Recycled Plastic in Asphalt Binder and Mixtures

Presented By:

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Rutgers University
Acknowledgements

- Asphalt Binder: Nick Cytowicz, Chris Ericson
- Funding provide by University Transportation Research Center (UTRC) grant
Recycled Plastic in HMA

- Obvious interest in finding a means to reduce landfilling of used plastic
  - Limited alternative uses
- NAPA asked if recycled plastic could be incorporated within HMA
  - Recycled rubber tires
  - Recycled asphalt shingles
  - Need to make sure pavements do not become linear landfills!
Some general issues to consider;

- **Consistency & Handling**
  - Plastic waste stream highly variable
    - Melting points ≈212°F to ≈500°F
    - Differences in impact on asphalt performance

- **Micro-plastics**
  - Literature shows majority of field projects have used recycled plastics with a dry process
  - Can micro-plastics be generated during production? Milling?

(Nature, 2021)
Some efforts in plastic industry to pelletize and process different waste streams

- Provides level of sorting and consistency
- Volume reduction & transport ease

(Plastics Industry Assoc., NEMO Meeting, 2019)
Recycled Plastic in HMA

- Study evaluated “processed” recycled plastic material of European company
  - MR6 – “complex arrangement of polyolefins”
    - Bags, electrical cable coating, food packaging, crates/boxes, outdoor furniture
  - MR8 – “thermoplastic polymer”
    - Sports equipment, CD/DVD’s, drinking bottles, car parts, toys (LEGO’s)
  - MR10 – “co-block polymer”
    - PVC, Teflon, injection molding
Research workplan

- Asphalt binder testing
  - Used to determine “optimum” dosage
  - Separation was of major importance
  - High temperature
    - MSCR, PG grading
  - Intermediate temperature
    - DENT, Glover-Rowe, Loss Tangent
  - Low temperature
    - PG grading, ΔTc, ABCD
  - Original, RTFO, 20 Hr PAV, 40 Hr PAV
Research workplan

- Asphalt mixture testing
  - Use “optimum” plastic and dosage in a wet process
  - Use a product in the dry process
  - Stiffness
    - $E^*$
  - Rutting
    - APA, Hamburg, Flow Number, HT-IDT
  - Cracking
    - Overlay Tester, IDEAL-CT, SCB FI, Flexural Beam, DC(T)
  - Moisture Damage
    - TSR and Hamburg
  - Short-term and Long-term conditioned
Phase 1 – Asphalt Binder
Asphalt Binder Testing

- Binders prepared using high shear mixer
  - 165°C for 4 hours (as per manufacturer rec.)
    - Slotted disintegrating head on Silverson mixer
  - No crosslinker or compatibilizer used
  - Dosage rates of 3, 6, 9% by total weight of asphalt binder
  - PG58-28 & PG64-22
Asphalt Binder Testing

- **Separation (ASTM D7173)**
  - Will the modifier separate from the asphalt binder
    - Pour 50 grams of blended binder in “cigar tube” and seal
    - Maintain vertical in oven for 48 hours @ 163°C
    - Remove from oven & place vertically in freezer (0 to -20°C) for greater than 4 hrs
  - Remove and cut into 1/3 – place upper and lower 1/3 in container, heat and pour out contents
  - Traditionally used with softening point
    - High temperature DSR
Asphalt Binder Testing

- Separation
  - MR6 showed greatest potential for separation
  - MR8 showed lowest potential (comparable to base binders)
## Asphalt Binder Testing

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<thead>
<tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td>135°C 165°C</td>
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<td>% Rec</td>
<td>Stiffness (%)</td>
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<td>64-22</td>
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## Asphalt Binder Testing

### MR6 (polyolefins)
- Gain high temperature stiffness
- Lose m-value (relaxation)
- Increased viscosity

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### Asphalt Binder Testing

- **MR8** (thermoplastic)
  - No change in high temp
  - Slight improvement in Int. & low temp
  - No significant change in viscosity

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- **Dosage Rate:**
  - 0% (No change), 3%, 6%, 9%
- **Rotational Viscosity:**
  - 135C and 165C in Pa s
- **High Temperature PG Grade:**
  - Original, RTFO, MSCR @ 64C, Jnr (1/kPa), % Rec
- **Intermediate Temp PG Grade:**
  - Stiffness (S), m-Value, ΔTc
## Asphalt Binder Testing

- **MR10** (co-block polymers)
  - Gain high temperature stiffness
  - Lose m-value (relaxation)
  - Increased viscosity

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Asphalt Binder Testing

- Glover-Rowe Parameter

\[
\frac{G'}{\eta'} = \frac{|G^*| \cdot (\cos \delta)^2 \cdot \omega}{\sin \delta}
\]

Open symbols = Original
Gray filled = RTFO
Filled = 20 hr PAV

\[G^* @ 15^\circ C, 0.005 \text{rad/s (Pa)}\]

Phase Angle (degrees)
Crack Warning
Crack Limit
3% MR6
6% MR6
9% MR6
64-22

\[G^* @ 15^\circ C, 0.005 \text{rad/s (Pa)}\]

Phase Angle (degrees)
Crack Warning
Crack Limit
3% MR8
6% MR8
9% MR8
64-22

\[G^* @ 15^\circ C, 0.005 \text{rad/s (Pa)}\]

Phase Angle (degrees)
Crack Warning
Crack Limit
3% MR10
6% MR10
9% MR10
64-22
Asphalt Binder Testing

- Double Edge Notched Tension (DENT)
  - Measure of asphalt binder’s ductility
  - Conducted at 25C
  - Compared crack tip opening displacement (CTOD)
Asphalt Binder Testing

- **Asphalt Binder Cracking Device (ABCD)**
  - The ABCD determines the critical cracking temperature due to thermally induced stress
  - Asphalt binder poured between an invar and latex mold to form a ring
  - Chamber cools the specimens at -20°C per hr
  - Strain gauge determines when “cracking” occurs; specimen temperature when this occurs is determined as $T_{cr}$
  - NCHRP 9-60 recommends to use in conjunction with $\Delta T_c$

![Graph showing fracture toughness and age hardening/relaxation properties with pass/fail criteria](image)
Asphalt Binder Testing

- **ABCD Testing Results**

  - **Recycled Plastic Modified**
    - Open = 3%; Gray = 6%; Solid = 9%

  ![Graph showing ABCD Testing Results](image)

  - **BBR-Based Low Temperature PG Grade**
    - **Stiffness**
    - **m-value**
    - $R^2 = 0.7649$
    - $R^2 = 0.4326$

  ![Graph showing BBR-Based Low Temperature PG Grade](image)

  - **Continuous Low Temperature PG Grade**
    - $y = 0.5994x - 14.891$
    - $R^2 = 0.8568$

  ![Graph showing Continuous Low Temperature PG Grade](image)

- **Recycled Plastic Modified**
  - 58-28
  - 58-28 + MR6
  - 58-28 + MR8
  - 64-22
  - 64-22 + MR6
  - 64-22 + MR8
  - 64-22 + MR10
  - 76-22
Asphalt Binder Conclusions

- The MR8 (Thermoplastic) resulted in the better performance
  - Little to no change in HT; slight improvement in LT; lower potential to separate; best for “fatigue” analysis
- MR6 (PP/PE) pulled PG grade warmer and separated
- MR10 (Co-block) pulled PG grade warmer but not as bad for separation
Phase 2 – Mixture Study
Mixture Study

- Wet Process
  - Selected MR8 at 6% to 9% by total weight of binder based on binder results
- Dry Process
  - Selected MR6 at 1% by weight of mix
  - Used dry in other projects (VTRC, 2021)
- 9.5mm NMAS, Trap Rock aggregate
  - 6.1% asphalt content
  - No RAP
  - VMA = 17.1%
- Short-term (4 hrs, 135C) and Long-term Conditioned (24 hrs, 135C)
Rutting evaluated using:
- Asphalt Pavement Analyzer (64°C)
- Hamburg (50°C)
- High Temperature IDT (44°C)
- AMPT Flow Number (54°C)

Mixtures were only conditioned for short term conditioning
Rutting Results

**APA Rutting (mm)**
- PG64-22: 3.4
- PG76-22: 1.54
- 6% MR8: 2.73
- 9% MR8: 2.13
- MR6 Dry: 1.4

**Hamburg Rutting (mm)**
- PG64-22: 7.48
- PG76-22: 1.69
- 6% MR8: 4.67
- 9% MR8: 3.02
- MR6 Dry: 1.28

**HT-IDT (psi)**
- PG64-22: 40
- PG76-22: 67.7
- 6% MR8: 37.6
- 9% MR8: 47.7
- MR6 Dry: 53.2

**Flow Number (cycles)**
- PG64-22: 280
- PG76-22: 2703
- 6% MR8: 322
- 9% MR8: 386
- MR6 Dry: 3454

**Notes:**
- 64S-22 < 7.0 mm
- 64E-22 < 5.0 mm
- 64S-22 > 23.0 psi
- 64E-22 > 47.0 psi

*Source: NCHRP Report 714*
Fatigue Cracking Results

SCB FI

<table>
<thead>
<tr>
<th>SCB Flexibility Index @ 25C</th>
<th>PG64-22</th>
<th>PG76-22</th>
<th>6% MR8</th>
<th>9% MR8</th>
<th>MR6 Dry</th>
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</thead>
<tbody>
<tr>
<td>STOA 135°C, 24 Hrs</td>
<td>14.6</td>
<td>7</td>
<td>9.2</td>
<td>872</td>
<td>7.6</td>
</tr>
</tbody>
</table>

IDEAL-CT

<table>
<thead>
<tr>
<th>IDEAL-CT Index</th>
<th>PG64-22</th>
<th>PG76-22</th>
<th>6% MR8</th>
<th>9% MR8</th>
<th>MR6 Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>STOA 135°C, 24 Hrs</td>
<td>166.8</td>
<td>169.2</td>
<td>159.5</td>
<td>158.9</td>
<td>150.6</td>
</tr>
</tbody>
</table>

OT

<table>
<thead>
<tr>
<th>Overlay Tester (cycles)</th>
<th>PG64-22</th>
<th>PG76-22</th>
<th>6% MR8</th>
<th>9% MR8</th>
<th>MR6 Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>STOA 135°C, 24 Hrs</td>
<td>1122</td>
<td>724</td>
<td>790</td>
<td>869</td>
<td>441</td>
</tr>
</tbody>
</table>

DC(T)

<table>
<thead>
<tr>
<th>DC(T) Fracture Energy (J/m²)</th>
<th>PG64-22</th>
<th>PG76-22</th>
<th>6% MR8</th>
<th>9% MR8</th>
<th>MR6 Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>STOA 135°C, 24 Hrs</td>
<td>758.2</td>
<td>792.7</td>
<td>809.3</td>
<td>828.3</td>
<td>791.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DC(T) Fracture Energy (J/m²)</th>
<th>PG64-22</th>
<th>PG76-22</th>
<th>6% MR8</th>
<th>9% MR8</th>
<th>MR6 Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>STOA 135°C, 24 Hrs</td>
<td>559</td>
<td>626.4</td>
<td>723.7</td>
<td>722.2</td>
<td>547.3</td>
</tr>
</tbody>
</table>
Fatigue Cracking Results – Flexural Beam

1,000,000
10,000,000
1,000,000
10,000,000

Flexural Fatigue Life (cycles)

Tensile Strain (micro-strain)

64-22 STOA
76-22 STOA
6% MR8 STOA
9% MR8 STOA
Dry MR6 STOA

64-22 LTOA
76-22 LTOA
6% MR8 LTOA
9% MR8 LTOA
Dry MR6 LTOA
Moisture Damage Potential

- No mix showed an inflection point during Hamburg testing.

<table>
<thead>
<tr>
<th></th>
<th>PG64-22</th>
<th>PG76-22</th>
<th>6% MR8</th>
<th>9% MR8</th>
<th>MR6 Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength Ratio (%)</td>
<td>82.2</td>
<td>81.9</td>
<td>85.4</td>
<td>97.3</td>
<td>79.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>PG64-22</th>
<th>PG76-22</th>
<th>6% MR8</th>
<th>9% MR8</th>
<th>MR6 Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength (psi)</td>
<td>110.3</td>
<td>134.2</td>
<td>139.2</td>
<td>169.9</td>
<td>107.8</td>
</tr>
</tbody>
</table>

- Wet 64-22  | 110.3 | 134.2 | 139.2 | 169.9 | 107.8 | 126.2 | 97.5 | 100.3 | 150.3 |
- Dry 76-22  |       |       |       |       |       |       |      |       |       |
- Wet 6% MR8 |       |       |       |       |       |       |      |       |       |
- Dry 9% MR8 |       |       |       |       |       |       |      |       |       |
- Wet MR6 Dry|       |       |       |       |       |       |      |       |       |
- Dry MR6 Dry|       |       |       |       |       |       |      |       |       |
Moisture Damage Potential

MR8 (Wet Process; 9% by Wt. of Binder)

MR6 (Dry Process; 1% by Wt. of Mix)
Other Considerations
Inclusion of plastic will impact the volumetrics of your design and production

- Statistically significant when using the dry process
- Need to take into account for Gmm and Gsb

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Gmm (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>64-22</td>
<td>2.670</td>
</tr>
<tr>
<td>76-22</td>
<td>2.670</td>
</tr>
<tr>
<td>6% MR8</td>
<td>2.683</td>
</tr>
<tr>
<td>9% MR8</td>
<td>2.682</td>
</tr>
<tr>
<td>1% Dry MR6</td>
<td>2.628</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Gsb (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Process</td>
<td>2.964</td>
</tr>
<tr>
<td>Dry Process</td>
<td>2.897</td>
</tr>
</tbody>
</table>
Solvent Extraction

- Recycled plastic remaining as part of aggregate
  - Some will float during washed gradation
Recycled plastic will come up as mass loss in dry process
Will need to include in correction factor (similar to fibers in SMA and OGFC)
  - Aggregate correction factor was 0.55%
    - Control: 6.14% loss
    - Dry MR6: 7.06% loss
The type of recycled plastic will significantly impact asphalt performance

- Wet process vs Dry process?
- Selection of plastic type?

Moving forward in NJ, pilot proposed

- Running through refinery
- Enough to supply ≈ 3,000 mix tons of HMA
  - 3% MR8 ≈ 9,000 lbs of recycled plastic (4.5 tons)
  - 4.5% MR8 ≈ 13,500 lbs of recycled plastic (6.75 tons)
  - 6% MR8 ≈ 18,000 lbs of recycled plastic (9 tons)
Thank you for your time! Questions?

BE CAREFUL WHEN YOU ONLY READ CONCLUSIONS...

Reference: The Anscombe's quartet, 1973

Designed by @YLMSportScience

THOSE FOUR DATASETS HAVE IDENTICAL MEANS, VARIANCES & CORRELATION COEFFICIENTS

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