Extended Aging of RAS Mixes with Rejuvenator
An Update

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Acknowledgements

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  – Mary Ryan, Doug Herlitzka, and Steve Engber

• Mathy Construction Staff
  – John Jorgenson and Chad Lewis
Original Motivation

• Cracking is the most prominent state agency concern
  – High levels of binder replacement, especially from RAS can cause durability concerns.
  – Materials used to soften asphalt can have unintended consequences.
• These risks aren’t apparent until after long-term aging.
• Evaluate different long-term aging methods.
Background

• Current long term aging protocols in specifications
  – Binder (M320/M332): 1 PAV aging cycle.
  – Mix (R30): 5 days compacted mix aging at 85°C

• This study focuses on extended aging. Why?
  – Identify aging susceptible materials in the mix (RAS) or binder (softening additives).
  – Under current specifications most of these materials appear acceptable.
Mix Aging Study

Objectives

1. Compare aging stability of bio-based rejuvenator modified binders to conventional PG asphalt.

2. Evaluate effects of multiple aging methods and conditioning times on physical properties and composition.
Mix Aging Study

Materials

• RAS: Tear-off shingles from a commercial source in Central-WI (TOS #1)
• Asphalt: PG 58-28 and PG 52-34 sampled from MIA.
• Additives:
  – Experimental Product (EP #1)
  – Bio-based Oils (BO #1 and BO #2)
• Blends
  – PG 58-28 + 5% bio oil was used to target a final grade of PG 52-34.
### Mix Aging Study

**PG of Binder Blends**

<table>
<thead>
<tr>
<th>Blend</th>
<th>HT PG (Unaged)</th>
<th>LT PG 20hr PAV</th>
<th>LT PG 40hr PAV</th>
<th>ΔTc 20 hr PAV</th>
<th>ΔTc 40 hr PAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 52-34</td>
<td>54.0</td>
<td>-35.3</td>
<td>-32.2</td>
<td>0.5</td>
<td>-1.9</td>
</tr>
<tr>
<td>PG 52-34 + 5% EP#1</td>
<td>52.7</td>
<td>-34.2</td>
<td>-32.7</td>
<td>0.56</td>
<td>0.61</td>
</tr>
<tr>
<td>PG 52-34 + 2.5% BO#1 + 5% EP#1</td>
<td>48.3</td>
<td>-36.5</td>
<td>-35.6</td>
<td>1.6</td>
<td>0.4</td>
</tr>
<tr>
<td>PG 58-28</td>
<td>59.6</td>
<td>-29.7</td>
<td>-25.1</td>
<td>-0.2</td>
<td>-3.1</td>
</tr>
<tr>
<td>PG 58-28 + 5% BO#1</td>
<td>51.2</td>
<td>-36.5</td>
<td>-33.3</td>
<td>-0.4</td>
<td>-1.5</td>
</tr>
<tr>
<td>PG 58-28 + 5% BO#2</td>
<td>49.3</td>
<td>-36.2</td>
<td>-33.1</td>
<td>0.6</td>
<td>-0.5</td>
</tr>
</tbody>
</table>
### Mix Aging Study

#### RAS Binder Properties

<table>
<thead>
<tr>
<th>RAS Binder</th>
<th>R – value</th>
<th>HT PG</th>
<th>LT PG</th>
<th>ΔTc</th>
<th>S(60)</th>
<th>m(60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOS #1</td>
<td>6.03</td>
<td>146</td>
<td>6.0</td>
<td>-31.4</td>
<td>-25.4</td>
<td>6.0</td>
</tr>
</tbody>
</table>

- RAS AC content = 22.1%
- All mixes used in this study included 5% RAS by weight.
Mix Aging Study

Mix Design

- Mix represents a normal surface course used for intermediate traffic levels in WI.
  - Design Traffic Level: 3 million ESALs (E3), 75 gyrations for Ndes.
  - NMAS: 12.5 mm

- Aggregate Source: Granite + 25% nat. sand

- Gradation: Fine, 70% passing the #4 sieve.

- Design AC: 5.7% (19.4% binder replacement from RAS)
## Original Mix Aging Study

### Aging Methods

<table>
<thead>
<tr>
<th>Aging Method</th>
<th>Aging Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose Mix + PAV</td>
<td>As-Recovered (after 2 hrs at 135°C)</td>
</tr>
<tr>
<td></td>
<td>As-Recovered + PAV (Blending Chart)</td>
</tr>
<tr>
<td></td>
<td>As-Recovered + 2PAV</td>
</tr>
<tr>
<td>Loose Mix</td>
<td>12 hrs at 135°C</td>
</tr>
<tr>
<td></td>
<td>24 hrs at 135°C</td>
</tr>
<tr>
<td>Compacted Mix</td>
<td>5 days at 85°C (AASHTO R30) – <em>Test results pending</em></td>
</tr>
<tr>
<td></td>
<td>10 days at 85°C</td>
</tr>
<tr>
<td></td>
<td>20 days at 85°C</td>
</tr>
</tbody>
</table>
Mix Aging Study  
Description of Work

• After the prescribed aging protocol asphalt binder was extracted and recovered from mix.

• Recovered residue evaluated using:
  – DSR: 25 mm and 4mm Parallel Plate
  – Iatroscan: Determine composition

• Future work will use torsion bar modulus on compacted mix samples and aging of additional samples

NOT GOING TO SHOW DATA FROM ORIGINAL PRESENTATION, IF YOU ARE INTERESTED GO BACK AND LOOK AT THAT PRESENTATION FROM THE SEPTEMBER 2016 FALL RIVER MEETING
Mix Aging Study

What’s New

• Torsion bar modulus on 20 day and 10 day, 85°C aged compacted mix samples
  – Only will discuss 20 day aged because 10 day although showing the same trends was not aged significantly

• Looked at aging additional mixes with no RAS and RAS + additional 0.5% binder
  – Further investigation of extent to which RAS does or does not participate in the mix aging
MIX TORSION BAR TEST
≈50 mm X 12 mm X 7 mm
TESTED AT -40°C TO +40-80° DEPENDING ON MIX STIFFNESS
From data such as these we determined $G^*$ mastercurves and interconverted to relaxation modulus mastercurves and Black space plots for mixtures.
COMPARISON OF MIXTURE MODULUS AND BINDER MODULUS

MASTERCURVES @ 25°C REFERENCE TEMPERATURE

MIXTURE MODULUS IS ABOUT 1 ORDER OF MAGNITUDE GREATER THAN BINDER MODULUS
IS TESTING OF RECOVERED BINDER FROM AGED RAS MIXTURES MEANINGFUL?

• To evaluate this we looked at relaxation modulus of recovered binder from 20 day aged @ 85°C compacted mix compared to relaxation modulus of the 20 day aged mix based on torsion bar testing

• At the very least we should expect the relaxation modulus to rank order the same for the recovered binder and the mix
Relaxation Modulus of Binder Recovered from 20 day, 85°C Compacted Mix with 5% RAS and Different Binders

![Graph showing relaxation modulus (G(t)) vs. reduced time, for different binders and conditions. The graph includes lines for each condition, with corresponding identifiers and details.]
Relaxation Modulus of Compacted Mix aged 20 days @ 85°C
all mixes contained 5% RAS, different Binders and Additives were employed

Modulus results obtained using Torsion Bars tested on Dynamic Shear Rheometer, 5 specimens tested for each mix and results averaged
Slope of Torsion Bar Relaxation Modulus of 20 day, 85°C aged mix

First Derivative of the Relaxation Modulus VS Reduced Time plot

Reduced Time, Seconds, Log Scale

BETTER RELAXATION

POOR RELAXATION

Legend:
- dG(t)/dt 1531 Summary 07-05-16-BB 58-28, 5% RAS only
- dG(t)/dt 1531 Summary 1531, 07-05-16-AV, 58-28, 5% AZ RS1100, 20d85, RSS.
- dG(t)/dt 1531 Summary 1531, 07-05-16-AY, 58-28, 5% Cargill 1103, 20d85, RSS.
- dG(t)/dt 1531 Summary 07-05-16-AP 52-34, 5% RAS only
- dG(t)/dt 1531 Summary 07-05-16-AM 52-34 5% RAS, 5% sterol
- dG(t)/dt 1531 Summary 07-05-16-AS 52-34, 5% sterol, 2.5% 1103, 5% RAS, 20 d aged.
Plot of $\Delta T_c$ of recovered binder to predict the slope of mixture relaxation modulus curve

Slope of Torsion Bar Relaxation Modulus at 25°C @ 1 second

$R^2 = 0.85$

ΔTc of Recovered Binder 20 Day Aged Mix

- Slope of Relaxation Modulus @ 1 sec as Function of ΔTc of Binder recovered from 20...

- Fitted Curve
Black Space plot of @ 25°C Reference Temperature for Binder Recovered from Compacted mix Aged for 20 days at 85°C. All Mixtures Contained 5% RAS

The legend is arranged in the order in which the data is plotted from the uppermost data plot to the lower most data plot. Data for plots #1 & #2 are similar, for plots #3 & #4 are similar and for #5 & #6 are similar.
5 specimens tested for each mix and results averaged for each sample

Legend:
- AS 07-05-16-AS PG 52-34 + 5% RAS, 5% EP1, 2.5% 1103 20 Day aged
- AM 07-05-16-AM PG 52-34 + 5% RAS, 5% EP1, 20 day 85°C HR3-3
- AP 07-05-16-AP PG 52-34 + 5% RAS 20 day 85°C HR3-2
- AY 07-05-16-AY PG 58-28 + 5% RAS, 5% BO#1, 20 Day aged
- AV 07-05-16-AV PG 58-28 + 5% RAS, 5% BO#2, 20 Day aged
- BB 07-05-16-BB PG 58-28 + 5% RAS, 20 Day aged HR3-2
We believe that an unique relationship between binder recovered from the RAS containing mixes and at property measured on the mix itself supports the position that the RAS is indeed participating in the mix aging and not just functioning as Black Rock.
R-Value = F(ΔTc) for original RAS mixtures, all mixes had 5% RAS and 4.5% Virgin Binder Addition

- 58-28, 5% BO1, 5% RAS
- 58-28 + 5% RAS
- 52-34 + 5% RAS
- (58-28 + 5% BO1) 5% RAS
- 58-28 5% RAS
- 52-34 + 5% RAS
- (52-34 + 5% EP1) 5% RAS
- 58-28, 5% BO1, 5% RAS
- 52-34 + 5% RAS
- 58-28 + 5% RAS
- 58-28 + 5% EP1 + 5% RAS
- 52-34 + 5% RAS
- 52-34 + 5% RAS
- (52-34 + 5% EP1) + 5% RAS

RED CIRCLED DATA WAS MIX AGED FOR 24 HRS. AT 135°C, REST WERE AGED FOR 12 HRS. AT 135°C

y = -0.134x + 2.6106
R² = 0.947

\[ y = -0.134x + 2.6106 \]
\[ R² = 0.947 \]
Comparison of R-Value vs. $\Delta T_c$ for mixes with 5% RAS + 4.5% Virgin AC (5.1% total AC) and mixes with NO RAS and only 4.5% Virgin AC

Challenged that if the mix was deficient in AC that the same aging would produce the same results as the RAS mix.

Supposition is that RAS is only Black Rock and doesn’t participate in the mix.
Comparison of R-Value vs. ΔTc for mixes with 5% RAS + 4.5% Virgin AC (5.1% total AC) and mixes with NO RAS and only 4.5% Virgin AC

This plot shows the virgin (NO RAS/low binder) mix results paired with the same mix with RAP.
Comparison of R-Value vs. ΔTc for mixes with 5% RAS + 4.5% Virgin AC (5.1% total AC) and mixes with NO RAS and only 4.5% Virgin AC) + RAS mixes with Extra 0.5% Binder
Comparison of R-Value vs. ΔTc for mixes with 5% RAS + 4.5% Virgin AC (5.1% total AC) and mixes with NO RAS and only 4.5% Virgin AC) + RAS mixes with Extra 0.5% Binder

The 5% RAS mix + 0.5% binder merely moves the aging along the same aging line connecting the original RAS mix and the reduced binder virgin only mix.
Comparison of Colloidal Index vs. $\Delta T_c$ for mixes with 5% RAS + 4.5% Virgin AC (5.1% total AC) and mixes with NO RAS and only 4.5% Virgin AC) + RAS mixes with Extra 0.5% Binder

- y = 0.0446x + 1.9723
  R² = 0.906

- y = 0.082x + 2.1363
  R² = 0.9261

Legend:
- **Diamond**: RAS containing mixes
- **Square**: Virgin mixes 0.5% less AC
- **Circle**: 5% RAS mixes + 0.5% Extra Bitumen
Comparison of Colloidal Index vs High Temp PG Grade of Binder Recovered from Aged Mix and Binder Aged in thin films in 135°C Oven

\[ y = -38.292x + 176.77 \]
\[ R^2 = 0.9089 \]

\[ y = -31.55x + 152.04 \]
\[ R^2 = 0.8693 \]

KEY: FOR EXAMPLE 17/52 MEANS 17 g OF BINDER WAS AGED IN 135°C OVEN FOR 52 HOURS

KEY: 10d 85C MEANS BINDER WAS RECOVERED FROM MIX AGED FOR 10 DAYS AT 85C

PG 58-28 + 20% Recovered Shingle Binder
PG 58-28 + 5% RAS, Rec AC
Comparison of Colloidal Index as a Function of $\Delta T_c$ of Binder Recovered from Aged Mix and Binder Aged in thin films in 135°C Oven

CI = $1.1882 + 1.4522 \times \exp(-X/-6.8032)$

$R^2 = 0.96$

This is where we were at end of 2016
Additional Mixes & Binders Aged

• Binders were aged in PAV pans in 135°C oven to ascertain comparison to loose mix aging
  – Mass varied from 50 grams to 17 grams
  – Times varied from 52 hours to 20 days
• Loose mix aging conducted for 20 days at 95°C based on Dr. Kim’s 2016 ETG presentation
• Virgin and RAS containing mixes
• Virgin binder and binder + 20% recovered shingle binder
All 20 day aged materials were aged at 95°C, all other mixes and binders aged at 135°C

For all these materials the relationship between binder compositional changes and change in ΔTc generated a uniformly changing relationship
Summary Comments

• It appears as though RAS is participating in the mix and contributes negatively to its aging properties

• Accelerated aging at 95°C for longer periods of time yields changes in asphalt compositional properties and ΔTc (also R-value) similar to those caused by shorter term aging at 135°C
  – The goal of our work was to produce mixes and binders aged to a condition matching the aging in the surface ½ inch of the field mix
THANK YOU FOR YOUR ATTENTION

QUESTIONS OR COMMENTS
Thank You!