Asphalt Mixture
Characteristics Affecting
Durability Cracking

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Durability

  • Resistance of asphalt mixture to disintegration due to the combined effects of weathering and traffic
    • Surface (wearing) mixes have most severe exposure
  • The most durable mixes have...
    • Good fatigue resistance
    • Low permeability to air and water
Importance of Air Voids

• Field performance has shown that typical mixtures designed with low air voids (maybe < 2%) are susceptible to rutting and shoving.

• Mixtures designed over about 5% air voids are susceptible to raveling, oxidation and a general lack of durability.

• 4% air void design is an empirically derived target that allows for thermal expansion of the binder along with a cushion for future compaction.
Importance of VMA

- VMA is the volume of the voids in a compacted aggregate sample to accommodate asphalt and air.
  - Assure sufficient binder coating
  - Maintain 4% Air voids
Durability

  • Resistance of asphalt mixture to disintegration due to the combined effects of weathering and traffic
    • Surface (wearing) mixes have most severe exposure
  • The most durable mixes have...
    • Good fatigue resistance
    • Low permeability to air and water
  • To accomplish this...
    • High binder content
    • Reasonable amount of fine material
  • ...and most importantly...
    • Well-compacted during construction
Table 6-1. Effect of mixture composition on performance.

<table>
<thead>
<tr>
<th>Component</th>
<th>Factor</th>
<th>Resistance to Rutting and Permanent Deformation</th>
<th>Resistance to Fatigue Cracking</th>
<th>Resistance to Low Temperature Cracking</th>
<th>Resistance to Moisture Damage</th>
<th>Durability/Resistance to Penetration by Water and Air</th>
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<tbody>
<tr>
<td>Asphalt Binder</td>
<td>Increasing High Temperature Binder Grade</td>
<td>↑↑↑</td>
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<td>Increasing Low Temperature Binder Grade</td>
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<tr>
<td></td>
<td>Increasing Intermediate Temperature Binder Stiffness</td>
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<tr>
<td>Aggregates</td>
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<tr>
<td></td>
<td>Increasing Proportion of Flat and Elongated Particles</td>
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<td></td>
<td>Increasing Nominal Maximum Aggregate Size</td>
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<td></td>
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<td></td>
<td>Increasing Clay Content</td>
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<tr>
<td>Volumetric Properties</td>
<td>Increasing Design Compaction Level</td>
<td>↑↑</td>
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<tr>
<td></td>
<td>Increasing Design Air Void Content</td>
<td>↑↑</td>
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<tr>
<td></td>
<td>Increasing Design VMA and/or Design Binder Content</td>
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<td></td>
<td>Increasing Field Air Void Content</td>
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<td>Increasing Field Air Void Content</td>
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</tbody>
</table>
• Effect of Mix Variables on Fatigue Life
  • For every 1% increase in in-place air voids, relative fatigue life decreases by a nearly constant amount of about 22%.
    • An increase in in-place air voids of 2% will decrease fatigue resistance by nearly 50%.
    • Probably understates the importance of in-place air voids to fatigue life because it neglects the effect of changes in air voids on permeability and age hardening.
  • Other analytical studies (Linden et al.) showed a predicted 10% to 30% reduction in fatigue life for every 1% increase in in-place air voids
    • General rule of thumb is 10% overall reduction in performance for every 1% increase in in-place air void content.
• Effect of Mix Variables on Fatigue Life
  • Relationships exist between the fatigue resistance of asphalt mixtures and volumetric composition
    • Fatigue resistance increases with increasing volume of effective binder (VBE)
      • assuming no change in design compaction, design air voids and in-place air voids.
    • Fatigue resistance increases with increasing Ndesign
      • assuming no change in VBE, design air voids and in-place air voids.
    • Fatigue resistance increases with decreasing in-place air voids (increasing compaction)
      • Assuming no change in VBE, design air void content, and Ndesign.
• Effect of Mix Variables on Fatigue Life
  • “Although an in-depth study of the effect of in-place air voids on pavement performance is outside the scope of this research, successful implementation of the results of this research will depend in part on achieving proper field compaction of mixtures designed according to the recommendations put forth in this report.”
• Effect of Mix Variables on Age Hardening
  • Results partly confirmed a relationship between permeability and age hardening, in that the amount of age hardening clearly increased with increasing air voids.
  • The extent of age hardening also depended strongly on the specific aggregate and binder used in a mixture.
• Effect of Mix Variables on Age Hardening
  • Mixture age hardening increases with increasing air voids and decreasing aggregate specific surface.
    • Indicated by complex modulus
    • Age-hardening ratios decrease 2% to 7% for each 1% increase in FM300
    • Age-hardening ratios increase 5% to 14% for each 1% increase in field air voids at a MAAT of 15.6°C.
    • Combined effect of high air voids and low aggregate specific surface can increase age hardening by 50% or more.
  • Also strongly dependent upon the specific binder used and the MAAT.
• Effect of Mix Variables on Age Hardening
  • Increasing in-place air voids by 2%...
    • Increases age hardening by a factor of 2 at an MAAT of 15.6°C (60°F)
    • Increases age hardening by a factor of 3 at an MAAT of 23.9°C (75°F).
    • Comparable with the effect of decreasing FM300 by 5%.
      • Careful control of aggregate specific surface should help maintain good resistance to age hardening
  • “The very high binder viscosities that can potentially exist in aged pavements could contribute significantly to surface cracking by preventing any healing from occurring at the pavement surface during hot summer weather.”
“The missing link in successful long-term performance of pavements is the construction of that pavement. ...even a 10% greater success ratio for the pavements being built each year would represent a savings of millions of dollars to the states and other public agencies.”
Effect of Density on Performance

Performance or Life Expectancy

- Initial Density
- Construction Costs
- Additional Equipment
- Slowed Production
Kentucky Density Effects Study

• 12.5-mm Mixture
  • Crushed Limestone (80-90%) and Natural Sand (10-20%)
  • PG 76-22 asphalt binder
    • Typical asphalt binder for interstate applications in Kentucky
• Three Asphalt Binder Contents
  • Optimum (4.8%)
  • Low (4.3%)
  • High (5.3%)
Effect of Percentage of Air Voids on Fatigue Life
20C, 500 microstrain
Effect of Voids on Service Life, $N_f$

- Hicks (1984)
- Washington State
- KY Lab Density
Kentucky Density Effects Study

• Testing of Field Mix Samples
  • Assume any given sample represented the entire project
    • BIG assumption, but better than sampling and testing at every location
  • Compact specimens in lab (SGC) to 92% density (8% air voids) and air voids representing average project density
    • average of trimmed mean at each sampling location
  • Conduct rutting, fatigue, low temperature cracking tests on each mix
AMPT – Flow Number
Figure 6-2. Typical data from the flow number test.
AMPT Flow Number

- Established standard test conditions
  - Unconfined
  - 600 kPa axial stress
  - 0.1-second pulse loading, 0.9-second rest period
  - 10,000 cycles maximum
  - 100 mm diameter by 150 mm height specimens
  - 7.0% air voids (mix design)
  - Test temperature equal to the average 7-day maximum pavement temperature at a depth of 20 millimeters for the project location (the “50% Reliability” temperature in LTPPBind software Version 3.1)
AMPT Flow Number: Recommended Criteria

- Recommended criteria from NCHRP Report 673
- Uses calculated Flow Number

<table>
<thead>
<tr>
<th>Traffic (ESAL)</th>
<th>Flow Number, cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3</td>
<td>n/a</td>
</tr>
<tr>
<td>3 to &lt;10</td>
<td>≥ 53</td>
</tr>
<tr>
<td>10 to &lt;30</td>
<td>≥ 190</td>
</tr>
<tr>
<td>≥30</td>
<td>≥ 740</td>
</tr>
</tbody>
</table>
Kentucky Density Effects Study: Flow Number (Rutting)

Unconfined Flow Number at 54°C (Franken Model)

\[
\frac{FN_{\text{Project}}}{FN_8} \approx 0.46
\]
Flexural Beam Fatigue (IPC)
Fatigue Testing
Flexural Beam Fatigue Test
Fatigue Testing

Effect of Strain on Fatigue Life

Cycles to Failure

Strain, $\times 10^{-6}$
Fatigue Testing

Effect of Strain and Density on Fatigue Life

- Strain, $x10^{-6}$
- Cycles to Failure
- Criteria:
  - 96%
  - 93%
Kentucky Density Effects Study: Fatigue Cycles to Failure (Cracking)

Range from 30%-100%

\[
\frac{N_{f_{\text{Project}}}}{N_{f_8}} \approx 0.59
\]
Disk-Shaped Compact Tension Test: DC(T)
DC(T) Output

\[ G_f = \frac{\text{AREA}}{B \times (W - a)} \]
DC(T) Results: MN TH-56

-24°C, Top 25-mm

Load, N vs. Crack Mouth Opening Displacement, mm

- 2000
- 2001
- 2002
- 2003
- No Sealing
Kentucky Density Effects Study: Fracture Energy (Cracking)

Fracture Energy at -12°C, J/m²

Air Voids, %

\[
\frac{G_{f_{\text{Project}}}}{G_{f_8}} \approx 0.87
\]
Kentucky Density Effects Study

$y = -1650 \ln(x) + 23848$

$R^2 = 0.9254$

Total Cracking, (feet/mile)

Nf ($20^\circ$C, 400 $\mu$ε), cycles
Kentucky Density Effects Study

\[ y = -1650 \ln(x) + 23848 \]

\[ R^2 = 0.9254 \]

<table>
<thead>
<tr>
<th>Nf (20°C, 400 με), cycles</th>
<th>Total Cracking, (feet/mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000 - 100,000</td>
<td>13.2%</td>
</tr>
<tr>
<td>100,000 - 1,000,000</td>
<td>11.6%</td>
</tr>
<tr>
<td>1,000,000 - 10,000,000</td>
<td>12.9%</td>
</tr>
<tr>
<td>10,000,000 - 100,000,000</td>
<td>10.7%</td>
</tr>
</tbody>
</table>

11.5%
Durability and Recycled Materials

• A few words about durability and recycled materials (e.g., RAP and RAS)...
  • Understand effects of materials
    • Adding age-hardened asphalt binder with reduced relaxation to mix in some proportion
    • “The very high binder viscosities that can potentially exist in aged pavements could contribute significantly to surface cracking by preventing any healing from occurring at the pavement surface during hot summer weather.” ~ NCHRP Report 567
A few words about durability and recycled materials (e.g., RAP and RAS)...

- Understand effects of materials
  - Properly account for amount of recycled binder that is available for use by the mix (i.e., how well is it actively blended?)
    - Can lead to under-asphalted mixes
  - If using premium asphalt binders, consider impact of added aged binder
    - Reduction in polymer loading?

- Mix performance testing
Fatigue Study: Effect of Modifier Concentration

ASTM 4760 4-point Flexural Fatigue
Cycles*Stiffness Analysis
20°C Test Temperature

$y = 1.03 \times 10^{22}x - 5.88 \times 10^0$
$R^2 = 9.98 \times 10^{-01}$

$y = 8.45 \times 10^{20}x - 5.56 \times 10^0$
$R^2 = 9.33 \times 10^{-01}$

$y = 8.69 \times 10^{19}x - 5.33 \times 10^0$
$R^2 = 9.33 \times 10^{-01}$

$y = 1.20 \times 10^{19}x - 5.33 \times 10^0$
$R^2 = 1.00 \times 10^0$
## Fatigue Study: Effect of Modifier Concentration

### Binder Strain (E-06)

<table>
<thead>
<tr>
<th>Binder</th>
<th>22,500</th>
<th>30,000</th>
<th>40,000</th>
<th>50,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>737</td>
<td>1.61E+05</td>
<td>3.45E+04</td>
<td>7.37E+03</td>
<td>2.23E+03</td>
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<tr>
<td>748</td>
<td>8.86E+04</td>
<td>1.91E+04</td>
<td>4.13E+03</td>
<td>1.26E+03</td>
</tr>
<tr>
<td>Ratio 748/737</td>
<td>55%</td>
<td>56%</td>
<td>56%</td>
<td>57%</td>
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</tbody>
</table>

### Mix Strain (E-06)

<table>
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<tr>
<th>Mixture</th>
<th>450</th>
<th>600</th>
<th>800</th>
<th>1000</th>
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<tbody>
<tr>
<td>737</td>
<td>2.33E+06</td>
<td>5.35E+05</td>
<td>8.19E+04</td>
<td>2.25E+04</td>
</tr>
<tr>
<td>748</td>
<td>1.61E+06</td>
<td>3.05E+05</td>
<td>4.98E+04</td>
<td>2.09E+04</td>
</tr>
<tr>
<td>Ratio 748/737</td>
<td>69%</td>
<td>57%</td>
<td>61%</td>
<td>93%</td>
</tr>
</tbody>
</table>
Summary

• Mixture Durability
  • Proper materials
    • Asphalt binder, aggregate, recycled materials
  • Proper design volumetric properties (air voids, VMA)
    • Appropriate (sufficient!) design asphalt binder content
    • Gradation to minimize permeability
  • Proper as-produced properties
    • Volumetric properties
    • Asphalt binder content
    • Gradation
• Proper construction
  • Well-compacted
Thanks!

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