Effects of Reclaimed Asphalt Pavement Content and Virgin Binder Grade on Properties of Plant Produced Mixtures

Rebecca S. McDaniel
Ayesha Shah
Gerald A. Huber
Audrey Copeland

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Growing Interest in RAP Use

- Economic and environmental benefits.
- Higher RAP contents in more mixtures.
- More fractionating.
CONVENTIONAL WISDOM

- RAP will stiffen mix.
- More RAP will stiffen mix more.
- Improves rut resistance at high temperatures.
- May reduce fatigue resistance.
- May worsen thermal cracking.
- Need soft virgin binder to compensate.
CURRENT US (AASHTO) GUIDELINES

- Account for RAP binder
  - 0 to 15% RAP, no binder grade change
  - 16–25% RAP, decrease virgin binder grade
  - Over 25% RAP, test RAP binder to determine virgin grade (or allowable RAP content)

- Based on
  - Mixture testing
  - Percentage by weight of RAP in the mixture
  - Non-fractionated mixes
  - 5% binder in RAP and new mix

- Many states have modified these.
**QUESTIONS**

- At what RAP content do you need to change grades?
- Effect of RAP on low temperature cracking? High temperature stiffness? Intermediate fatigue?
- Are things different when plant mixes are tested?
**APPROACH**

- Evaluated 5 sets of plant-produced mixes
  - 4 from Indiana, 1 from Michigan
- Compared
  - Dynamic modulus
  - Low temperature properties and cracking
  - Fatigue (TFHRC) *(not presented today)*
  - Extracted/recovered and virgin binders

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# Five Contractors

<table>
<thead>
<tr>
<th>Binder Grade</th>
<th>RAP Content*</th>
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<tr>
<td></td>
<td>0%</td>
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<tr>
<td>PG 64-22</td>
<td>X</td>
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<td>PG 58-28</td>
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*By mass of mix
Mix Designs

- Contractors designed 9.5 mm mixes
  - Two coarse, three fine
- Full mix design on one mixture
- Adjust for changes in RAP content
- Keep gradations consistent while using existing stockpiles
  - Generally within 3% on any sieve
- Typically one point verification
  - Substantial spec compliance
Mix Production

- Routine processing and production
- RAP crushed and screened
  - Four used 12.5 mm screen
  - One used 15.9 mm (5/8 in.) screen
- Plant types – parallel and counter-flow drums, double drum, and aggregate dryer with separate mixing drum
- Sampled from one truck at plant – loose mix and gyratory samples
Mix Volumetrics

- Variations in mixes did occur
  - NCSC results → apparent low air voids
  - Low VMA for one set and one other mix
  - Binder contents almost all within ±0.3%

- Most within tolerances for single sample

- 3 contractors’ QC results
  - Higher $G_{mm} \rightarrow$ higher air voids and VMA
  - Samples reheated and no dryback at NCSC
Binder Testing

- Virgin binders met specified grades
- Recovered RAP binders graded at 80 to 89°C and −9 to −20°C
- Compared to virgin binder true grade, binders recovered from mixes showed:
  - High temp grades increased ~8°C for PG64–22 and 12°C for PG58–28
    - Virgin mix was ~7°C higher
  - Low temp grades ~4°C warmer than PG64–22 and ~5°C for PG58–28
  - Increasing RAP from 0 to 25% with no grade change increased LT grade ~2°C
In general, as RAP content increased, mix modulus, $|E^*|$, did increase.

But, in most cases, modulus was not substantially greater than control for up to 25% RAP.

40% RAP mixes tended to be stiffer than or comparable to control.
ONE EXAMPLE – MIX $|E^*|$
ANOTHER EXAMPLE – MIX $|E^*|$

![Graph showing the relationship between reduced frequency and $|E^*|$ for Mix2-A (0% RAP), Mix2-B (15% RAP), Mix2-C (25% RAP), and Mix2-D (40% RAP) with PG64-22 asphalt binder.](image)
Use of PG58–28 generally reduced mix modulus compared to PG64–22.

Mixes with 40% RAP were usually much stiffer than with 25% RAP.

In some cases, mix with 25% RAP and PG58–28 was much less stiff than control.
EXAMPLE – PG64–22 VS PG58–28

[Graph showing the relationship between Log Reduced Frequency (Hz) and Log |E'| (MPa) for different mixes: MixC (25% RAP), MixD (40% RAP), MixE (25% RAP), MixF (40% RAP).]
Example – Control vs PG58–28

Control versus PG58-28

Reduced Frequency, Hz

$|E'|$, MPa

Mix4-A (0% RAP)
Mix4-E (25% RAP)
Mix4-F (40% RAP)
STATISTICAL ANALYSIS

ANOVA and comparison of means test at different temperatures (4 to 54.4°C) showed:

- Mixes with PG64–22 either
  - not significantly different OR
  - 40% RAP mix was different from the others

- Mixes with PG58–28 were sometimes different from each other
BONAQUIST ANALYSIS

- Compare measured mix modulus to estimated modulus
  - Hirsch model using recovered binder (blended) and mix volumetrics

- Suggests how the combination of binders is behaving in the mix
  - Does the mix act as if the binders mixed or not?
THOROUGH MIXING

![Graph showing Modulus vs. Reduced Frequency](image)

- **Estimated**
- **Measured**

Modulus, $|E^*|$ MPa against Reduced Frequency, Hz
POOR MIXING

Reduced Frequency, Hz

Modulus, |E*| MPa

- Estimated
- Measured
<table>
<thead>
<tr>
<th>Summary of Mixing</th>
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<tr>
<td>Mix A</td>
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<td>RAP %</td>
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<td>PG</td>
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LOW TEMPERATURE MIX TESTS

- IDT Creep Compliance and Strength
  - Calculated critical cracking temperature, $T_c$

- With PG64–22
  - 15 to 25% RAP changed $T_c$ by $\sim 2^\circ$C (warmer)
  - 40% RAP changed $T_c$ by $\sim 4^\circ$C

- With PG58–28
  - 25% RAP was comparable to control
  - 40% RAP mix was $\sim 1^\circ$C warmer than control
Critical Cracking Temperatures

- Assume -22 needed to resist thermal cracking
- 12 of 29 mixes had $T_c$ warmer than -22 (“failed”)
- 3 of 5 virgin mixes “failed”
- Same for PG64–22 with 15 and 25% RAP
- With PG58–28, 1 of 5 “failed” at both RAP contents
- So, softer binder did improve failure rate but PG64–22 + RAP mixes performed comparably to virgin mixes
OBSERVATIONS AND CONCLUSIONS

Recovered Asphalt Binder

- As RAP increased, high temp grade increased 1 to 3°C
- Low temp grade increased 1 to 2°C
- Both increased, but less than expected
- PG58–28 decreased high and low grades about half a grade (3°C)
Mixture Stiffness

- As RAP increased, $E^*$ increased, especially at intermediate and high temps
  - Not in all cases
- No significant difference for mixes with PG64–22 and 0 to 25% RAP
  - Significant difference for some at 40%
- PG58–28 typically did reduce mix stiffness
  - Usually significant difference between 25 and 40% RAP
Low Temperature Properties

- $T_c$ increased 1°C for PG64–22 with up to 25% RAP
- $T_c$ increased 4°C for PG64–22 with 40% RAP compared to virgin mix
  - $T_c \sim -19$ to $-22°C$ – OK for the area
- $T_c$ with PG58–28 only 1 to 3°C lower than with PG64–22
OBSERVATIONS AND CONCLUSIONS

- Findings suggest no grade change needed for RAP contents ≤25%
- Binder grade should be one grade softer for 40% RAP mixes
- Applicable to these materials and conditions; not necessarily true elsewhere
- Review your typical materials, especially typical RAPs, to explore applicability
ACKNOWLEDGMENTS

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Questions?

Full Report