mold (12.7 mm x 12.7 mm cross section)

Allow for at least 4 times maximum aggregate size
BBR test modification

- **LVDT Position:**
  - Excessive thickness, LVDT \(\rightarrow\) raised

- **Load:**
  - 2000 mN \(\rightarrow\) deflections not significant
  - 3000 mN \(\rightarrow\) deflections close to LVDT resolution
  - 4000 mN \(\rightarrow\) better, not enough

- **Temperature**
  - \(-6.0 \, ^\circ C\)
  - \(0.0 \, ^\circ C\)

- **Specimen Thickness**
  - 12.7 mm changed to 10.0 mm
BBR test – new mold

New mold
(10 mm Thick x 12.7 mm Wide)
BBR test – experiment 1

☑ 2000 mN → deflections not significant

☑ 3000 mN → deflections close to LVDT resolution

☑ 4000 mN → better, not enough
Effect of RAP Binder Aging
On RAP Mortar BBR Stiffness

![Graph showing the effect of RAP binder aging on RAP mortar BBR stiffness. The graph plots loading time against S(t)/MP. Different markers represent different binder types: RAP Mortar-PAVx2 + 15% Binder, RAP Mortar-Natural, Fresh Binder + RAP agg, Binder-PAVx2, and Binder-RTFO. The graph compares RAP mortars with binder-only samples.]
Repeatability of BBR Test
RAP Mortar Samples

![Graph showing the repeatability of BBR test on RAP mortar samples. The graph plots loading time against the modulus (S(t)). The legend indicates different samples such as Natural RAP + 15% Fresh Binder, Artificial RAP + 15% Fresh Binder, 15 + 5.1 Fresh Binder, and 15 + 5.1 Fresh Binder.](image)
How much is needed to Move RAP Mortar within Spec (Adjust Mortar S(60))

Target S(60) of Recycled Mortar

Aged RAP grade

Fresh Grade
New BBR set-up
Several up-grades
Next steps: Fracture Properties
SENB – Hesp et al. - Manitoba
Interim Findings

- Recycling is one of the most important advantages of using asphalts; when done properly can reduce cost and depletion of natural resources.

- Changes in PG grading and in rheology are simple:
  - A linear relationship is shown adequate for the prediction of changes in PG grading

- Limiting temperature blending charts can used to select grade and amount of fresh bitumen needed
Interim Findings

- A method for measuring/estimating the need for changing PG grade is under development.
- It is based on the BBR.
- Initial data is promising.
- Challenges:
  - Sample preparation
  - Modification of BBR
  - Acceptance limits
Thank you for your time!

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  - Work is part of ARC
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- Questions?