Seeking Increased Pavement Performance Through Increased Density

John E. Haddock, PhD, PE
Professor of Civil Engineering
Director, Indiana Local Technical Assistance Program
Purdue University
Lyles School of Civil Engineering
Flexible pavements generally reach end of service because of durability issues after 15-20 years

- Caused in part by oxidized binder
- Rutting has been significantly reduced
- Reducing permeability decreases rate of binder aging
Background

- Increase initial in-service density by 1% (Tran et al., 2016):
  - 8.2% - 43.8% fatigue performance improvement
  - 7.3% - 66.3% rutting resistance improvement
  - 10% - 30% increase in the pavement service life
Concept

- Lower initial in-service air voids to improve pavement durability
- Do not sacrifice asphalt mixture mechanical properties
- Design at 5% air voids, field compact to 5% air voids
- Keep effective binder content the same
- No increase in compaction effort
- Increase pavement in-service life
Scope

- Laboratory study (proof of concept)
  - Use 3 standard asphalt mixtures
  - Re-design each mixture at 5% air voids
    - Maintain effective binder content
    - Use 70, 50, 30 gyrations
  - Test all mixtures for dynamic modulus and flow number (anticipated in-service air voids)
- Place field projects
## Experimental Matrix

<table>
<thead>
<tr>
<th>Traffic (MESAL)</th>
<th>No. Gyrations</th>
<th>9.5-mm</th>
<th>19.0-mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 3 (3-10)</td>
<td>30</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>70</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Category 4 (10-30)</td>
<td>30</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Materials

- Coarse aggregates
  - Limestone, dolomite, blast furnace slag
- Fine aggregates
  - Limestone, dolomite, natural sand
- PG 64-22
- No recycled materials
## Category 3, 9.5-mm Designs

<table>
<thead>
<tr>
<th></th>
<th>N100</th>
<th>N70</th>
<th>N50</th>
<th>N30</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_b$, %</td>
<td>5.9</td>
<td>5.9</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>$P_{be}$, %</td>
<td>4.6</td>
<td>4.6</td>
<td>4.6</td>
<td>4.7</td>
</tr>
<tr>
<td>$V_a$, %</td>
<td>4.1</td>
<td>5.1</td>
<td>4.9</td>
<td>5.3</td>
</tr>
<tr>
<td>VMA, %</td>
<td>15.0</td>
<td>16.0</td>
<td>15.8</td>
<td>16.3</td>
</tr>
<tr>
<td>VFA, %</td>
<td>72.9</td>
<td>67.9</td>
<td>68.9</td>
<td>67.6</td>
</tr>
</tbody>
</table>
Category 3, 9.5-mm

Sieve Size raised to 0.45 power, mm
Category 3, 9.5-mm

Dynamic Modulus (MPa) vs. Reduced Frequency (Hz)

- N100/ 7%
- N70
- N50
- N30
- N100/ 5%
### Category 3, 9.5-mm

<table>
<thead>
<tr>
<th>Gyrations</th>
<th>Average Flow Number</th>
<th>Average Strain at FN (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100- 7%</td>
<td>91</td>
<td>18,114</td>
</tr>
<tr>
<td>100- 5%</td>
<td>166</td>
<td>18,174</td>
</tr>
<tr>
<td>70</td>
<td>167</td>
<td>17,704</td>
</tr>
<tr>
<td>50</td>
<td>163</td>
<td>20,300</td>
</tr>
<tr>
<td>30</td>
<td>156</td>
<td>19,204</td>
</tr>
</tbody>
</table>
Field Trial 1

- SR-13 near Ft. Wayne, IN
- New overlay, Category 4, 9.5-mm
- Original design, N100, 4%, 7%
- Redesigned, N50, 5%, 5%
- Steel slag and limestone coarse aggregates, limestone and natural sands, RAS, PG 70-22
Mixture Gradations

Percent Passing

Sieve size raised to 0.45 power, mm

Original - N100

Redesigned - N50
In-place Densities

- N100, 18 cores, average density 91.8%
- N50, 6 cores, average density 94.7%
- Same rollers and rolling patterns
Dynamic Modulus Results

![Graph showing dynamic modulus results for N100 and N50.]
Field Trial 2

- Georgetown Road, Indianapolis, IN
- Intermediate layer, Category 3, 19.0-mm
- Original design, N100, 4%, 7%
- Redesigned, N30, 5%, 5%
- Limestone coarse aggregates, dolomite sand, RAS, RAP, PG 64-22
In-place Densities

- N100, 20 cores, average density 94.0%
- N30, 20 cores, average density 95.2%
- Same rollers and rolling patterns
Dynamic Modulus Results

![Graph showing dynamic modulus results for different asphalt mixtures. The graph plots dynamic modulus (MPa) against reduced frequency (Hz). The graph includes data for N100 Unaged, N-100 Aged, N-30 Unaged, and N-30 Aged asphalt mixtures.]
US-40 Field Project

- INDOT demonstration project
  - US 40, Richmond, IN (1.8 miles)
  - Mill and replace 1.5 in. of asphalt surface
  - Control section using best practices
  - Test section using new technique
Materials

- Limestone coarse aggregate
- Natural sand
- Crushed gravel sand (test mixture only)
- RAP
- RAS
- PG 70-22
## Mixture Design

<table>
<thead>
<tr>
<th>Volumetric Property</th>
<th>Control Mixture</th>
<th>Test Mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of design gyrations</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>$V_{a} @ N_{des}$, %</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Design $P_{b}$, %</td>
<td>6.7</td>
<td>7.1</td>
</tr>
<tr>
<td>Design $P_{be}$, %</td>
<td>5.2</td>
<td>5.2</td>
</tr>
<tr>
<td>VMA, %</td>
<td>15.6</td>
<td>16.7</td>
</tr>
<tr>
<td>Target in-place density, %</td>
<td>94.0</td>
<td>95.0</td>
</tr>
</tbody>
</table>
Quantities

- 5300 tons of asphalt mixture placed
  - Control mixture lot = 2650 tons
    - 5 sublots, 530 tons each
  - Test mixture lot = 2650 tons
    - 5 sublots, 530 tons each
Production and Placement

- Drum mix facility
- Mixing temperature, $315 \pm 25^\circ F$
- Plant production, 210 tons/hour
- Emulsified tack coat
- Mixture temperature at the paver, $290 \pm 25^\circ F$
- Compaction temperature, $260 \pm 25^\circ F$
<table>
<thead>
<tr>
<th></th>
<th>Breakdown</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rollers</td>
<td>2 (echelon)</td>
<td>1</td>
</tr>
<tr>
<td>Vibratory passes</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Static passes</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Operating weight, tons</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Drum width, in.</td>
<td>77</td>
<td>67</td>
</tr>
</tbody>
</table>
Rollers
Field Testing

- Plate samples
  - 6 samples/sublot
  - Air voids, asphalt binder content, and VMA
- Core samples
  - 4 samples/sublot
  - In-place density
Average Densities

- Average in-place density:
  - Control mixture = 93.3% (SD 1.0)
  - Test mixture = 95.3% (SD 0.8)
Conclusions

- Mixtures can be designed at 5% air voids without lowering effective binder content
- Mixtures designed and placed at 5% air voids can have mechanical properties equivalent to traditional Superpave-designed mixtures
- Asphalt mixtures designed at 5% air voids can be field compacted to 95% density without additional compaction effort
Implementation

- 50 design gyrations for medium to high traffic levels
- 30 design gyrations for low traffic levels
- Place and monitor additional field projects
- Provisional specification written, up to three projects let next year
- IMP will monitor construction and report results
Thank You!