IMPACTS OF MIX REJUVENATORS ON PERFORMANCE

Ryan Barborak, P.E.
Asphalt Paving 42nd Annual Conference
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The Problem is...

- **Cracking**
  - Although there are many causes...traffic conditions, pavement structure, poor drainage, climate
  - Focus is on how recycled materials are used
    - Reclaimed asphalt pavement (RAP)
    - Recycled asphalt shingles (RAS)
RAP and RAS

- **Benefits**
  - Economics
  - Reduced rutting
  - Environment
  - Source of aggregate

- **Disadvantages**
  - Stiffens mix
  - Dry mixtures
  - Mixes may be more prone to cracking
RAP and RAS PG Grade Determination

Virgin
Average PG=70

RAP
Average PG=91

MWAS
Average PG=131

TOAS
Average PG=178

Courtesy of Fujie Zhou, TTI
What is the latest on recycled materials in surface mixtures?

- No recycle
  - 6 districts

- No RAS
  - 16 districts
    - Additional 2 districts without RAS producers, 1 only 1 contractor uses

- Allow RAP
  - 19 districts

- Allow RAP and RAS
  - 9 districts

Notes:
LBB does not allow RAP in SMA which is their primary surface mix
YKM most producers don't use RAS
ELP no RAS producers
ODA no RAS producers
Methods to Address Cracking

- Limit the quantity of RAP/RAS
  - Maximum recycled binder ratio
- Discount the effective asphalt content of RAP/RAS
  - TxDOT currently uses 100% effective for designing with RAP and RAS
- Use Superpave mix design procedure to allow more asphalt
  - TxDOT shift is towards using Superpave gyratory compactor
- Use softer virgin binders
  - PG 58-28
    - Consider lower temperature grade binders (e.g. PG XX-28, PG XX-34)
- Use a balanced mix design approach
  - Overlay test (cracking)
  - Hamburg wheel tracking test (rutting)
- Add rejuvenators to the mix
Rejuvenator Types

- **Bio-based**
  - Arizona Chemical, Green Asphalt Technologies, Ingevity, Cargil, Collaborative Aggregates, Sonneborn, Roadsciene

- **Aromatic extracts**
  - HollyFrontier, Reclamite

- **Re-refined waste materials**
  - Re-refined engine oil bottoms (REOB)
  - Re-refined waste fast food vegetable oil
Rejuvenator Function

- **Asphalt composition**
  - Asphaltenes (insoluble, brittle, not affected by oxidation)
  - Maltenes (oily, flexible, affected by oxidation)
  - *Aging unbalances* the ratio of asphaltenes to maltenes

- **Role of rejuvenators**
  - *Re-balance* the ratio of asphaltenes to maltenes
  - Rheological effect:
    - Lowers high temp. PG grade (DSR)
    - Softens aged binders (BBR creep stiffness, $S$)
    - Improves relaxation (BBR $m$-value)
Rejuvenator Effectiveness

- Virgin Binder PG 64-22

![Graph showing the effect of rejuvenator dosage on PG-High replacement of asphalt. The graph indicates a decrease in PG-High with increasing rejuvenator dosage, with separate lines for different rejuvenators, including REOB and aromatic extract.]
- Virgin Binder PG 64-22

- REO
- B
- Aromatic extract
- Bio-rejuvenators

Replacement of Asphalt
Bio-Based, Aromatic Extract, and REOB vs. ΔTc

![Graph showing the comparison of Bio-rejuvenators, Aromatic extract, and REOB with ΔTc values.](image)

- **Bio-rejuvenators**
- **Aromatic extract**
- **REOB**
Four Step Design Process

- Step 1 – Select rejuvenator
- Step 2 – Select rejuvenator dosage range (binder testing)
- Step 3 – Obtain balanced mix design data (mix testing)
- Step 4 – Select dosage based on engineering judgement
Step 1 – Select Rejuvenator

- Arizona Chemical/Kraton
- Manchester Pavement Solutions
- Ingevity
- Cargill
- Collaborative Aggregates
- Sonneborn
- Roadscience
- Texas Road Recyclers
- HollyFrontier
- Reclamite
Step 2 – Select Rejuvenator Dosage Range

- Three aspects:
  - Rheological properties:
    - PG high grade requirement
    - PG low grade requirement
  - Binder quality requirement
    - $\Delta T_c$ requirement
  - Aging characteristics of the blended binder
    - Similar (or even better) aging characteristics of virgin binder

- Example: FM468
  - A new construction in Laredo District, Texas;
  - Very heavy oil truck traffic
  - Hot weather all year long
Step 2 – Select Rejuvenator Dosage Range

- Example: Original Binder Specified = PG 70-22
- Proposed: 30% RAP (PG 94-10) and PG 64-22
  - Extract and combine asphalt from RAP with virgin binder at proposed binder ratios according to the mix design
- Add rejuvenator until DSR high temperature grade and BBR low temperature grade match original specified binder: PG 70-22
  - Dosage range = 1.1% – 3.7%

![Graph showing rejuvenator dosage against low and high temperature PG grades with linear equations and correlation coefficients.]
Step 2 – Select Rejuvenator Dosage Range

- Binder quality requirement: $\Delta T_c \geq -6^\circ C$
  - Minimum rejuvenator dosage: 1.4%
Step 2 – Select Rejuvenator Dosage Range

- Check aging characteristics
  - Glover-Rowe parameter
  - Goal is to match aging characteristics of virgin binder
### Step 2 – Select Rejuvenator Dosage Range

- **Summary table for rejuvenator dosage range: binder testing**
  - **R1: 1.8-3.7%**
  - **R2: 1.7-4.8%**
  - **R3: 2.6-3.6%**

<table>
<thead>
<tr>
<th>Blend</th>
<th>Rejuvenator</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PG High =70</td>
<td>PG Low =-22</td>
<td>ΔTc=5</td>
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<tr>
<td>70%PG64-22 + 30%PG94-10 RAP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>3.7%</td>
<td>1.1%</td>
<td>1.4%</td>
</tr>
<tr>
<td>R2</td>
<td>4.8%</td>
<td>1.7%</td>
<td>1.4%</td>
</tr>
<tr>
<td>R3</td>
<td>3.6%</td>
<td>0.7%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>
Step 3 – Obtain Data from Balanced Mix Design

- Perform Hamburg wheel tracking tests and Overlay tests on mix produced in the laboratory
  - Overlay requirements are determined by Overlay program (TxACOL)
  - New constructions are determined by TxME pavement design
  - Cracking resistance index is project specific (traffic, climate, pavement structure, etc.)
Step 4 – Select Rejuvenator Dosage

- Use data gathered from Steps 1-3 to select rejuvenator dosage
  - Use engineering judgement to decide actual dosage
    - Higher rejuvenator dosage in areas more prone to cracking
    - Lower rejuvenator dosage in areas less prone to cracking
  - Factors include:
    - Traffic conditions
      - Interstate/high traffic levels
        » May consider lower rejuvenator dosage
      - FM roads with less traffic levels
        » May consider higher rejuvenator dosage
    - Pavement structure
    - Climate
Test Sections

- Tyler District, SH31, included 5 test sections, 6/14/2014
- Laredo District, FM468, included 5 test sections, 9/15/2015
- Houston District, FM1463, included 4 test sections, 7/16/2016
- San Angelo, US67, included 5 test sections, 4/12/2017
Dense Grade Type C Mix Designs:
- Virgin mix, PG 70-22, AC = 4.5%
- 10% RAP, 5% RAS, PG 64-22, AC = 4.6%
- 10% RAP, 5% RAS, PG 64-22, 2.6% R01, AC = 4.5%
- 10% RAP, 5% RAS, PG 64-22, 3.7% R02, AC = 4.7%
- 10% RAP, 5% RAS, PG 64-22, 2.0% R03, AC = 4.9%

Reflective cracking was observed on all sections

After 2.5 years, cracking was similar with all sections
Lessons learned

- Dosage of rejuvenators may have been too conservative
- Two lift overlay was constructed over jointed concrete pavement
  - Crack attenuating mix (CAM) was placed before winter and had previously cracked prior to placing test sections
  - Solution – Construct both sections at the same time
Laredo District – FM468

- **Superpave Type C Mix Designs**
  - Virgin mix, PG 70-22, AC =6.1%
  - 30% RAP, PG 64-22, AC = 6.3%
  - 30% RAP, PG 64-22, 3.0% R1, total AC = 6.3%
  - 30% RAP, PG 64-22, 3.2% R2, total AC = 6.3% (accidentally removed)
  - 30% RAP, PG 64-22, 2.2% R3, total AC = 6.3%

- **No cracking; no visible rutting, although heavy trucks**

Oct. 9, 2017
Houston District – FM1463

- Dense Grade Type D Mix Designs
  - 17% RAP, 3% RAS, PG 64-22, AC = 5.2%
  - 17% RAP, 3% RAS, PG 64-22, 3.5% RR1, AC = 5.2%
  - 17% RAP, 3% RAS, PG 64-22, 4.0% RR2, AC = 5.2%
  - 17% RAP, 3% RAS, PG 64-22, 7.5% RR3, AC = 5.2%

- Overall good: No rutting but a few fine longitudinal cracks were spotted on Jan. 8, 2018.
San Angelo District – US67

- **Dense Grade Type C Mix Designs**
  - 13% RAP, PG 64-22, AC = 5.3%
  - 21% RAP, PG 64-22, AC = 5.3%
  - 21% RAP, PG 64-22, 3.0% RRR1, AC = 5.3%
  - 21% RAP, PG 64-22, 3.0% RRR1, AC = 5.3%
  - 21% RAP, PG 64-22, 11.0% RRR1, AC = 5.3%

- **No rutting; no cracking**

July 3, 2017
Conclusions

- Rejuvenators have been shown to improve cracking resistance of RAP/RAS mixes in the laboratory.

- Use of rejuvenators may impact lab molded density and compaction effort in the field:
  - Consider changing lab molded density requirements/decrease number of gyrations.
  - Roller patterns will need to be adjusted (less compaction effort).

- Too early to determine their effectiveness in the field:
  - No problems were encountered with meeting air void requirements.
  - Difficult to know cost savings:
    - Performance based (more service life).
    - Will allow use of more recycled materials.

- Continuation of monitoring field test sections is needed.
Questions
GAINING PERFORMANCE WITH RECYCLING AGENTS

March 12, 2018

Grant Wollenhaupt
Vice President of Strategy & Innovation
Superior Bowen
Benchmarking

Let’s Set Some Realistic Expectations Here
Less Like
More Like
Objective

TO LEARN THE BASICS or JUST ENOUGH TO ASK QUESTIONS
Oil

 Totally not a politically loaded word...
Oil
Oil
Oil
Oil?

PLASTIC IS MADE OF OIL

OIL IS MADE OF DINOSAURS
PLASTIC DINOSAURS ARE MADE FROM REAL DINOSAURS
Oil
## What’s in a Barrel of Crude Oil?

### Crude Oil Types

<table>
<thead>
<tr>
<th>Type</th>
<th>Characteristics</th>
<th>Yields</th>
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</thead>
<tbody>
<tr>
<td><strong>Light Sweet</strong></td>
<td>&gt; 34 API Gravity</td>
<td>32%</td>
</tr>
<tr>
<td>(e.g. WTI, LLS, Brent)</td>
<td>&lt; 0.7% Sulfur</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>35% Demand</td>
<td>35%</td>
</tr>
<tr>
<td></td>
<td>Most Expensive</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Medium Sour</strong></td>
<td>24 – 34 API Gravity</td>
<td>24%</td>
</tr>
<tr>
<td>(e.g. Mars, Arab Light, Arab Medium, Urals)</td>
<td>&gt; 0.7% Sulfur</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td>50% Demand</td>
<td>48%</td>
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<tr>
<td></td>
<td>Less Expensive</td>
<td>2%</td>
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<tr>
<td><strong>Heavy Sour</strong></td>
<td>&lt; 24 API Gravity</td>
<td>1%</td>
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<tr>
<td>(e.g. Maya, Cerro Negro, Cold Lake, Western Canadian Select)</td>
<td>&gt; 0.7% Sulfur</td>
<td>1.5%</td>
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<tr>
<td></td>
<td>15% Demand</td>
<td>2.1%</td>
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<tr>
<td></td>
<td>Least Expensive</td>
<td>63%</td>
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</table>

### 2006 U.S. Production

- **8%** Refinery Gases
- **49%** Gasoline RFG
- **33%** Conventional CARB Premium
- **33%** Distillate Jet Fuel Diesel Heating Oil
- **10%** Heavy Fuel Oil & Other

Source: U.S. Refiner Production

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Refineries upgrade crude oil to higher value products.
Asphalt
Binder is Different...

• Performance Grading: 64-22, 58-28
  • Think of it more 64 -22
• Expanding the PG range: 64-28, 70-22, 58-34
  • That’s modification
Modifiers

To accent or augment performance

Cost savers
Why We Modify

- Performance
  - Stripping (TSR, Hamburg)
  - Rutting (Hamburg)
  - Cracking (SCB, DCT, TSRST)
  - Aging
- Cost
- Environmental Benefit
Types of Modification

- Stripping
  - Hydrated Lime
  - Liquid Anti-Strips
- Rutting
  - SBS
  - GTR
- Recycled Materials
  - RAP
  - RAS
Recycling Agents

- Pig Sh*t
- Plant-Based
  - Tall Oil
  - Vegetable Oil
- Petroleum Based
  - Flux
  - Fuel Oils
  - REOB
We May Have a Problem

T5RC with 0% RAP  PG78-20
T5RC with 27% RAP/3% RAS  PG90-12
Evaluation

You Can’t Just Swipe Left or Right for Looks

That’s a Tinder Joke, Folks
What to Look For

• Safety
  • Environmental
• Ease of Use
• Performance
• Cost
Your Nose Knows
Nobody Likes Melting
Devastatingly Deadly to Aquatic Life
How to Get the Sauce on the Rocks
An Argument Against Old Cucumbers
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<th>RTFO</th>
<th>PAV</th>
<th>RTFO Effect</th>
<th>PAV Effect</th>
<th>Total Age Effect</th>
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<tr>
<td>Virgin 64-22 8-30-12</td>
<td>-30.39</td>
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<td>16%</td>
<td>18%</td>
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<td>Virgin w/ 5% Product A</td>
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<td>-32.41</td>
<td>-29.11</td>
<td>5%</td>
<td>10%</td>
<td>15%</td>
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<tr>
<td>Virgin w/ 8% Product A</td>
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<td>-35.01</td>
<td>-31.51</td>
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<td>13%</td>
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<td>10%</td>
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<td>-33.22</td>
<td>-30.11</td>
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<td>9%</td>
<td>14%</td>
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<td>7%</td>
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<td>Virgin w/ 10% Product B</td>
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<td>6%</td>
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<td>6%</td>
<td>8%</td>
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<td>Virgin w/ 8% Product C</td>
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<td>-34.77</td>
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<td>6%</td>
<td>15%</td>
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<td>Virgin w/ 10% Product C</td>
<td>-45.29</td>
<td>-37.85</td>
<td>-35.91</td>
<td>16%</td>
<td>5%</td>
<td>21%</td>
</tr>
</tbody>
</table>
When You Don’t Want What You Ask For

T5RC with 0% RAP           PG78-20
T5RC with 27% RAP/3% RAS    PG90-12
When You Don’t Want What You Ask For

T5RC with 0% RAP          PG78-20
T5RC with 27% RAP/3% RAS   PG90-12

Add Rejuvenator
When You Don’t Want What You Ask For

T5RC with 0% RAP  PG78-20
T5RC with 27%RAP/3% RAS  PG90-12

Add Rejuvenator

T5RC WITH 27%RAP/3% RAS  PG75-23
T5RC WITH 25%RAP/5% RAS  PG81-22
Performance Testing

All for Naught Without a Proper Baseline
Hamburg
Illinois Flexibility Index Test IFIT
Disc-Shaped Compact Tension Test DCT(T)
### Obligatory Data Page

<table>
<thead>
<tr>
<th></th>
<th>190 C</th>
<th>125 SMA I-435</th>
<th>095 SMA I-435</th>
<th>T5 City Overlay 40R</th>
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<tbody>
<tr>
<td>Virgin AC PG</td>
<td>64-22</td>
<td>64V-22 GTR</td>
<td>64V-22 GTR</td>
<td>52-34</td>
<td>58-28</td>
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<tr>
<td>Virgin AC %</td>
<td>3.50%</td>
<td>6.50%</td>
<td>6.00%</td>
<td>2.60%</td>
<td>1.50%</td>
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<tr>
<td>Additive %</td>
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<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
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<td>Recycle AC %</td>
<td>1.50%</td>
<td>0.00%</td>
<td>0.00%</td>
<td>2.00%</td>
<td>2.90%</td>
</tr>
<tr>
<td>Total AC %</td>
<td>5.00%</td>
<td>6.50%</td>
<td>6.00%</td>
<td>4.60%</td>
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<tr>
<td>Air Voids</td>
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<td>4.80%</td>
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<td>2.70%</td>
<td>2.00%</td>
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<tr>
<td>Rut Depth (mm)</td>
<td>3.19</td>
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<td>Passes</td>
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<td>DCT (J/m²)</td>
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<td>714</td>
<td>626</td>
<td>347</td>
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<td>Continuous Grade</td>
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<td>72.1-26.1</td>
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### Ranking

<table>
<thead>
<tr>
<th></th>
<th>190 C</th>
<th>095 SMA I-435</th>
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<td>1</td>
<td>3</td>
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<td>Average</td>
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<td><strong>1.7</strong></td>
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<tr>
<td>Price</td>
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<td>4</td>
<td><strong>2</strong></td>
<td><strong>1</strong></td>
</tr>
</tbody>
</table>
Elementary Grant: The road to hell is paved with good intentions
High School Grant: The road to heaven is also paved with good intentions
College Grant: The vast majority of roads are paved with good intentions
Contractor Grant: Good intentions are low caliber roadbuilding materials
Resources
Resources

• AAPT
• NCAT
• NAPA, APA, SAPAs
• CMTG (Kansas City)
• Manchester Pavement Solutions
Questions?

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