100% RAP Recycling in Indiana
Analysis of a HyRap Project, Ft. Wayne, IN

Geoffrey Rowe, Abatech
John Barry, Crowley Chemicals
Ken Crawford, Crowley Chemicals

Presentation to TRB Committee AFH60
Monday, January 13th, 2014
Eggeman Rd, Fort Wayne, IN
Ft. Wayne – High RAP Project

Study
- 5 core locations – 3 High RAP, 2 Control
- Volumetrics
- Gradations
- PG comparison with other sites
- Binder complex modulus $G^*$ comparison
- Mixture complex modulus $G^*$ comparison
- Mixture flexural cracking test
- Analysis of binder and cracking potential

Laboratory work conducted by
- North Central Superpave Center
- MTE
Site

- Eggeman Rd, Fort Wayne, IN 46814
- Total length of road – approx. 1 mile
- Approximately ½ of this length is high-rap materials
## Core locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Mix Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>0+00</td>
<td>South End of new pavement at intersection with Aboite Center Road</td>
<td></td>
</tr>
<tr>
<td>5+50</td>
<td>Location #1  Northbound 4 ½ ft from Centerline</td>
<td>HyRap Mix</td>
</tr>
<tr>
<td>10+50</td>
<td>Location #2  Southbound Right Wheel Path</td>
<td>HyRap Mix</td>
</tr>
<tr>
<td>17+00</td>
<td>Location #3  Southbound Right Wheel Path</td>
<td>HyRap Mix</td>
</tr>
<tr>
<td>30+00</td>
<td>Location #4  Southbound 5 ft from Centerline</td>
<td>Conventional Mix</td>
</tr>
<tr>
<td>35+00</td>
<td>Location #5  Southbound Right Wheel Path</td>
<td>Conventional Mix</td>
</tr>
</tbody>
</table>
Location 1 – 5+50, High RAP

Lane center
Location 2 – 10+50, High RAP

Wheel path
Location 3 – 17+00, High RAP

Wheel path
Location 4 – 30+00, Control

Lane center
Location 5 – 35+00, Control

Wheel path
## Core analysis summary

<table>
<thead>
<tr>
<th>ID</th>
<th>G&lt;sub&gt;mm&lt;/sub&gt;</th>
<th>G&lt;sub&gt;mb&lt;/sub&gt;</th>
<th>%AV</th>
<th>%AC</th>
<th>Minus 200, %</th>
<th>G&lt;sub&gt;se&lt;/sub&gt;*</th>
<th>G&lt;sub&gt;sb&lt;/sub&gt;</th>
<th>P&lt;sub&gt;ba&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>2.484 2.486</td>
<td>2.424 (1A) 2.415 (1E) 2.421 (1F)</td>
<td>2.5 2.8 2.6</td>
<td>6.6 6.9</td>
<td>7.8 7.7</td>
<td>2.772 2.596</td>
<td>2.45</td>
<td></td>
</tr>
<tr>
<td>#2</td>
<td>2.475 2.489</td>
<td>2.350 (2B) 2.354 (2D) 2.347 (2F)</td>
<td>5.3 5.2 5.4</td>
<td>5.6 6.2</td>
<td>7.3 6.9</td>
<td>2.722 2.605</td>
<td>1.65</td>
<td></td>
</tr>
<tr>
<td>#3</td>
<td>2.478 2.477</td>
<td>2.279 (3D) 2.278 (3E) 2.277 (3F)</td>
<td>8.0 8.1 8.1</td>
<td>5.9 6.2</td>
<td>7.8 8.1</td>
<td>2.705 2.614</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>#4</td>
<td>2.494 2.492</td>
<td>2.259 (4D) 2.261 (4E) 2.244 (4F)</td>
<td>9.4 9.3 10.0</td>
<td>6.1 5.7</td>
<td>5.2 5.1</td>
<td>2.739 2.596</td>
<td>2.01</td>
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</tr>
<tr>
<td>#5</td>
<td>2.496 2.495</td>
<td>2.335 (5D) 2.338 (5E) 2.221 (5F)</td>
<td>6.4 6.3 6.6</td>
<td>5.7 5.5</td>
<td>5.3 5.2</td>
<td>2.728 2.600</td>
<td>1.80</td>
<td></td>
</tr>
</tbody>
</table>

*Assumed G<sub>b</sub> = 1.023
Gradation results

- Analysis results in compliance with gradation requirements as a 9.5mm mix
- The mix being finer than 47% on the 2.36mm sieve restricts use to Category 1 & 2 roads

<table>
<thead>
<tr>
<th>size (d, mm)</th>
<th>Cumulative Percent Passing</th>
<th>IN DOT Clause 401.05 (Table) – requirements for 9.5mm Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#1</td>
<td>#2</td>
</tr>
<tr>
<td>12.5</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>9.5</td>
<td>94.3</td>
<td>94.0</td>
</tr>
<tr>
<td>4.75</td>
<td>72.0</td>
<td>72.5</td>
</tr>
<tr>
<td>2.36</td>
<td>49.0</td>
<td>49.3</td>
</tr>
<tr>
<td>1.15</td>
<td>36.5</td>
<td>36.0</td>
</tr>
<tr>
<td>0.6</td>
<td>27.5</td>
<td>25.7</td>
</tr>
<tr>
<td>0.3</td>
<td>17.9</td>
<td>16.6</td>
</tr>
<tr>
<td>0.15</td>
<td>11.0</td>
<td>10.8</td>
</tr>
<tr>
<td>0.075</td>
<td>8.4</td>
<td>8.5</td>
</tr>
</tbody>
</table>

*The mix design gradation shall be less than or equal to the PCS control point for 9.5mm category 3, 4 and 5 surface mixtures. The PCS control point is 47 – for a 9.5 mm mix.
PG Comparison

- 10 conventional sites versus 2 High RAP locations
- Similar results for all sites
- All sites constructed in similar time frame
Master curve development

- Why master curves?
  - Tests conducted at multiple loading times and frequencies
  - The data is analyzed in a manner that the stiffness of the mix can be determined over a wide range of loading times (frequency) or temperature
  - Enables simple comparisons to be made
  - Etc., etc.
Binder – example data set

Sample ID: 1.5+50 (2)

Storage Modulus and Loss Modulus Isotherms

Add / Remove Ism:
- T -40
- T -35
- T -30
- T -20
- T -15
- T -10
- T 0
- T 10
- T 20
- T 30
- T 40
- T 50
- T 60
- T 70

G', G'' Pa

Legend:
- Red = Storage Modulus
- Blue = Loss Modulus

Frequency, rad/sec
0.01 0.1 1 10 100 1000
Binder Master curve of $G^*$, 25°C

Plot of $G^*$ and $\delta$ versus frequency shows time dependency.

Plot of shift factor versus temperature shows temperature dependency.
Data in this format shows very similar rheological behavior for all five locations.
Master curves

- Shape and position analyzed to provide information on aging

- Critical parameters
  - Rheological index
  - Cross over frequency
Considered way theological shape of master curve changing

Rheological Index – R and crossover frequency $\omega_o$

$$G^*(\omega) = G_0[1+(\omega_o / \omega)^\beta]^{-\kappa/\beta}$$

$R= \log_2/\beta$

$R$ is the distance between the $G^*$ curve and the glassy modulus (typically 1E9) at the point where $\delta=45^\circ$ or $G'=G''$ (as a log number)

$\omega_o$ – crossover frequency is the frequency at this same point
R and $\omega_o$

- $R$ – provides information with regard to the relaxation spectra, it is also related to the chemical composition of the binder
- $\omega_o$ – provide the position of the master curve and the hardness of the material

As materials age

- $R$ increases with oxidative aging
- $\omega_o$ reduces as materials get harder
Values obtained from binder recovered from cores
Both binders very similar
$\omega_0$ and R-value

- Values obtained from binder recovered from cores
- Both binders very similar
- When compared to other binders the material shows good performance
Glover–Rowe parameter introduced to predict durability/block cracking.

Binder in this show no propensity for cracking.

Similar performance from both HyRap and conventional
Mix testing

- On slices produced from core samples
- Torsion bar testing for master curve development
- Three point bending test for flexural strength
Mix Master curve of $G^*$, 25°C

Data from all works gives very similar master curves.
Master curve, Black space
Conducted in triplicate on BBR samples

Loading rate selected to ensure brittle failure occurred

Provides indication of cracking propensity at low temperatures
Tensile strength

![Graph showing flexural strength at different locations for HyRap and Conventional methods.](image-url)
Tensile strength, normalization with air voids

![Graph showing flexural strength vs. air voids.](image)

- **Equation:**
  \[ y = 0.0261x^3 - 0.452x^2 + 1.7589x + 7.737 \]
  \[ R^2 = 0.9979 \]
Summary

- Performance in road very good after 1–year
- Volumetrics acceptable
- Gradation – slightly fine of 47% (47.2 to 49.3) on 2.36mm – results in an acceptable 9.5mm mixture for Category 1 and 2 roads
- Recovered PGs similar on High RAP to other sites and control
- Master curve shows control materials have similar stiffness (G*) compared to High RAP materials
- Tensile properties show that materials have similar cracking resistance
- Difficult to differentiate between conventional and HyRap performance