Implementation of High RAP HMA Mixtures

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http://www.abatech.com/Information.htm
High RAP mixtures

- HMA is the most recycling product in the USA by mass
  - However ..... 
- Large volumes exist all over New Jersey and significantly in major population areas over the USA
  - We can’t build overlays higher due to constraints of our infrastructure – we mill and repave
    - If we don’t reuse our stock piles grow higher

- The need – Higher RAP mixes
  - The question – how do we do this .....
The ultimate goal! 95%-100% RAP HMA!
What's new ....

- Plant technology ....
  - 1970s Batch plants/parallel flow drum
  - 1980s Coater drums
  - Contra flow drums with mixing area
  - Double drum/barrel drum
  - Various technologies
  - Various advanced systems

- 0% Rap
- 15–30%
- 15–45%
- Higher RAP
Plant modifications and improvements

- Typical contra-flow drum
- Aggregate in section of drum ahead of flame
- RAP added and mixed – avoiding direct application of flame
- Others
  - Double barrel
  - Mixing barrel
  - Etc., etc.
## Recommendations for RAP

- **AASHTO recommendations (M323)**

<table>
<thead>
<tr>
<th>Recommended Virgin Asphalt Binder Grade</th>
<th>RAP Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change in binder selection</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Select virgin binder one grade softer than normal (e.g., select a PG 58-28 if a PG 64-22 would normally be used)</td>
<td>15 to 25</td>
</tr>
<tr>
<td>Follow recommendations from blending charts</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>

- Currently, little use of the extraction-recovery process, instead state specifications generally have been modified to allow use of a softer grade of asphalt binder to a higher RAP rate. The highest such upper limit has been set at 40%.

- NJDOT standard specifications allow for 25% RAP in base and intermediate courses and 15% RAP in surface course.
NJDOT requirements

- **901.02 Stockpiles**: Do not stockpile RAP higher than 15 feet and cover/protect stockpiles to prevent buildup of moisture.
- **901.05.04 RAP**: Process RAP via screening/crushing to ensure that 100% passes the max aggregate size. Shall be free from solvents or other contamination. Other requiems regarding aggregate conformance … etc.
- **901.10.03 Virgin and RAP Mixture**: Can add 50% of RAP to DGA
- **902.01.01 Asphalt binder**: Use PG64-22 except that ME may direct that an asphalt of softer grade be used when the mixture contains a high percentage of RAP and except where otherwise specified.
- **902.02.02 Composition of Mixtures**: W/C ≤ 15% - Ensure that the finished mix does has <1% contamination from Crushed Recycled Container Glass (CRCG). I/C, B/C ≤ 25%
- **902.02.04 Sampling and Testing**: Sample and test RAP according to the approved QC plan for the plant. When using RAP, ensure that the supplier has in operation an ongoing daily QC program to evaluate the RAP - as a minimum, this program shall consist of the following:
  - 1. An evaluation performed to ensure that the material conforms/compares favorably with the design.
  - 2. An evaluation of the RAP material performed using a solvent or an ignition oven
  - 3. Quality control reports as directed by the ME.
- **OGFC/Ultra-Thin HMA/SMA/AR-OGFC/HPTO**: RAP not allowed
Concerns
- Black rock or usable binder
- Mixes will be brittle and crack

- How do we assess?

Three approaches
- Evaluation of predicted versus estimated modulus values.
- Assessment of diffusion
- Fracture properties on mixed materials
Predicted vs. estimated modulus

- Use of PG binder properties to predict binder and mix master curve
  - Complex equations
- Assessment of degree of blending from evaluation of predicted vs. estimated modulus relationships
  - Complex since assumption is that mixing of binder is complete
- Difficult to apply!
Diffusion

- Does the binder blend with RAP binder?
  - Some binder is absorbed
  - Suggestion is that large part of diffusion occurs early in mixing/transportation and laydown
  - Some may continue
Diffusion

- Diffusion slows down as the mix cools.
- Diffusion continues during service at a lower rate.
- Time for complete diffusion could be nearly immediate to a few months or even years.
- Depends on the thermal history provided.

A profile of the diffusion obtained from testing of viscosity at three different temperatures.

Note: The time scale is on a log basis resulting in a very large difference at the three temperatures of interest.
Addresses industry major concern

Methods
- Bending beam fatigue test
- Tensile tests
  - Use of beam, direct or indirect tension

Methods (cont.)
- Fracture tests
  - Texas Overlay Tester
  - Direct compact tension test
  - Semi-circular bend test
Measurement of fracture properties

- Different states adopting different methods
- Texas using the “Overlay Tester”

HMA mixes that last over 300 load cycles (at a stress reduction of 93% in the initial load) are acceptable (Zhou et al 2006).
Measurement of fracture properties

- Work at Rutgers/NJDOT
  - Consider properties in “Overlay Tester”
  - Also → Asphalt Pavement Analyzer (APA) Rut tests
  
  - NJ Performance (>10 M ESAL mix)
    
    | Wearing  | Intermediate |
    |----------|--------------|
    | PG64–22  | >150 cycles  | >100 cycles  |
    | PG76–22  | >175 cycles  | >125 cycles  |

  - Added deformation test with APA to make sure binder is not too soft and would lead to rutting
  - Work included 20% minimum RAP in w/c and 30% minimum in intermediate
Binder rejuvenation

- Binder rejuvenation since the 1970s
- Use of softer binder grades is majority of the US market
  - Many rejuvenators in the market place
- As binders age absorption and oxidative reactions result in significant changes to both physical and chemical properties
- The changes in physical properties can be captured by rheological properties – two major effects
  - Binder hardens
  - Relaxation properties
- Consistent with the binder oxidizing
Testing in DSR

- Crossover frequency is a measure of hardness
- R-value is a measure of the rheological type
  - Blown or oxidized asphalts have higher R-value
- When adding a rejuvenator we are looking for a restoration of properties
G–R parameter & asphalt cracking

- Important – since as the rheology changes the asphalt binder propensity to crack increases.
- Hardening results in binder embrittlement—fracture at a lower strain “march to death” for an asphalt binder.
Improvement in mix design

- The balanced mix design approach
- Allows volumetrics to be as low as 2% air voids
- Considers performance testing on mixtures – deformation/moisture and cracking performance
High Rap Mixes

- HMA with high rap contents (above 75%) have been used in the USA for a number of years in either an experimental or pioneering manner
  - CYCLEAN – implemented in the Los Angeles area of California in 1988 – 100% RAP
  - More recently other technologies have been implemented that produce high RAP mixtures
    - Examples – HyRap® – 90 to 100% RAP
In this process fractionated RAP (FRAP) is fed through multiple entry points in a drum mix plant which has been specially modified to minimize the production of smoke from flame contact with the old RAP binder.
Demonstration project
Eggeman Rd, Fort Wayne, IN
Study
- 5 core locations – 3 High RAP, 2 Control
- Volumetrics
- Gradations
- PG comparison/Rheology comparison
- 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 $\frac{1}{2}$ of this length is high-rap materials
Core locations

0+00  South End of new pavement at intersection with Aboite Center Road

5+50  Location #1  Northbound 4 ½ ft from Centerline  HyRap Mix

10+50 Location #2  Southbound Right Wheel Path  HyRap Mix

17+00 Location #3  Southbound Right Wheel Path  HyRap Mix

30+00 Location #4  Southbound 5 ft from Centerline  Conventional Mix

35+00 Location #5  Southbound Right Wheel Path  Conventional Mix
Location 1 – 5+50, High RAP

Lane center
Location 4 – 30+00, Control

Lane center
# Core analysis summary

<table>
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<tr>
<th>ID</th>
<th>$G_{mm}$</th>
<th>$G_{mb}$</th>
<th>%AV</th>
<th>%AC</th>
<th>Minus 200, %</th>
<th>$G_{se}$</th>
<th>$G_{sb}$</th>
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*Assumed $G_b = 1.023$
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 (mm)</th>
<th>Cumulative Percent Passing</th>
<th>IN DOT Clause 401.05 (Table) – requirements for 9.5mm Mix</th>
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</thead>
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</table>

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

Legend
- Observed Data Points
  - Storage Modulus
  - Loss Modulus
Binder Master curve of G*, 25°C

Plot of G* and δ 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 $\omega_o$

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

$R = \log 2 / \beta$

$R$ 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
\( \omega_0 \) and R-value

- Values obtained from binder recovered from cores
- Both binders very similar

![Graph showing data developed at 25°C]
$\omega_0$ and R-value

- Values obtained from binder recovered from cores
- Both binders very similar
- When compared to other binders the material shows good performance

![Graph showing data points and trend lines related to $\omega_0$ and R-value.](39)
Glover–Rowe parameter introduced to predict durability/block cracking.

Binder in this show no propensity for cracking.

Similar performance from both HyRap and conventional

Damage onset: \( G^* \left( \frac{(\cos \delta)^2}{\sin \delta} \right) = 180 \text{ kPa} \)

Significant cracking: \( G^* \left( \frac{(\cos \delta)^2}{\sin \delta} \right) = 450 \text{ kPa} \)
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.
Mixture flexural strength

- Conducted in triplicate on BBR samples
- Loading rate selected to ensure brittle failure occurred
- Provides indication of cracking propensity at low temperatures
Tensile strength

[Bar graph showing flexural strength at different locations for HyRap and Conventional methods]
Tensile strength, normalization with air voids

\[ y = 0.0261x^3 - 0.452x^2 + 1.7589x + 7.737 \]

\[ R^2 = 0.9979 \]
Performance of Eggeman Rd very good after 2½ years
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
Conventional RAP specifications – 15 to 40%
High RAP – percentages as high as 70% have been tried in conventional HMA plants
RAP contents > 55 to 75% require specialized plants
At High RAP contents – softer grades and/or binder rejuvenation is required
Testing is necessary to ensure properties are being achieved
Research suggests that most binder is still working in a functional manner
RAP good practice is key to successful projects
Bibliography/references


Thanks for listening ...

Questions?
Comments!

This presentation can be found at
http://www.abatech.com/Information.htm