Oxidative Aging of Asphalt Binders in Hot Mix Asphalt Mixtures

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Introduction

• Binder aging affects nearly all critical performance aspects of HMA pavements ← *important to quantify*!

• Binders aged outside of mixtures have been frequently studied.

• Will binders aged in HMA mixtures have same engineering properties?
Research Objective

- **Quantifying Oxidation of Asphalt Binders Aged in Compacted Mixtures**
  - Others have compared aging to binder viscosity or stiffness
  - Lack sufficient aging measurements of the binder
  - Lack of previous studies specifically relating mixture properties to adequate aging measurements
Overview

Experimental Design

A. Aggregate sources: 2 (NV & CO)

B. Binders, single source: 2 (PG64-22 & PG64-28)

C. Mixture oven-aging levels: 4 (0, 3, 6 and 9 months at 140°F)
A. Aggregate sources: NV & CO

Water Abs:
NV: 2.7%
CO: 0.9%
Experimental Design

B. Binders: single base stock and supplier (Paramount Petroleum Corp.)

- Neat PG64-22
- SBS Modified PG64-28
C. **Agg. sources and binders combine to 4 different Superpave designed mixtures (6×10^6 ESALS)**

<table>
<thead>
<tr>
<th>Source ID</th>
<th>Source Location</th>
<th>Mineralogy</th>
<th>Agg. Water Abs. (%)</th>
<th>Binder Grade</th>
<th>Binder Content (% TWM)</th>
<th>App. Film Thickness (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nevada</td>
<td>Sparks</td>
<td>Rhyolite, Silica Sand</td>
<td>2.7</td>
<td>PG64-22</td>
<td>5.4</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PG64-28</td>
<td>5.2</td>
<td>9</td>
</tr>
<tr>
<td>Colorado</td>
<td>Morrison</td>
<td>Mica Gneiss, Mica Schist, Quartz Sand</td>
<td>0.9</td>
<td>PG64-22</td>
<td>4.5</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PG64-28</td>
<td>4.5</td>
<td>11</td>
</tr>
</tbody>
</table>
Experimental Design

C. 4 Mixture oven-aging levels:
- 0, 3, 6, & 9 months at 140°F
- All samples short-term aged loose 4 hrs at 275°F
- SGC Compacted Specimens
- 7±0.5% Air Voids
Experimental Plan

Virgin Aggregate

Asphalt Binder

Loose Mix

Short-term oven aging: 4 hrs at 275°F

Compacted Specimen

Long-term oven aging: 3, 6, 9 mo. at 140°F

No Aging (i.e. 0 mo.)

Dynamic Modulus, |E*|

FTIR, Carbonyl Area, CA

Mix CA

Original CA

Asphalt Research Consortium
Experimental Analysis

- CA vs Aging
- $|E^*|$ vs Aging
- $|E^*|$ vs CA
Results, Example

Carbonyl Area, CA (measurements are being done by Glover at A&M)

Wave numbers for the CA measurements between 1,650 and 1,870 cm$^{-1}$
Results, Carbonyl Area
Statistics, Carbonyl Area

\[ CA = \beta_0 + \beta_1(Age) + \beta_2(Mix) + \beta_3(Mix)(Age) \]  \[\text{Eqn 1}\]

- CA – measured Carbonyl Area;
- \(\beta_i\) – regression coefficients, \(i = 0,\ldots,3\);
- Age – months of oven aging at 140° F;
- Mix – categorical variable to differentiate the two mixtures being compared, value of 1 or 0 depending on which agg. and binder combination being considered.
Statistics, CA

\[ CA = [\beta_0 + \beta_2 (\text{Mix})] + [\beta_1 + \beta_3 (\text{Mix})] \text{ (Age)} \] [Eqn 1]

<table>
<thead>
<tr>
<th>CA vs. Age</th>
<th>Comparison I</th>
<th>Comparison II</th>
<th>Comparison III</th>
<th>Comparison IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix Variable</td>
<td>C022</td>
<td>NV22</td>
<td>C028</td>
<td>NV28</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Statistics, CA Example

\[ CA = [\beta_0 + \beta_2(Mix)] + [\beta_1 + \beta_3(Mix)] \text{ (Age)} \]  \hspace{1cm} [\text{Eqn 1}]  

Comparison I

- Mix = 0, CO22  \rightarrow  CA_{CO22} = [\beta_0] + [\beta_1] \text{ (Age)}
- Mix = 1, NV22  \rightarrow  CA_{NV22} = [\beta_0 + \beta_2] + [\beta_1 + \beta_3](\text{Age})
Statistics, CA

CA = [β₀ + β₂(Mix)] + [β₁ + β₃(Mix)] (Age)  [Eqn 1]

<table>
<thead>
<tr>
<th>Mixes Compared</th>
<th>β₂</th>
<th>P-value</th>
<th>Sig.</th>
<th>β₃</th>
<th>P-value</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO22 NV22</td>
<td>-0.0137</td>
<td>0.600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO28 NV28</td>
<td>0.0089</td>
<td>0.702</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO22 CO28</td>
<td>0.1343</td>
<td>&lt;0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NV22 NV28</td>
<td>0.1122</td>
<td>&lt;0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing Correlation Between Mixture Aging and Carbonyl Area](graph.png)

**Graph Description:**
- The graph illustrates the correlation between mixture aging (in months) and carbonyl area.
- Different mixtures (CO22, NV22) are represented by various markers.
- The x-axis represents mixture aging (in months), ranging from 0 to 10.
- The y-axis represents carbonyl area, ranging from 0.7 to 1.7.

**Legend:**
- CO22
- Reg. CO22
- CO28
- Reg. CO28
- NV22
- Reg. NV22
- NV28
- Reg. NV28
Findings, Carbonyl Area

1) CA increased linearly with Age;

2) Generally, CA was higher for PG64-22;

3) Within each binder, the intercepts were stat. the same;
   a) Aggregate source did not significantly affect short-term oxidation;

4) Oxidation rates were different between agg. sources;
   a) Agg. source, as it influences mix properties affected binder aging
Findings, Carbonyl Area

5) Within each agg., the intercepts were stat. different;
   a) Short-term aging of binders were not the same (original CA was the same)
   b) Polymer modification influences the Non-Linear Fast Rate Oxidation (short-term region)

6) Within each agg. source, after Fast Rate Oxidation, the binders aged at the same rate;
   a) Binders from same base stock (similar oxidation characteristics)
   b) Indicating Mix Characteristics Influence the rate of binder oxidation
Results, \(|E^*|\)

Nevada Mixes
Results, $|E^*|$  

Colorado Mixes
Statistics, $|E^*|$ vs. CA

$$|E^*| = \beta_4 + \beta_5(CA) + \beta_6(Mix) + \beta_7(Mix)(CA) \quad [\text{Eqn 2}]$$

- $|E^*|$ – measured Dynamic Modulus, 0.1Hz;
- $\beta_j$ – regression coefficients, $j = 4, \ldots, 7$;
- CA – measured Carbonyl Area;
- Mix – categorical variable to differentiate the two mixtures being compared, value of 1 or 0 depending on which agg. and binder combination being considered.
Statistics, $|E^*|$ vs. CA

$$|E^*| = [\beta_4 + \beta_6(Mix)] + [\beta_5 + \beta_7(Mix)](CA)$$  \[Eqn 2\]

<table>
<thead>
<tr>
<th>70 and 100°F</th>
<th>Comparison I</th>
<th>Comparison II</th>
<th>Comparison III</th>
<th>Comparison IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO22</td>
<td>NV22</td>
<td>CO28</td>
<td>NV28</td>
</tr>
<tr>
<td>Mix Variable</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

- Analysis conducted for both 70 and 100°F
Statistics, $|E^*|$ Example

\[ |E^*| = [\beta_4 + \beta_6(Mix)] + [\beta_5 + \beta_7(Mix)](CA) \]  
\[ \text{[Eqn 2]} \]

Comparison I at 70° F

- Mix = 0, CO22 \rightarrow |E^*|_{70-CO22} = [\beta_4] + [\beta_5(CA)]
- Mix = 1, NV22 \rightarrow |E^*|_{70-NV22} = [\beta_4 + \beta_6] + [\beta_5 + \beta_7](CA)
- Same model form for both 70° F and 100° F
Statistics, $|E^*|$, 70°F

\[ |E^*|_{70} = [\beta_4 + \beta_6(Mix)] + [\beta_5 + \beta_7(Mix)](CA) \]  \[\text{[Eqn 2.a]}\]

<table>
<thead>
<tr>
<th>Mixes Compared</th>
<th>$\beta_6$</th>
<th>P-value</th>
<th>Sig.</th>
<th>$\beta_7$</th>
<th>P-value</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO22 NV22</td>
<td>-67.58</td>
<td>0.255</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO28 NV28</td>
<td>-36.43</td>
<td>0.530</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO22 CO28</td>
<td>-73.79</td>
<td>0.173</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NV22 NV28</td>
<td>-104.94</td>
<td>0.119</td>
<td>NS</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing data points and regression lines](image-url)
Findings, $|E^*|$, 70°F

7) Within each binder, the intercepts were stat. the same;
   a) Agrees with CA vs Age analysis, Item 3.a

8) Within each binder, Rates of $|E^*|$ increase lower for CO;
   a) Rate of $|E^*|$ increase dependent upon mixture characteristics;

9) Within each agg., rate of $|E^*|$ increase lower for PG64-28;
   a) Supports that different binders influence the binder aging, particularly polymer modification
\[ |E^*|_{100} = [\beta_4 + \beta_6 (\text{Mix})] + [\beta_5 + \beta_7 (\text{Mix})] (\text{CA}) \quad \text{[Eqn 2.b]} \]
Findings, $|E^*|$, 100°F

10) Within each binder, Rates of $|E^*|$ increase lower for CO;
   a) Rate of $|E^*|$ increase dependent upon mixture characteristics;

11) Within each agg., the intercepts of the PG64-22 mixtures were sig. lower than the PG64-28
   a) Supports that different binders influence the binder aging, Item 9)

12) Within each agg., the rate of $|E^*|$ increase is higher with PG64-22;
   a) Supports that different binders influence the binder aging, particularly polymer modification
Conclusions

• Carbonyl indicates:
  
  — mix properties *did not affect short-term aging in loose condition*, but the binder properties do play a roll

  — mix properties *did affect long-term aging in compacted mixes*, but the binder did age at nearly the same rate with respect to time
Conclusions, cont’d

- Mixture stiffness, $|E^*|$, indicates:
  - mix properties *may affect short-term aging in loose condition* (depending on analysis temperature)
  - mix properties *did affect long-term aging in compacted mixes*
Conclusions, cont’d

- $|E^*| \text{ vs. CA}$ indicates significantly different aging characteristics between the two binder grades.

- Both the binder and the mix characteristics influence the aging of asphalt binders in mixtures.
Further/On-Going Research

- Further consideration of
  - influence of agg. properties on binder aging (Abs.)
  - mix characteristics (AV [total vs. accessible], AFT, \( P_{b\text{-eff}} \) vs. \( P_{b\text{-total}} \), etc.)

- Evaluate ext./rec. binder properties (\( G^* \), ZSV, SENB, etc.)

- Evaluate low temperature properties of aged mixes:
  - fracture temperature and stress (TSRST)
Acknowledgments

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www.arc.unr.edu

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Thank You