MIX DESIGN
FOR HMA RECYCLING

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PRESENTATION OUTLINE

- Outline current practice with RAP mix design and how we got to this point

- Lay groundwork for other presentations showing possible refinements and other considerations
**Possible Effects of RAP**

- At low RAP contents, there may be little aged binder to affect properties of blend
- At higher RAP contents, the hardened RAP binder may stiffen the mix
  - Good for rutting, not so good for cracking
- The aggregate in the RAP may affect structure and stability of the mix
- Mix design should consider/account for these possible effects
RAP Mix Design Basics

Aggregate Considerations

- Include RAP aggregate in determinations of:
  - Specific gravity
  - Gradation
  - Fine aggregate angularity
  - Coarse aggregate angularity
  - Flat and elongated content

- RAP Specific Gravity
  - Use RAP agg effective specific gravity, or
  - Backcalculate bulk s.g. from Rice density and assumed absorption
RAP Mix Design Basics

Binder Considerations

- Reduce added binder to account for RAP binder

- For higher RAP contents, use softer virgin binder grade to blend with and “soften” the hardened RAP binder
  - Cost and construction (compaction) implications
CURRENT TIERS

- Up to 15% RAP, no change in binder grade.
- 16-25% RAP, lower binder grade by one increment.
- More than 25%, create blending charts.
  - Assumes linear blending
  - Extract, recover and test RAP binder
  - High, low and intermediate temperatures
  - DSR (orig, RTFO, PAV), BBR (S and m)
HIGH TEMPERATURE BLENDING CHART, KNOWN RAP CONTENT

Percentage of RAP

T_{critical}, \degree C

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

0 52 58 64 70 76 82 88

54.3
LOW TEMPERATURE BLENDING CHART, KNOWN VIRGIN BINDER

\[ T_{critical}, ^\circ C \]

Percentage of RAP

0% 20% 40% 60% 80% 100%
So, How Did We Get Here?

- NCHRP 9-12, *Incorporation of Reclaimed Asphalt Pavement in the Superpave System*
  - NCSC and the Asphalt Institute
  - RAP from Connecticut, Florida, and Arizona
  - Completed 2000, published 2001
  - Changes in three AASHTO standards

- Regional study, *Use of Reclaimed Asphalt Pavement Under Superpave Specifications*
  - RAP from Indiana, Missouri, Michigan
  - Completed 2003
**Issues Addressed**

- In NCHRP 9-12
  - Is RAP a “black rock”?  
  - Effects of RAP on binder grade  
  - Effects of RAP on mixture properties

- In Regional study
  - Do NCHRP 9-12 findings apply?  
  - Can you use 40 to 50% RAP in a Superpave mix?  
  - Is linear blending appropriate?  
  - Compared plant produced mix stiffness to blending chart stiffness
MAJOR FINDINGS OF NCHRP 9-12

- RAP is not a black rock
- But, at low RAP contents, there is not enough RAP to change binder or mix properties
- As RAP content increases, effects become appreciable
- Shear testing, beam fatigue and low temperature testing showed similar stiffening.
  - Important – must account for this to avoid increased cracking (use softer virgin binder)
- Linear blending charts valid
REGIONAL STUDY

- Largely confirmed NCHRP findings
- Can design Superpave mixes with 40-50% RAP
  - Aggregate gradation in the RAP may limit how much you can use
- Linear blending charts generally appropriate
- Lab and plant produced mixes agree pretty well
FREQUENCY SWEEP - MO

![Graph showing frequency sweep with different curves for Plant, Lab0, Lab20, and Lab50.]
DOES LINEAR BLENDING WORK?

Michigan

Critical Temperature, °C

RAP Content (%)

0 20 40 60 80 100

Blue: Original
Green: Rtfo
Red: Rtfo-Pav

Plant Mix
STILL NOT CONVINCED?

Missouri

Critical Temperature, \( ^\circ C \)

RAP Content (%)

Plant Mix

- Original
- Rtfo
- Rtfo-Pav
LINEAR BLENDING IS NOT PERFECT

Not linear – but stiffer than expected.
**Estimated vs. Measured**

<table>
<thead>
<tr>
<th>Aging</th>
<th>IN</th>
<th>MI</th>
<th>MO</th>
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</thead>
<tbody>
<tr>
<td>Orig</td>
<td>-6.2°</td>
<td>-6.6°</td>
<td>-7.8°</td>
</tr>
<tr>
<td>RTFO</td>
<td>-3.2°</td>
<td>-0.4°</td>
<td>-0.4°</td>
</tr>
<tr>
<td>PAV</td>
<td>-3.5°</td>
<td>0.5°</td>
<td>0.7°</td>
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</tbody>
</table>

Estimated - Measured
INDIANA ANOMALY?

- Consistent pattern in binder and mix
- Not observed in MI, MO or 9-12 mixes
- Plant may have stiffened binder more than expected
- Materials were one year older than MI and MO
AFTERMATH OF PREVIOUS STUDIES

- RAP use increased after AASHTO standards were issued
- Most Midwestern states report RAP use is back to where it was pre-Superpave
  - Higher in places like Missouri
- Experiences with RAP generally very good – like they were pre-Superpave
  - Many contractors prefer RAP mixes
  - Linear blending works frequently – but not always
LIMITATIONS

- Only three RAP sources evaluated in each study
- RAP fractionation not considered – not common at the time
- Newer, better tests not yet common
- Experience and research show the recommendations may be too simple
Low-Temperature Performance Properties of Hot Mix Asphalt Containing RAP

- So-called “Plant Mix Study”
- Evaluated plant-produced mixes with up to 40% RAP and two virgin binder grades
- Originally proposed to focus on effects of RAP on low temperature properties
- Expanded to other properties and more materials….
- FHWA funded
WHAT WE DID

- Milestone Contractors LLC produced six mixes through one plant over two days
- Heritage Research Group and NCSC tested RAP, virgin and mixture properties
  - Binder properties – PG binder tests
  - Mix properties – Indirect Tensile Strength, Dynamic Modulus, Shear Modulus
## Experimental Design

<table>
<thead>
<tr>
<th>Binder Grade</th>
<th>0%</th>
<th>15%</th>
<th>25%</th>
<th>40%</th>
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<tbody>
<tr>
<td>PG 58-28</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>PG 64-22</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
## Critical Cracking Temperatures

<table>
<thead>
<tr>
<th>Mix</th>
<th>RAP Content</th>
<th>Tc (°C)</th>
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</thead>
<tbody>
<tr>
<td>A – PG64-22</td>
<td>0</td>
<td>-28.9</td>
</tr>
<tr>
<td>B – PG64-22</td>
<td>15</td>
<td>-23.3</td>
</tr>
<tr>
<td>C – PG64-22</td>
<td>25</td>
<td>-25.6</td>
</tr>
<tr>
<td>D – PG64-22</td>
<td>40</td>
<td>-22.8</td>
</tr>
<tr>
<td>E – PG58-28</td>
<td>25</td>
<td>-27.2</td>
</tr>
<tr>
<td>F – PG58-28</td>
<td>40</td>
<td>-23.9</td>
</tr>
</tbody>
</table>
PG64-22, 15% RAP

![Graph showing log modulus vs. log reduced frequency for different materials and conditions.](image)
PG64-22, 40% RAP

Log Modulus, MPa

Log Reduced Frequency, Hz
PHYSICALLY BLENDED BINDERS
WHAT DOES THIS SUGGEST?

- For *these materials and this plant*, the RAP did not have as much impact as expected.
- The higher RAP contents were, in general, not significantly stiffer than virgin mix.
- The binder did not stiffen linearly with increasing RAP content.
- In this case, dropping the virgin grade to PG58-28 for 25% RAP was not necessary.
- Why? Compatibility problem?
IS THIS CONCLUSIVE?

- Certainly not!
  - Only one plant, one RAP source, one set of virgin materials
- May be exception rather than rule
- We need to test more materials from more plants to understand true effects
- Four more contractors have replicated the plant mix experiment
- Testing is in progress
- We will also investigate effect of extraction/recovery method
What this suggests

- But, it does suggest that there is more that we need to understand about RAP, its effects and its “compatibility” with virgin materials plus plant operations
- Maybe current binder grade recommendations are too restrictive – too simplified
CURRENT STATE OF KNOWLEDGE

- With many materials and plants, complete (or nearly complete) blending does occur.
- In other cases -- especially with very hard binders (shingles), high RAP contents or ???-- complete blending may not occur.
  - Temperature, Time, Compatibility, Plant
  - Colloid effect?
- There is much we still do not understand about RAP
MORE INFO:

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