Impact of Emulsion Type on Cold-in-Place Recycled (CIR) Asphalt Mixtures

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Acknowledgment

• Nevada Department of Transportation

• Ergon Asphalt & Emulsions.
Background

• CIR: a process that has successfully been used for many years.
  • Existing asphalt material is reused in place.
  • Material mixed in-place without the application of heat.

• Regardless of its good performance & positive sustainability, the performance characteristics of CIR have not been developed.

• The Nevada Department of Transportation has long used CMS-2S emulsion for CIR projects.

• Observed difference in CIR performance with changing emulsion technology prompted assessment of CIR properties.
Objectives

• Evaluate the impact of asphalt emulsion type on the properties of CIR mixtures.
  • Superpave Design of CIR Mixtures.

• Engineering Property: Dynamic Modulus.

• Performance Characteristics.
  • Rutting.
  • Fatigue cracking.
  • Reflective cracking.
## Asphalt Emulsions Used in Research

<table>
<thead>
<tr>
<th>Asphalt Emulsion</th>
<th>Asphalt Residue (%)</th>
<th>True High Grade (°C)</th>
<th>True Intermediate Grade (°C)</th>
<th>True Low Grade (°C)</th>
<th>S-controlled</th>
<th>m-controlled</th>
<th>True Grade of Asphalt Residue</th>
<th>Superpave PG of Asphalt Residue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A: CMS-2S</td>
<td>65</td>
<td>55.2</td>
<td>13.2</td>
<td>-34.6</td>
<td>-35.9</td>
<td>55.2-34.6</td>
<td>52-34</td>
<td></td>
</tr>
<tr>
<td>Type B: Latex-Modified</td>
<td>72</td>
<td>68.1</td>
<td>20.1</td>
<td>-28.5</td>
<td>-28.7</td>
<td>68.1-28.5</td>
<td>64-28</td>
<td></td>
</tr>
<tr>
<td>Type C: Polymer-Modified</td>
<td>76</td>
<td>68.3</td>
<td>22.3</td>
<td>-30.2</td>
<td>-28.9</td>
<td>68.3-28.9</td>
<td>64-28</td>
<td></td>
</tr>
<tr>
<td>Type D: Rubber-Modified</td>
<td>63</td>
<td>59.4</td>
<td>16.6</td>
<td>-32.1</td>
<td>-31.1</td>
<td>59.4-31.1</td>
<td>58-28</td>
<td></td>
</tr>
</tbody>
</table>
RAP Material: Gradation & Binder

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>% Passing Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inch (25 mm)</td>
<td>100</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>30–65</td>
</tr>
</tbody>
</table>

**True Grade**

<table>
<thead>
<tr>
<th>True Grade</th>
<th>PG</th>
</tr>
</thead>
<tbody>
<tr>
<td>86.1-16.6</td>
<td>82-16</td>
</tr>
</tbody>
</table>
Superpave Mix Design: CIR

• Mix samples at: 2.5, 3.0, 3.5, and 4.0% emulsion by dry weight of RAP
• Lime slurry: 6.0% (by dry mass of milled materials)
• Measure $G_{mm}$ at emulsion content of 3.0%
• Calculate $G_{se}$
• Calculate $G_{mm}$ at others assuming constant $G_{se}$
Superpave Mix Design: CIR

- Compact 2 replicates to $N_{\text{design}}$ & measure $G_{mb}$:
  - Perforated mold.
  - $N_{\text{design}} = 75$ (graded RAP).
  - Sample size: 150mm dia. x 115±5mm height.

- Curing of extruded CIR mix sample:
  - 140°F for 24 hrs for volumetric properties.
  - 140°F for 48 hrs for $E^*$ & Performance properties.

- Measure $G_{mb}$ using ASTM D1188 parafilm.
Optimum Emulsion Content (OEC)

- Air Voids at $N_{design} = 13\pm1\%$.
- Sample Height: 115±5mm.
- Minimum dry TS at 77°F: 50 psi.
- Minimum TSR: 70% per AASHTO T 283 with 1 F-T cycle.
Optimum Emulsion Content (OEC) & Moisture Sensitivity

<table>
<thead>
<tr>
<th>Asphalt Emulsion</th>
<th>Lime Slurry (%)</th>
<th>OEC (%)</th>
<th>Avg Dry TS @77°F (psi)</th>
<th>Avg Moisture-Conditioned TS @77°F (psi)</th>
<th>TSR @77°F (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A: Standard CMS-2S</strong></td>
<td>6.0</td>
<td>4.0</td>
<td>52</td>
<td>40</td>
<td>77</td>
</tr>
<tr>
<td><strong>B: Latex-Modified</strong></td>
<td>6.0</td>
<td>3.0</td>
<td>57</td>
<td>45</td>
<td>79</td>
</tr>
<tr>
<td><strong>C: Polymer-Modified</strong></td>
<td>6.0</td>
<td>2.5</td>
<td>76</td>
<td>60</td>
<td>79</td>
</tr>
<tr>
<td><strong>D: Rubber-Modified</strong></td>
<td>6.0</td>
<td>4.0</td>
<td>56</td>
<td>43</td>
<td>77</td>
</tr>
</tbody>
</table>
Comparison of Dynamic Modulus E*

Emulsion A: CMS-2S
OEC = 4.0%
PG 52-34

Emulsion B: LM
OEC = 3.0%
PG 64-28

Emulsion C: PM
OEC = 2.5%
PG 64-28

Emulsion D: RM
OEC = 4.0%
PG 58-28
Comparison of Dynamic Modulus $E^*$

$E^*$ @ 68°F, 10Hz (ksi)

- Type A
- Type B
- Type C
- Type D

$E^*$ @ 104°F, 10Hz (ksi)

- Type A
- Type B
- Type C
- Type D

Emulsion A: CMS-2S
OEC = 4.0%
PG 52-34

Emulsion B: LM
OEC = 3.0%
PG 64-28

Emulsion C: PM
OEC = 2.5%
PG 64-28

Emulsion D: RM
OEC = 4.0%
PG 58-28
Comparison of Rutting Resistance: HWTT

- Performed at OEC at 13±1% air voids.
- Performed at 50°C (122°F).
- Failure criteria: 12.5 mm max rut depth & 20,000 cycles to failure.
Comparison of Rutting Resistance: Repeated Load Triaxial Test @ High Temp.

<table>
<thead>
<tr>
<th>Permanent Deformation (%)</th>
<th>Number of Load Repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01%</td>
<td>1</td>
</tr>
<tr>
<td>0.10%</td>
<td>100</td>
</tr>
<tr>
<td>1.00%</td>
<td>10,000</td>
</tr>
<tr>
<td>10.00%</td>
<td>100,000</td>
</tr>
</tbody>
</table>

Flow Number FN

Primary Stage  Secondary Stage  Tertiary Stage
Comparison of Rutting Resistance: CIR

![Graph comparing rutting resistance for different emulsions](image)

**Emulsion A: CMS-2S**
- OEC = 4.0%
- PG 52-34

**Emulsion B: LM**
- OEC = 3.0%
- PG 64-28

**Emulsion C: PM**
- OEC = 2.5%
- PG 64-28

**Emulsion D: RM**
- OEC = 4.0%
- PG 58-28
Rutting Resistance Models: CIR

<table>
<thead>
<tr>
<th>Asphalt Emulsion</th>
<th>Rutting Model</th>
</tr>
</thead>
</table>
| A: Standard CMS-2s        | \[
\frac{\varepsilon_p}{\varepsilon_r} = 10^{-10.93031} (N)^{0.32408} (T)^{5.30878}
\] |
| B: Latex-Modified         | \[
\frac{\varepsilon_p}{\varepsilon_r} = 10^{-8.10753} (N)^{0.24871} (T)^{4.08190}
\] |
| C: Polymer-Modified       | \[
\frac{\varepsilon_p}{\varepsilon_r} = 10^{-1.75152} (N)^{0.20540} (T)^{0.79574}
\] |
| D: Rubber-Modified        | \[
\frac{\varepsilon_p}{\varepsilon_r} = 10^{-10.16571} (N)^{0.34739} (T)^{4.76969}
\] |
Comparison of Fatigue Resistance

![Graph showing comparison of fatigue resistance for different types of materials at 70°F. The x-axis represents fatigue life in number of cycles, and the y-axis represents flexural strain in microstrain. The graph includes lines for Type A, Type B, Type C, and Type D materials.](image-url)
## Fatigue Cracking Models: CIR

<table>
<thead>
<tr>
<th>Asphalt Emulsion</th>
<th>Fatigue Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Standard CMS-2s</td>
<td>( N_f = 4.40 \times 10^{10} \left( \frac{1}{\varepsilon_t} \right)^{4.494} \left( \frac{1}{E} \right)^{3.749} )</td>
</tr>
<tr>
<td>B: Latex-Modified</td>
<td>( N_f = 7.42 \times 10^{10} \left( \frac{1}{\varepsilon_t} \right)^{4.771} \left( \frac{1}{E} \right)^{3.845} )</td>
</tr>
<tr>
<td>C: Polymer-Modified</td>
<td>( N_f = 1.80 \times 10^{13} \left( \frac{1}{\varepsilon_t} \right)^{4.409} \left( \frac{1}{E} \right)^{4.006} )</td>
</tr>
<tr>
<td>D: Rubber-Modified</td>
<td>( N_f = 1.16 \times 10^{5} \left( \frac{1}{\varepsilon_t} \right)^{4.104} \left( \frac{1}{E} \right)^{2.516} )</td>
</tr>
</tbody>
</table>
Resistance to Reflective Cracking: OT

• Texas Overlay Test:
  • Controlled displacement mode as per Tex-248-F.
  • Opening displacement of 0.01 inches (0.25 mm).
  • Sample size 150 mm long, 76 mm wide and 38 mm thick.
  • Performed at OEC with a Target air voids of 13 ± 1%.
  • Test temperature 25°C.
Resistance to Reflective Cracking: OT Analysis Criteria

• Number of cycles to failure ~ Drop of 93% of the maximum load.

• Resistance to Crack Initiation ~ Dissipated energy required to initiate a crack.

• Crack Propagation rate ~ Fitting a power equation to the load reduction curve.

\[ Y = X^b \]

\( b = \text{Crack Propagation Rate (CPR)} \)
Comparison of Reflective Cracking Resistance: CIR

<table>
<thead>
<tr>
<th>Asphalt Emulsion</th>
<th>Air Voids (%)</th>
<th>No of Cycles to Failure</th>
<th>Critical Fracture Energy (CFE)</th>
<th>Crack Propagation Rate (CPR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Standard CMS-2s</td>
<td>13.6</td>
<td>496</td>
<td>0.33</td>
<td>0.44</td>
</tr>
<tr>
<td>B: Latex-Modified</td>
<td>13.8</td>
<td>132</td>
<td>0.36</td>
<td>0.51</td>
</tr>
<tr>
<td>C: Polymer-Modified</td>
<td>13.1</td>
<td>280</td>
<td>0.20</td>
<td>0.41</td>
</tr>
<tr>
<td>D: Rubber-Modified</td>
<td>13.6</td>
<td>1,254</td>
<td>0.24</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Desired Properties:  
- High Cycles to Failure  
- High Critical Fracture Energy  
- Low Crack Propagation Rate
Conclusions

• OEC varied by emulsion type and asphalt binder residue.
• PM increased TS properties & improved resistance to moisture damage.
• PM increased the rutting resistance of CIR mixtures at the high critical rutting temperature of 60°C.
• The fatigue models of four CIR mixtures were comparable at the two critical fatigue temperatures of 13 and 21°C.
  • Follow-up mechanistic pavement analysis is needed to properly assess the mixtures resistance to fatigue cracking
Conclusions

• The rubber modifications increased reflective cracking resistance of CIR mixtures.

• Criteria for the OT parameters need to be established for CIR mixtures based on performance needs.