Hot Mix Asphalt 101
Definition of HMA

In simple terms…:

A mixture of asphalt binder and graded mineral aggregate, mixed at an elevated temperature and compacted to form a relatively dense pavement layer

(≈ 5% binder and ≈ 95% aggregate)
HMA Uses

- Highways
- Airfields
- Port Facilities
- Parking Lots
- Recreational (Bikeways, Tennis Courts, Tracks)
- Hydraulic Structures
- Recycled Material
Components

• Asphalt Binder
• Mineral Aggregate
• Air

• Optional Modifiers/Additives:
  – Binder Modifiers/Additives (e.g., polymers, elastomers, fibers, rubber)
  – Aggregate Modifiers/Additives (e.g., lime, granulated rubber, anti-strip agents)
Components (cont.)

- Air void
- Asphalt binder
- Mineral aggregate

Image showing the components of a pavement mix with labeled parts.
Components (cont.)

- Air  2-20%
- Asphalt binder  3-8%
- Absorbed asphalt binder  <1%
- Mineral aggregate  85-95%

NOTE: relative size of rectangles indicate approximate proportions of components in the mix.
Types of HMA Mixtures

- **Dense-Graded (DGA)**
  - Size evenly distributed from smallest to largest size (well-graded)

- **Open-Graded (or Uniformly-Graded) Friction Course (OGFC)**
  - Primarily coarse aggregate with few fines

- **Stone Mastic (Matrix) Asphalt (SMA)**
  - Mid-size aggregate missing or reduced
Hot Mix Asphalt

Mixture Design Objectives
Specific Mix Design Objectives

• Stability (permanent deformation resistance)
• Durability
  – Moisture damage and aging
• Fatigue cracking resistance
• Safety (adequate skid resistance)
• Resistance to thermal cracking
• Permeability
• Flexibility
## Mix Design Considerations

<table>
<thead>
<tr>
<th>Mixture Property</th>
<th>Component and Construction Effects on Mixture Properties</th>
<th>Asphalt Stiffness</th>
<th>Aggregate Gradation</th>
<th>Asphalt Content</th>
<th>Degree of Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hard</td>
<td>Soft</td>
<td>Dense</td>
<td>Open</td>
</tr>
<tr>
<td>Stability</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Fatigue Resistance</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
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<tr>
<td>Skid Resistance</td>
<td>X</td>
<td></td>
<td>-</td>
<td></td>
<td></td>
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<tr>
<td>Fracture Strength</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imperviousness</td>
<td>-</td>
<td>-</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Basic Mix Design Philosophy

Asphalt binder content

– As much asphalt as possible for
  • Durability
  • Fatigue resistance
  • Flexibility

– Not so much asphalt to affect
  • Stability
  • Friction
Asphalt Content Impact on HMA Performance – Balancing Act

Asphalt Content (% AC)

Rutting and Bleeding Potential

Durability and Cracking Potential
Consideration of Structural Composition on Mix Design

<table>
<thead>
<tr>
<th>Top 1/3</th>
<th>1 Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 Skid Resistance</td>
</tr>
<tr>
<td></td>
<td>3 Durability</td>
</tr>
<tr>
<td></td>
<td>4 Tensile Strength -Thermal Cracking</td>
</tr>
<tr>
<td>Middle 1/3</td>
<td>1 Stability</td>
</tr>
<tr>
<td></td>
<td>2 Durability</td>
</tr>
<tr>
<td>Bottom 1/3</td>
<td>1 Fatigue Resistance</td>
</tr>
<tr>
<td></td>
<td>2 Durability</td>
</tr>
</tbody>
</table>
Superpave Mixture Design

Superior Performing Asphalt Pavements
4 Steps of Superpave Mix Design

1. Materials Selection

2. Design Aggregate Structure

3. Design Binder Content

4. Moisture Sensitivity
Aggregate Properties

- **Consensus Properties** - required
  - coarse aggregate angularity (CAA)
  - fine aggregate angularity (FAA)
  - flat, elongated particles
  - clay content

- **Source Properties** - agency option
  - toughness
  - soundness
  - deleterious materials
Asphalt Binders

Polymer Modified Binders
“Ideal” Asphalt Binder

- Low stiffness at construction temperature
- High stiffness at high in-service temperature
- Low stiffness at low in-service temperature
- Excellent long-term durability
Sources of Asphalt Binder

• Asphalt occurs naturally or is obtained through distillation of petroleum crude oil.

• Examples of natural asphalt include the binder in rock asphalt and Trinidad Lake asphalt.

• More commonly, asphalt is obtained through distillation of crude oil.
Refinery Atmospheric Distillation

Decreasing Molecular Weight

Vapor
- Propane & Butane

Naphtha
- Feedstock for gasoline

Kerosene
- Aviation/domestic fuel

Gas Oil
- Feedstock for diesel

Residuum
- Lubrication oils
- Feedstock for asphalt binder production

Increasing Value ($)

Bottom of the Barrel
Polymer-Modified Binders

• The term “polymer” refers to a large molecule formed by chemically reacting many (“poly”) smaller molecules (monomers) to one another in long chains or clusters.

• Physical properties of a specific polymer are determined by the sequence and chemical structure of the monomers from which it is made.
# Why Polymer-Modified Asphalt?

<table>
<thead>
<tr>
<th>Site Feature</th>
<th>Condition Description</th>
<th>Estimated Increase in Service Life, Years&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation soils</td>
<td>Nonexpansive soils; coarse-grained soils</td>
<td>5–10</td>
</tr>
<tr>
<td></td>
<td>Expansive soils; moderately to highly plastic soils (PI&gt;35)</td>
<td>2–5</td>
</tr>
<tr>
<td></td>
<td>Frost susceptible soils in cold climates; moderately to highly frost susceptible (Class 3 and 4)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2–5</td>
</tr>
<tr>
<td>Water table depth</td>
<td>Deep</td>
<td>5–10</td>
</tr>
<tr>
<td></td>
<td>Shallow; adequate drainage</td>
<td>5–8</td>
</tr>
<tr>
<td></td>
<td>Shallow; inadequate drainage</td>
<td>0–2</td>
</tr>
<tr>
<td>Traffic</td>
<td>Low</td>
<td>5–10</td>
</tr>
<tr>
<td></td>
<td>Stop and go–intersections</td>
<td>5–10</td>
</tr>
<tr>
<td></td>
<td>Thoroughfares</td>
<td>3–6</td>
</tr>
<tr>
<td></td>
<td>Heavy loads–special containers</td>
<td>5–10</td>
</tr>
<tr>
<td></td>
<td>Moderate volumes</td>
<td>5–10</td>
</tr>
<tr>
<td></td>
<td>High volumes</td>
<td>5–10</td>
</tr>
<tr>
<td>Climate</td>
<td>Hot</td>
<td>5–10</td>
</tr>
<tr>
<td></td>
<td>Mild</td>
<td>2–5</td>
</tr>
<tr>
<td></td>
<td>Cold</td>
<td>3–6</td>
</tr>
<tr>
<td>Existing pavement condition</td>
<td>HMA</td>
<td>5–10</td>
</tr>
<tr>
<td></td>
<td>Good condition</td>
<td>5–10</td>
</tr>
<tr>
<td></td>
<td>Poor condition; extensive cracking&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1–3</td>
</tr>
<tr>
<td></td>
<td>PCC–jointed plain concrete pavement</td>
<td>3–6</td>
</tr>
<tr>
<td></td>
<td>Good condition&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3–6</td>
</tr>
<tr>
<td></td>
<td>Poor condition; faulting and midpanel cracking&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0–2</td>
</tr>
</tbody>
</table>
discrete polymer particles

polymer strands developing

continue polymer strands developing

more uniform dispersion almost cross-linked
Venezuelan binder modified with 7% EVA, cracked surface, 0.5 x 0.7 mm. Wegan and Brulé, AAPT, 1999.

SMA produced from the modified Venezuelan binder, 0.5 x 0.7 mm. Wegan and Brulé, AAPT, 1999.

Gap-graded HMA produced from the modified Venezuelan binder, 0.5 x 0.7 mm. Wegan and Brulé, AAPT, 1999.
Middle East binder modified with 7% EVA, cracked surface, 0.5 x 0.7 mm. Wegan and Brulé, AAPT, 1999.

SMA produced from the modified Middle East binder, 0.5 x 0.7 mm. Wegan and Brulé, AAPT, 1999.
Rubbers and Plastics

Rubbers (Elastomers) \(\leftrightarrow\) Thermoplastic

Plastics (Plastomers) \(\leftrightarrow\) Thermosetting
Definitions

• Thermoplastic materials soften and become plastic-like when heated but return to their hardened state upon cooling.

• Thermosetting materials flow under stress when heated but, once cooled, cannot be re-softened by heat.
Binder Grade is a function of environment and traffic level
Effect of Loading Rate on Binder Selection

- Example
  - for 55 mph highway
    PG 64-22
  - for 30 mph highway
    PG 70-22
  - for intersections
    PG 76-22

\textit{NJ Standard Grade}

\textit{Slow - Bump one grade}

\textit{Stopped - Bump two grades}
Grading System for Asphalt Binders

- Grading System Based on Climate

  PG 64-22

  Performance Grade  Average 7-day max pavement design temp  Min pavement design temp
Compaction level is a function of traffic and depth of layer.
Mix size is determined by thickness of layer

($\geq 4$ times Designation Name)
1) Nominal Maximum Aggregate Size (mm)

2) Compaction Level
   Low
   Medium
   High

3) Binder Grade

4) Location within the payment

HMA 12.5 H 64 Surface Course
2) Compaction Level
   - Low
   - Medium
   - High

3) Binder Grade

4) Location within the payment

HMA 19M64 Base Course
Dense Graded Mixes
“Ideal” HMA Mixture

- Resistant to permanent deformation
- Resistant to fatigue cracking
- “Impermeable”
- Workable
- Flexible
- Good surface texture
Dense-Graded Mixtures

Percent passing vs. Sieve size raised to the power of 0.45
Dense-Graded Mixtures

- Design procedure follows AASHTO R35
- Used extensively in the U.S.
- Binder content: typically 4.5 to 6%
- Field compacted air void content: typically 6 to 8%
Dense-Graded Mixtures: Advantages

- Good interlock of aggregate particles if compacted well
- Relatively low permeability if compacted well
- Strength and stiffness derived from binder and aggregate structure
- In NJ, generally a “stiff” mix
- Cheaper than other asphalt mixture types
  - Less asphalt binder, RAP
Dense-Graded Mixtures: Disadvantages

• Selection of optimum binder content:
  – Need enough binder for good durability and cracking resistance... BUT
  – Not too much binder for good permanent deformation resistance
  – Optimum asphalt binder content generally results in relatively thin binder film thickness

• Air void content and permeability are not optimum for moisture damage resistance
  – Design for 4% AV, generally placed between 6 to 8%
Open Graded Friction Course

OGFC
Open-Graded Mixtures

Percent passing vs. Sieve size raised to the power of 0.45

Inset: Aggregate particles in a typical open-graded mixture.
Open-Graded Mixtures: Advantages

- High permeability
- High asphalt binder contents resulting in thick binder films
- Lower noise generated by tires as compared with dense-graded mixtures
- Porous nature allows for surface water to drain off surface
  - Reduces splash and spray
- Best applied in areas of faster, continuous traffic with minimal sharp turns
Open-Graded Mixtures: Disadvantages

• Aggregate interlock is shape dependent (generally poor)

• Lower strength and stiffness

• Higher costs associated with polymer-modified binders, higher asphalt content and fibers

• Typically requires additional de-icing applications to maintain “ice free” in cold regions

• Recommended not to be used in areas of high, shear turning and slow moving traffic
  – High, shear turning may cause shoving-type failures
  – Slow moving traffic may clog porous structure
<table>
<thead>
<tr>
<th>Year</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total # Accidents</td>
<td>29</td>
<td>51</td>
<td>44</td>
<td>17</td>
<td>-58.9</td>
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<tr>
<td>Dry Weather Accidents</td>
<td>10</td>
<td>23</td>
<td>13</td>
<td>15</td>
<td>-2.2</td>
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<tr>
<td>Wet Weather Accidents</td>
<td>19</td>
<td>28</td>
<td>21</td>
<td>2</td>
<td>-91.2</td>
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<tr>
<td>Fatalities</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>-100</td>
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<tr>
<td>Total Injuries</td>
<td>25</td>
<td>16</td>
<td>21</td>
<td>0</td>
<td>-100</td>
</tr>
<tr>
<td>Annual Rainfall (in)</td>
<td>42.9</td>
<td>36.0</td>
<td>21.4</td>
<td>52.0</td>
<td>55.5</td>
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<tr>
<td>Total Rain Days</td>
<td>57</td>
<td>56</td>
<td>37</td>
<td>70</td>
<td>40.0</td>
</tr>
</tbody>
</table>
Reduction in Splash and Spray

Not Overlaid Yet
Reduced Pavement-Related Noise

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OGFC</td>
<td>97.2</td>
</tr>
<tr>
<td>Novachip®</td>
<td>98.8</td>
</tr>
<tr>
<td>9.5 mm SMA</td>
<td>98.0</td>
</tr>
<tr>
<td>12.5 mm SMA</td>
<td>100.5</td>
</tr>
<tr>
<td>Micro-Surfacing</td>
<td>98.8</td>
</tr>
<tr>
<td>12.5 mm SP</td>
<td>97.8</td>
</tr>
</tbody>
</table>
Stone Matrix (Mastic) Asphalt

SMA
Stone Mastic (Matrix) Asphalt (SMA) or Gap-Graded Mixtures

Percent passing vs. Sieve size raised to the power of 0.45
SMA Mixtures

- Used as a wearing course (e.g., SMA)
- Mix design methods:
  - AASHTO R46-08, Designing Stone Matrix Asphalt (SMA)
  - Some states have variations of AASHTO R46
- Binder content: typically 5 to 7%
  - Polymer-modified binder and fibers used to minimize draindown
- Compacted air void content: typically 6 to 8%
SMA Materials

• Usually use locally available aggregates:
  – Cubical and tough
  – Modified (lime, antistrip liquids)

• Usually use locally available binders:
  – Modified
SMA Advantages

- Good aggregate interlock
- Low permeability
- Strength and stiffness derived from binder and aggregate structure
- Relatively high binder contents provide good durability
- Best used in areas of heavy traffic where rutting and fatigue cracking are concerns
SMA Disadvantages

- Asphalt suppliers not accustomed to producing – some “growing pains”
- Additional time and effort in material production
  - Aggregates!
- Typically use a modified binder (higher cost)
  - Costs typically prohibit use in “normal” traffic areas
Designing with Asphalt Rubber
Asphalt Rubber Applications

- Asphalt rubber is the process of adding recycled, crumb rubber to hot mix asphalt (called dry process) or the asphalt binder (called wet process) to modify the final mixture.
- Difficult to use in dense-graded mixtures due to residual crumb rubber.
- Best used in gap-graded type mixtures (SMA and OGFC).
Why Put Tire Rubber in Asphalt?

Tire rubber is an engineering tool to:

- Reduce cracking
- Naturally increase asphalt content and asphalt film thickness (providing an increase in durability)
- High asphalt binder viscosity prevents bleeding, flushing and drain-down
- Asphalt enhancement due to rubber increases both the high and low temperature performance
- Limited research has shown the addition of rubber also reduces pavement-related noise
AR-OGFC Uses Approximately 1000 Tires Per Lane-Mile
What Defines Asphalt Rubber?

ASTM D6114

- Asphalt rubber is a blend of asphalt cement, reclaimed tire rubber and certain additives, in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles.
Swelling of Crumb Rubber

Electron-microscope: Immediately after mixing (dry process)
Swelling of Crumb Rubber (cont.)

Electron-microscope: 2 hours after mixing (dry process)
Asphalt Rubber

Methods of adding rubber to asphalt

- **Wet Process** – rubber is added to the liquid asphalt binder before being mixed at the hot mix asphalt plant (i.e., rubber is wet before mixing)

- **Dry Process** – rubber is added at the same time the asphalt and aggregate are mixed (i.e., rubber is dry before mixing)
Designing with Asphalt Rubber

- If wet process, previous SMA and OGFC design procedures can be used
  - Some state agencies utilize the “Arizona” method

- Only exception is evaluating compatibility and modification of crumb rubber with proposed base asphalt binder
Asphalt Rubber Binder

- Brookfield viscosity
- Resilience (ASTM D5329)
- Softening point
- Penetration
- Ductility
Fatigue Cracking Resistance of Asphalt Rubber Mixtures vs. Conventional Mixtures

Years

Percent Cracking

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Overlays/Inlays Neat Asphalt
Asphalt-Rubber
AR-OGFC vs. Unmodified OGFC

### Tire/Pavement Noise Results

(Bennet et al., 2005)