Overview

- Aggregate Pre-Qualification Testing
- Volumetric Mix Design Procedures
  - Dry Batching Aggregates
  - Mixing Specimens
  - HMA Testing (Bulk, Rice, Stability & Flow)
  - Analysis of Marshall Curves
  - Anti-Stripping Test
Introduction

- P 401 hot mix asphalt design used during airport construction
- Mix Design Methodology:
  - Asphalt Institute MS-2, Mix Design Methods (*Best Source*)
- Material requirements for the P 401 mixture will be listed in the contract specifications and are determined by the engineer
- The JMF developed by the contractor is prepared on standard forms (Appendix A)

Summary of FAA Mix Design

1. Aggregates properties are tested (soundness, abrasion, crush count, liquid limit, plasticity index, sand equivalence) and must be acceptable in accordance with requirements
2. Aggregate blends are developed that fall within the general limits established, blends are plotted on a power 0.45 curve
3. Batches of the proposed aggregate blend are prepared, three to five specimens are used for each asphalt content for bulk analysis, another two need to be batched for maximum theoretical specific gravity analysis
Summary of FAA Mix Design

4. 5 asphalt contents will be prepared, each differing by 0.5%, with the intention of bridging the optimum asphalt content.

5. Bulk specific gravity and maximum theoretical specific gravities are measured for each asphalt content, volumetric properties are derived through calculation.

6. Stability and flow properties are tested and measured.

7. Volumetric properties and stability and flow measurements are plotted against asphalt content.

8. Optimum asphalt content is chosen from plots and verified with additional batches.

9. TSR testing is performed at the optimum asphalt content.
**Volumetric Principles**

- Effective Asphalt
- Absorbed Asphalt
  - Coarse & Fine Aggregate

**Volumetrics**

- Air: 4.0%
- Asphalt: 11.0%
- Absorbed Asphalt
- Aggregate: 85.0%
### JOB MIX FORMULA

<table>
<thead>
<tr>
<th>DATE</th>
<th>AIRP PROJECT NO.</th>
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<tbody>
<tr>
<td>11/30/06</td>
<td>Project No. 58-263</td>
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**AIRPORT NAME AND LOCATION**
- Your Airport
  - Anytown, PA

**CONTRACTOR NAME AND LOCATION**
- Best Construction
  - Anytown, PA

**BITUMINOUS PLANT**

<table>
<thead>
<tr>
<th>NAME AND LOCATION</th>
<th>TYPE</th>
<th>CAPACITY</th>
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<tbody>
<tr>
<td>Best Asphalt</td>
<td>CMI Drum Mix</td>
<td>350 Tons/Hour</td>
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**SPECIFICATIONS**
- P401 3/4" Max

**PREPARED BY**

<table>
<thead>
<tr>
<th>NAME</th>
<th>LOCATION</th>
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<tr>
<td>Advance Testing Company</td>
<td>Campbell Hall, NY</td>
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### Initial Material Acceptance Testing

<table>
<thead>
<tr>
<th>Property</th>
<th>Test</th>
<th>Value*</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Course Aggregate</td>
<td>ASTM c131</td>
<td>18.6</td>
<td>&lt;= 40% Surface wear, &lt;= 50% Base</td>
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<tr>
<td>Wear Abrasion</td>
<td>ASTM c88</td>
<td>0.2</td>
<td>&lt;= 10% Loss &lt;= 13%</td>
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<tr>
<td>Soundness Sodium Sulfate</td>
<td>ASTM c68</td>
<td>0.2</td>
<td>&lt;= 10% Loss &lt;= 13%</td>
</tr>
<tr>
<td>Soundness Magnesium Sulfate</td>
<td>ASTM c68</td>
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<td>&lt;= 10% Loss &lt;= 13%</td>
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<tr>
<td>Flat Elongated Pieces</td>
<td>ASTM D4791</td>
<td>5</td>
<td>&lt;= 8% 5:1 Ratio &lt;= 20:1 Ratio</td>
</tr>
<tr>
<td>Crushed Pieces</td>
<td>ASTM c29</td>
<td>100</td>
<td>One Face &gt;= 85%</td>
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<tr>
<td>less than 60,000</td>
<td>ASTM c29</td>
<td>100</td>
<td>Two or more &gt;= 70%</td>
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<tr>
<td>Aircraft Weight</td>
<td>ASTM D2419</td>
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<td>One Face &gt;= 65%</td>
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<tr>
<td>(lbs.)</td>
<td>ASTM D2419</td>
<td>81</td>
<td>Two or more &gt;= 50%</td>
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<tr>
<td>Slag Density</td>
<td>ASTM c29</td>
<td>N/A</td>
<td>&gt;= 70 lb/ft³</td>
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<tr>
<td>Fine Aggregate</td>
<td>ASTM D4318</td>
<td>&lt;= 6</td>
<td>Plasticity Index</td>
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<td>N/A</td>
<td>Plasticity Index (Filler)</td>
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<tr>
<td>Liquid Limit</td>
<td>ASTM D4318</td>
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<td>Liquid Limit</td>
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<td>Sand Equivalent Value</td>
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<td>&lt;= 35%</td>
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<td>Plasticity Index (Filler)</td>
<td>ASTM D242</td>
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<td>&lt;= 4%</td>
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</table>

* Note: All Values shall be listen even if from state certification.

**Producer**
- Best Asphalt
  - Specification: P401 3/4" Max

**Project**
- Your Airport
  - Date: 11/30/06

**Signature**
- C.M. Brower
  - Affiliation: Advance Testing Company, Inc.
FAA P 401 MIX DESIGN

**Job Mix Formula Gradation**

**Producer:** Best Asphalt  
**Spec:** P-401 3/4" Max  
**Project:** Your Airport  
**Date:** 11/30/06

<table>
<thead>
<tr>
<th>1 1/2&quot; Stone</th>
<th>3 1/2&quot; Stone</th>
<th>Stone Sand</th>
<th>Screened</th>
<th>Natural Sand</th>
<th>JAP</th>
<th>Grading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bin No. 1</td>
<td>Bin No. 5</td>
<td>Bin No. 4</td>
<td>Bin No. 3</td>
<td>Bin No. 2</td>
<td>Bin No. 1</td>
<td>Min</td>
</tr>
<tr>
<td>12%</td>
<td>18%</td>
<td>24%</td>
<td>30%</td>
<td>36%</td>
<td>48%</td>
<td>100%</td>
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<tr>
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<td>2</td>
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<td>2</td>
</tr>
</tbody>
</table>

**Notes:** The materials reported above were sampled from the hot bins.

**Signed:** C.M. Bower  
**Affiliation:** Advance Testing Company, Inc.

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**FAA P 401 MIX DESIGN**

**PRODUCER:** Best Asphalt  
**DATE:** 11/30/06  
**PROJECT:** Your Airport

**UNITED STATES BUREAU OF PUBLIC ROADS 0.45 POWER GRADATION CHART**

SIEVE SIZES RAISED TO 0.45 POWER

- **Black:** Blood
- **Upper Limit:**
- **Lower Limit:**
### AGGREGATE PROPERTIES

<table>
<thead>
<tr>
<th>Material</th>
<th>Source</th>
<th>Percent used in final aggregate blend</th>
<th>Bulk specific gravity $G_{sb}$</th>
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<tbody>
<tr>
<td>1/2&quot; Stone</td>
<td>Best Asphalt, Anytown, PA</td>
<td>28</td>
<td>2.729</td>
</tr>
<tr>
<td>3/8&quot; Stone</td>
<td>Best Asphalt, Anytown, PA</td>
<td>18</td>
<td>2.725</td>
</tr>
<tr>
<td>Stone Sand</td>
<td>Best Asphalt, Anytown, PA</td>
<td>24</td>
<td>2.743</td>
</tr>
<tr>
<td>Screenings</td>
<td>Best Asphalt, Anytown, PA</td>
<td>18</td>
<td>2.736</td>
</tr>
<tr>
<td>Natural Sand</td>
<td>Sand Industries, Beach City, PA</td>
<td>12</td>
<td>2.652</td>
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</table>

### ASPHALT PROPERTIES

<table>
<thead>
<tr>
<th>Grade</th>
<th>Source</th>
<th>Specific Gravity</th>
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<tbody>
<tr>
<td>PG 64-28</td>
<td>Citgo, Asphalt</td>
<td>1.036</td>
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</table>

*Note: When a blend of natural sand and stone screenings are used, indicate the percentage of each.*

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### Hot Mix Design Data

**By The Marshall Method**

<table>
<thead>
<tr>
<th>Producer</th>
<th>Best Asphalt</th>
<th>Project</th>
<th>Your Airport</th>
<th>Specific Gravity AC</th>
<th>1.036</th>
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</thead>
<tbody>
<tr>
<td>Specific Gravity Total Aggregate</td>
<td>2.724</td>
<td>Date</td>
<td>11/30/06</td>
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</table>

<table>
<thead>
<tr>
<th>% AC by Weight of Mix</th>
<th>% AC by Weight of Agg</th>
<th>Spec. Height/Im (in)</th>
<th>In Air</th>
<th>In Water</th>
<th>Solid Silt in Air</th>
<th>Bulk volume cc</th>
<th>Bulk Spec. Gravity</th>
<th>Bulk Min. Theor</th>
<th>% V.F.B</th>
<th>Voids</th>
<th>% V.M.A</th>
<th>% V.M.A</th>
<th>Used Wt. PCI (lb/m³)</th>
<th>Measure</th>
<th>Stability BS</th>
<th>Flow (1/3)% (2.5 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>5.3</td>
<td>2 1/4</td>
<td>1210.9</td>
<td>715.4</td>
<td>1213.4</td>
<td>498.0</td>
<td>2.432</td>
<td>2.547</td>
<td>4.52</td>
<td>151.7</td>
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<td>5.0</td>
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<td>2.547</td>
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<td>12.0</td>
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</tbody>
</table>

**Type of Compaction Hammer Used:** Mechanical  
**Number of Blows:** 75

**Signature:** C.M. Brower  
**Affiliation:** Advance Testing Company, Inc.
### Hot Mix Design Data

**By The Marshall Method**

<table>
<thead>
<tr>
<th>Project</th>
<th>Your Airport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Anytown, PA</td>
</tr>
</tbody>
</table>

**Average Bulk Specific Gravity Total Aggregate: 2.724**

<table>
<thead>
<tr>
<th>% AC by Total Weight of Mix</th>
<th>% AC by Weight of Aggregate</th>
<th>Specific Gravity</th>
<th>Bulk Volume</th>
<th>% V.I. B</th>
<th>Voids</th>
<th>% V.I.A.</th>
<th>Unit Wgt. (pcf)</th>
<th>Stability Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
<td>G</td>
<td>H</td>
<td>I</td>
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<td>1219.1</td>
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<td>1/4</td>
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<td>1219.1</td>
<td>495.9</td>
<td>2.457</td>
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<td>1/4</td>
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<td>1225.9</td>
<td>500.0</td>
<td>2.450</td>
</tr>
</tbody>
</table>

**Type of Compaction Hammer Used:** Mechanical

**Number of Blows:** 75

**Signature:**

C. M. Brower

**Affiliation:** Advance Testing Company, Inc.
### FAA P 401 Mix Design

#### Producer:
Tilcon Conn. Inc.

#### Project:
Groton Airport

#### Spec.:
P-401 3/4" MAX

#### Date:
11/30/06

---

### Test Property Curves

<table>
<thead>
<tr>
<th>Percent Asphalt</th>
<th>Unit Wt. (lbs./cu. ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
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<td>5</td>
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<tr>
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<tr>
<td>6.5</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>7.5</td>
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### Stability

<table>
<thead>
<tr>
<th>Percent Asphalt</th>
<th>Stability (lbs.)</th>
</tr>
</thead>
<tbody>
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<td>4.5</td>
<td>50.00</td>
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<td>5</td>
<td>60.00</td>
</tr>
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</tr>
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<td>7</td>
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### Percent Voids in Mineral Aggregate

<table>
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<th>Percent Asphalt</th>
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<th>15.00</th>
<th>20.00</th>
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<tbody>
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<td>15.50</td>
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### Flow

<table>
<thead>
<tr>
<th>Percent Asphalt</th>
<th>Flow (1/100 inches)</th>
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<td>14.00</td>
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<td>5</td>
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<tr>
<td>6.5</td>
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### Center Voids Spec.
3.5
### Hot Mix Design Data

**By The**

**Marshall Method**

<table>
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<th>Producer</th>
<th>Best Asphalt</th>
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<tbody>
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<td>Location</td>
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</tr>
<tr>
<td>Date</td>
<td>11/30/06</td>
</tr>
</tbody>
</table>

| Mix Design | % AC by Weight of Mix | % AC by Weight of Aggregates | Spec. Gravity | Mass Grains | Bulk Volume | Spec. Gravity | % V.I. | Voids | % V.I.M.A. | Unit Wt/ 
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
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<td>G</td>
<td>H</td>
<td>I</td>
<td>J</td>
</tr>
<tr>
<td></td>
<td>5.4</td>
<td>5.7</td>
<td>0.0</td>
<td>2.0</td>
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<td>1212.8</td>
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</tr>
<tr>
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<td>2.0</td>
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<td>1212.2</td>
<td>716.9</td>
<td>1212.2</td>
<td>495.3</td>
<td>2.446</td>
</tr>
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<td>2.0</td>
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<td>1211.3</td>
<td>716.7</td>
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<td>2.445</td>
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<td>5.7</td>
<td>0.0</td>
<td>2.0</td>
<td>5/16</td>
<td>2.445</td>
<td>77.00</td>
<td>3.48</td>
<td>15.08</td>
<td>152.6</td>
</tr>
</tbody>
</table>

**Type of Compaction Hammer Used:** Mechanical

**Number of Blows:** 75

**Signature:**

C.M. Brower

**Affiliation:** Advance Testing Company, Inc.

---

### Maximum Specific Gravity of Bituminous Paving Mixture

**ASTM D 2041 (Rice Method)**

- Maximum Specific Gravity of Bituminous Paving Mixtures = \( G_m \)
- \( G_m \) = Weight of dry sample in air (grams)
- \( G_m \) = Weight of fresh mix with percent air voids to \( T \% \) (25°C) grams
- \( G_m \) = Weight of fresh mix with 25°C water and sample at \( T \% \) (25°C) grams
- \( G_m = A/(A-D-E) \)

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>P-401.34&quot; MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Producer</td>
<td>Best Asphalt</td>
</tr>
<tr>
<td>Location</td>
<td>Anytown, PA</td>
</tr>
<tr>
<td>Project</td>
<td>Your Airport</td>
</tr>
<tr>
<td>Date</td>
<td>11/30/06</td>
</tr>
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</table>

**One Point Verification at:** 5.4 % AC

### Test Results

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### JMF Test Properties at Optimum Asphalt Content

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<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Mixing Temp., °F</td>
<td>320</td>
<td>See Binder Specification</td>
</tr>
<tr>
<td>Compaction Temp., °F</td>
<td>298</td>
<td>See Binder Specification</td>
</tr>
<tr>
<td>Compactive Eff. No. of Blows</td>
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<td>75 Blows</td>
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<tr>
<td>Asphalt Content, %</td>
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<tr>
<td>Marshall Stability, lbs.</td>
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<td>2150 Min.</td>
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<td>Flow Value, 0.01 in.</td>
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<td>Air Voids, %</td>
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<td>V.M.A., %</td>
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<td>15 Min</td>
</tr>
<tr>
<td>Unit Weight, Ibs</td>
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<td>V.F.B, %</td>
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<tr>
<td>Tensile Strength Ratio</td>
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<td>75% Min.</td>
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**Producer:** Best Asphalt

**Project:** Your Airport

**Date:** 11/30/06

**Notes:**
- *Fill in other values from the project specifications.

**Signature:** C.M. Brower

**Affiliation:** Advance Testing Company, Inc.

### Job Mix Formula Gradation

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<thead>
<tr>
<th>Sieve Size</th>
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<th>Bin No. 4</th>
<th>Bin No. 3</th>
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<th>GMAT</th>
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<td>Max</td>
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<tr>
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<td>100</td>
<td>100</td>
<td>100</td>
<td>Min</td>
<td>Max</td>
</tr>
</tbody>
</table>

**Notes:** The materials reported above were from the hot bins

**Signed:** C.M. Brower

**Affiliation:** Advance Testing Company, Inc.

**Cold Feed:**

<table>
<thead>
<tr>
<th>Bin No</th>
<th>Setting</th>
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<td>4</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>
**Preliminary Procedures**

- Aggregate properties determined as per Appendix A
- JMF is developed using either plant bins or stockpiles (hot bins are highly recommended at a batch plant)

**Source Properties**

- **LA Abrasion**
  - Indicates an aggregate’s ability to withstand breakdown during handling, mixing and placement (compaction)
- **AASHTO T96**
- **“Impacts”**
  - Coarse grained Granite/Gneiss
    - Brittle in LA though perform well in field
  - Carbonates/Shale
    - Perform well in LA but degrade in field when wet
Wear-Abrasion (ASTM C 131)

- Measures the resistance to wearing as aggregate is subjected to impact and grinding
- Ensures that aggregate will not wear excessively during shipment and production
- Standard graded aggregate is subjected to impact and grinding by steel spheres inside a hollow steel chamber

Wear-Abrasion (ASTM C 131)

- A small shelf lifts the aggregate and steel spheres and as the chamber rotates, creating the impact
- The wear value is a measurement of the percent of loss (by mass) of the sample after it has been subjected to a specified number of revolutions in the chamber
Wear-Abrasion (ASTM C 131)

- This loss is measured over the 1.7 mm (#12) sieve
- Appendix A stipulates maximum 40% wear for surface courses, maximum 50% wear for base courses

Soundness (ASTM C 88)

- The soundness test subjects aggregate particles to alternating cycles of soaking in a salt solution (either sodium or magnesium sulfate) and drying in an oven regulated at 110±5°C (230±9°F)
- Salts permeate the voids of the aggregate during soaking and expand during drying, simulating the expansive pressures of water
Soundness (ASTM C 88)

- The soundness value is also a measure of loss of particles after the sample has been subjected to a specified number of soaking and drying cycles.
- Appendix A stipulates the maximum loss as 10% for sodium sulfate tests and 13% for magnesium sulfate tests.

Flat & Elongated (ASTM D 4791)

- Flat and elongated particles in an aggregate are measured using a proportional caliper device set to the appropriate ratios required by the agency.
- Flat AND elongated test: length to thickness is compared.
Flat and Elongated Particles

- Generally believed higher F & E detrimental to pavement performance
- ASTM D 4791
  - Highly variable at low ratios (< 5:1) F & E which could mask the relationship to actual pavement performance

Flat & Elongated (ASTM D 4791)

- Flat & Elongated (ASTM D 4791)
  - Flat or elongated particles in an HMA mixture may degrade more quickly than non flat or elongated particles, thereby reducing the durability of the pavement
  - Appendix A limits the amount of these particles in the coarse aggregate to no more than 8% at a 5:1 ratio and no more than 20% at a 3:1 ratio
Flat and Elongated

- Flat and Elongated
  - Changes with stockpile handling
  - Breakdown during the compaction process
  - Increasing F & E can improve VMA (under Marshall compaction)

Crushed Pieces

- In order to produce pavements that are resistant to deformation, it helps to use angular aggregate particles
- Angular aggregates tend to interlock and resist deformation even after repeated loading
- The crushed pieces requirement in Appendix A is meant to ensure the aggregate angularity is maintained
Crushed Pieces

• Requirements for crushed pieces in coarse aggregate are dependent upon anticipated loading of pavement

<table>
<thead>
<tr>
<th>Aircraft Gross Weight</th>
<th>One Fractured Face</th>
<th>Two Fractured Faces</th>
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<tbody>
<tr>
<td>&lt; 27,200 kg (60,000 lbs)</td>
<td>65</td>
<td>50</td>
</tr>
<tr>
<td>• 27,200 kg (60,000 lbs)</td>
<td>85</td>
<td>70</td>
</tr>
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</table>

Crushed Pieces

• FAA Eastern Region Lab Procedures indicate that a fractured face “shall be equal to at least 75% of the smallest mid-sectional area of the piece”
• When two fractured faces are contiguous, the angle between the planes of fractures shall be at least 30 degrees to count as two fractured faces
• Fractured faces shall be obtained by crushing
Coarse Aggregate Angularity

- Coarse Aggregate Angularity
  - “Fractured Faces”
  - Identified as 2nd most important predictor of pavement performance
    - Aggregate “interlock” and internal friction
- ASTM D5821
  - Highly subjective visual examination

Sand Equivalent

- Test yields a relative value of clay-like fines in material
  (higher values indicate more sand like material)
- It is assumed clay like materials will cause de-bonding, or lack of adhesion in the mixture
Sand Equivalent (ASTM D 2419)

- The sand equivalent value is a measure of the relative amount of fines in the fine aggregate sample.
- This is performed by placing the fines in suspension in a solution of calcium chloride above the sand.

Sand Equivalent (ASTM D 2419)

- The sand equivalent value itself is an expression of the sand reading in terms of the clay reading.
- Higher sand equivalent values therefore mean less clay like fines.
- Appendix A requires at least 45% for sand equivalent.
**Sand Equivalent**

- Several studies have shown that the sand equivalent does not correlate to:
  - Material passing #200 in manufactured sand
  - Performance tests or moisture sensitivity
    - Hamburg
    - TSR

---

**Specific Gravity**

- All matter has weight (mass) and occupies space (volume)
- Volumetrics are the relationships between mass and volume
- Density = MASS/VOLUME
Specific Gravity

- Specific Gravity of component materials in mix must be precisely defined because they are used in all calculations converting mass to volume.

Specific Gravity

- Specific Gravity or "Relative Density" relates mass to volume.
- Ratio of the solid unit weight of a substance relative to the weight of de-aired, water at room temperature displaced by that object.
  - Based on principles of buoyancy discovered by Archimedes in his "Eureka" moment.
**Bulk Specific Gravity**

- **Gsb or Bulk Dry Specific Gravity**
- The ratio of the weight in air of a unit volume of aggregate to an equal volume of water. This unit volume of aggregates is composed of the solid particle, permeable voids, and impermeable voids.
  - We use this value in HMA calculations because it is assumed that asphalt will be absorbed into the permeable voids.

\[
G_{sb} = \frac{A}{B - C}
\]

- \(A\) = Oven Dry Weight
- \(B\) = SSD Weight
- \(C\) = Weight in Water
**Gsb SSD (Saturated Surface Dry)**

- The ratio of the weight in air of a unit volume of aggregate including the weight of water within the voids filled to the extent achieved by submerging in water for a minimum of 15 hours.
  - Primarily used in PCC because of contribution of water in pores to water-cement ratio
**Apparent Specific Gravity**

- **Gsa = A / (A – C)**

- **Where:**
  - A = Oven Dry Weight
  - C = Weight in Water

**Specific Gravity**

- **Absorption**
  - The increase in weight of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles
  - % Absorption = ((B-A) / A) x 100

- **Where**
  - A = Oven dry weight
  - B = SSD Weight
Absorption

- Absorption

Specific Gravity

FAA P 401 MIX DESIGN
Specific Gravity

- Test Methods for Specific Gravity
  - Fine Aggregate
    - AASHTO T 84/ASTM 128
  - Coarse Aggregate
    - AASHTO T 85/ASTM 127

Specific Gravity of Coarse Aggregates (ASTM C 127)

- Specific gravity of coarse aggregate is performed in the lab on samples that have soaked for 24 ± 4 hours in water at room temperature
- Of particular interest to the HMA designer is the measurement of the stone's bulk specific gravity, $G_{sb}$
**Bulk Specific Gravity of Coarse Aggregates (ASTM C 127)**

- The bulk specific gravity uses the bulk volume of the aggregate particle, which includes the volume of pore space within the particle occupied by water.
- This requires that the mass of the particles used for the volumetric measurement is determined in an SSD (saturated, surface dry) condition.

**Specific Gravity of Fine Aggregates (ASTM C 128)**

- The specific gravity of the fine aggregate needs to be determined as well.
- This method uses a glass pycnometer of a known volume to determine the water displaced by the sample.
Specific Gravity of Fine Aggregates (ASTM C 128)

- The bulk specific gravity ($G_{sb}$) of the fine aggregate is also measured at an SSD condition.
- The SSD condition of the sand is often discerned using an inverted cone with a tamper.

Combined Bulk Specific Gravity

- The bulk gravities of the combined aggregates in the mixture have a significant effect on the overall density of the mixture.
- The combined bulk gravity of all constituents, based on their percentage in the blend, is used to calculate VMA (Voids in Mineral Aggregate).

$$G_{sb} = \frac{(P_1 + P_2 + P_3)}{G_1 + \frac{P_2}{G_2} + \frac{P_3}{G_3}}$$

- $G_{sb}$ = Bulk specific gravity of combined aggregate
- $P_i$ = Percent by mass of each aggregate in blend
- $G_{sb}$ of each aggregate in the blend

FAA P 401 MIX DESIGN
Liquid Limit (ASTM D 4318)

- The liquid limit test measures the water content of a material at the point it passes from a solid to a liquid state.
- This test is used in conjunction with the plastic limit test to determine the plasticity index.

Plasticity Index (ASTM D 4318)

- A fine aggregate with plasticity index of greater than 6 would indicate an aggregate with an excessive amount of cohesive fines.
- These cohesive fines might weaken the bond between the liquid binder and the aggregate particles, decreasing the durability of the HMA mixture.
- When mineral filler is used in the HMA mixture, a plasticity test is also required.
**Plasticity Index (ASTM D 4318)**

- The plasticity index is a measure of the range of moisture contents that a sample will act in a plastic fashion but not in a liquid fashion.
- Generally used with cohesive soils, this procedure is used on fine aggregates proposed for use in HMA to ensure that they exhibit minimal plasticity.

**Best Practices**

- Particle shape—cubical is desired but we need to work with what is locally available. Some F and E helps.
- Gsb—critical for all aggregates. Increase frequency as variability increases.
- Awareness of all properties and impact.
- Visual inspection imperative in identifying a change.
Gradation

• Combined aggregate gradation impacts mixture stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage.

Gradation

• Ideal gradation provides adequate space for minimum amount of asphalt binder and air voids, while ensuring adequate stability.
  • #200 / 0.075 µm
Gradation

- 0.45 Power Chart
- Incremental sieves double in size from fine to coarse along x-axis (intermediate fractions have been added as sieves sizes get larger)
- Maximum density line determined from sieve size raised to 0.45 power
  - Densest packing of materials (Nijboer, 1961)

Variability Analysis

#1a Stone Variation passing #4

![Variability Analysis Chart]

- Plant: Patonsville, Cresapville, East Kirksville, Onlein, Fairviewville, Dragonville
- Standard Deviation: #1a L7, #1a L8, #1a L9, #1a L10

FAA P 401 MIX DESIGN
Normal Distribution & Empirical Rule

- Most variants are normally distributed
- The standard deviation or dispersion is an indication in the “spread” of the data
- Data falls within the normal distribution (within dispersion) 68, 95, 99.7%

Gradation Variability

- Given the standard deviation of #4 screen at East Kingston facility of #1A stone of 10%, at 45% batch how often will sample fail gradation tolerance of +/- 5% which will result in change out of spec air voids?
Aggregate Gradation Requirements

- Proposed combined gradation (particle distribution) is plotted on a 0.45 power gradation chart.
- Grading curve must closely parallel the curves for the upper and lower JMF limits.
- Grading curve should display no abrupt changes.
Volumetric Mix Design Overview

- Must prepare lab specimens for bulk analysis (Gmb) and loose mix samples for theoretical density (Gmm) over a range of asphalt contents for testing
- Minimum of three bulk specimens per asphalt content (4 recommended)
- Typically five or six different asphalt contents (separated by 1/2 %) are used
- Design must display two asphalt contents above “optimum”, and two below optimum

Volumetric Mix Design Overview

- Test results on each of the blends are plotted graphically to show physical properties
- Optimum asphalt content is selected from graphical representations of test data
- Mix properties plotted against asphalt content as part of volumetric mix design method
Mixing Equipment

• Pans, metal, flat bottom for the heating of test specimens
• Oven and hot plate for heating asphalt and aggregate to required temperatures

Mixing Equipment

• Mixing bowl, round, approx. 4 liter capacity for mixing asphalt & aggregate
• Scoop, for batching aggregates
Mixing Equipment

- Container for heating asphalt (hopper with control valve recommended)
- Thermometers, armored glass, or metal stem (50 to 450° F with sensitivity of 5.0° F) for determining temperature of aggregate, asphalt, and asphalt mixture
- Balance, 4.5Kg capacity, sensitive to 0.5g for weighing aggregates and asphalt

Mixing Equipment

- Mixing spoons, spatulas, and rodding implement
- Mechanical shaker for sieves
- Large spatula for spading and hand mixing
- Mixing apparatus, mechanical recommended, commercial bread dough mixer with 4 liter (4 quart) capacity or larger with two metal mixing bowls and two wire stirrers
Compaction Pedestal

- 8” x 8” x 8” wooden post capped with a 12” x 12” x 1” steel plate
- Wooden post: oak, yellow pine, or other wood with dry unit weight of 42 to 48 pcf
- Wooden post secured by four angle brackets to a solid concrete slab
- Steel plate firmly fastened to post (no movement at all)
- Pedestal installed level, post is plumb, and no movement during compaction process

Compaction Mold

- Base plate, forming mold, and collar
- Forming mold has inside diameter of 4 inches and height of 3 inches
Compaction Hammer

- Flat circular tamping face, 3 7/8 inches (98.4mm diameter)
- 10 lb (4.5 kg) weight
- 18” (457 mm) drop of hammer onto specimen
- Spring tension device to hold compaction mold in place on compaction pedestal

Equipment

- Extrusion jack, for extruding compacted specimen from mold
- Gloves, insulated, for handling hot equipment
- Marking crayons for labeling specimens
Aggregate Batching

• Prepare at least 3 but no more than 5 batches for each asphalt content
• Aggregates in batches shall be dried to constant mass at 221 to 230°F (105 to 110°C) and separated by dry-sieving into the desired fractions
• Aggregate batches consist of the proposed blend of aggregates to be used in the HMA

Aggregate Batching

• Each particle size for each aggregate constituent is placed into each batch
• The size of the batches (around 1200 g) is intended (when mixed with the liquid binder) to produce bulk specimens that are 2.5±0.5 inches in height
Material Heating

- Aggregate is placed into an oven regulated 50°F (20°C) higher than the mixing temperature
- Liquid binder should be heated to the mixing temperature (not more than 1 hour prior to mixing) and covered
- Mixing should not begin until the aggregate and liquid binder have stabilized at the appropriate temperature

Mixing & Compaction Temperatures

- Mixing and compaction temperatures determined by the temperature viscosity chart
- Mixing temperature is defined as that range of temperatures that produces a viscosity of 0.17±0.02 kPa (170±20 centistokes) in the liquid binder (asphalt cement)
- Compaction temperature is defined as that range of temperatures that produces a viscosity of 0.28±0.03 kPa (280±30 centistokes) in the liquid binder (asphalt cement)
Preparation of Molds/Hammer

- Thoroughly clean the specimen mold assembly and the face of the compaction hammer
- Heat them on a hot plate (or in boiling water) to a temperature between 200–300°F (93–149°C)
- Use a protection disk in the bottom of each mold prior to charging the mold with HMA
Mixing HMA

- Keep all materials up to temperature as much as possible
- A hot plate may be used to keep the mixing bowl warm, however heat should be baffled to prevent localized overheating
- Charge heated bowl with aggregates, dry mix thoroughly

Mixing HMA

- Form a crater in the dry aggregate
- Weigh out the appropriate mass of liquid binder (asphalt cement) into the batch in accordance with accumulated batch weights
- Mix HMA with mechanical mixer or by hand as quickly and thoroughly as possible
- Mix HMA so that liquid binder coverage is uniform
Compacting Specimens

• Charge the specimen mold with the mixture

Compacting Specimens

• Spade the mixture vigorously with a heated trowel or spatula 15 times around the exterior and 10 times over the interior of the specimen
Compacting Specimens

• Remove the specimen mold collar and smooth the surface of the sample to a slightly rounded shape

• Determine the temperature of the sample, it should be within the compaction temperature range

• If the specimen is cold, it shall be discarded; reheating is not allowed
Compacting Specimens

- Replace collar on mold, place protection disk on top of specimen
- Place hammer apparatus into mold, apply appropriate number of blows (50 or 75, as indicated in contract specifications)
- Turn specimen over to compact the other side

When compaction is completed, remove specimen from apparatus, remove protection disks, and allow it to cool.
Compacting Specimens

• Cool long enough so that when it is extruded with the specimen extruder no deformation will result.

Test Procedure

• Each compacted specimen is subjected to a bulk test, stability and flow test, and voids analysis.
• Two maximum theoretical specific gravity samples are prepared and tested at each asphalt content in order to determine the void level of the bulk specimen.
**Bulk Test Equipment**

- Balance, 2 kg. minimum capacity, sensitive to 0.1g, to enable bulk specific gravity samples to be calculated to at least 4 significant figures
- Balance should be equipped with suspension apparatus to permit weighing specimen in water
- Water bucket, suitable for weighing bulk specimen (equipped with overflow outlet)
- Thermometers, for bulk test/rice test water batch to verify 77˚F (25˚C)

**Bulk Specific Gravity \( (G_{mb}) \) ASTM D 2726**

- Care should be taken to avoid distortion of specimen when removing from mold
- Specimens shall be free of foreign materials prior to testing
- Determine the mass of the specimen after it has been standing in air at room temperature for at least one hour, designate as mass A
**Bulk Specific Gravity (G_{mb}) ASTM D 2726**

- Immerse the specimen in a water bath at 77±1.8°F (25±1°C) for 3 to 5 minutes
- Maintain proper water level on weigh below apparatus with overflow outlet

**Bulk Specific Gravity (G_{mb}) ASTM D 2726**

- Record mass of immersed specimen as C mass
**Bulk Specific Gravity \((G_{mb})\) ASTM D 2726**

- Remove the specimen from the bath and quickly blot specimen with a damp towel (remove surface moisture of specimen, but leave internal moisture)
- Record mass of SSD (saturated, surface dry) specimen as \(C\)
- Bulk specific gravity \((G_{mb}) = \frac{A}{B-C}\)
- Report \(G_{mb}\) to nearest 0.001

**Stability & Flow Equipment**

- Marshall stability press, electric powered and designed to apply loads to test specimens through semicircular testing heads at a constant rate of 2 inches (51 mm) per minute
- Equipped with proving ring for determining applied force load
- Stability testing head assembly
- Flow meter for determining the amount of deformation at maximum load
Stability & Flow Equipment

- Testing machine may have automatic plotting function
- Stability & Flow Equipment
  - Water bath, at least 6 inches deep and thermostatically controlled to 140°±1.8°F (60±1°C), with perforated false bottom 2 inches above bath bottom
  - Thermometers, for hot stability bath with a range of 134-144°F (57-62°C)

Stability & Flow Testing

- Immerse the specimens in water bath at 140±1.8°F (60±1°C) for 30 to 40 minutes prior to testing
- Clean inside surfaces of testing heads, maintain temperature of testing heads at 70-100°F (21-38°C)
- Lubricate guide rods on testing head so that they move freely
- Check that proving ring dial is zeroed properly
- Check that flow meter is zeroed properly
Stability & Flow Testing

• With everything in readiness, remove specimen from hot bath, dry surface, and place on lower testing head
• Make sure specimen is aligned and centered in testing head properly
• Place upper testing head on specimen, fit entire assembly into stability press
• Place flow meter on forward guide rod and adjust to zero as necessary

Stability & Flow Testing

• Begin to apply load to specimen at rate of 2 inches per minute
• Observe stability press dial during loading, keep flow meter in position
• Watch stability dial for peak load and record
• The instant the stability dial begins to decrease remove the flow meter from the guide rod
Stability & Flow Testing

- Record the flow reading as a whole number, i.e. 15, but recall this means that the deformation of the specimen was 0.15 inches
- This specification requires that the stability and flow readings must be obtained within 30 seconds after removal of the specimen from the hot water bath

Stability & Flow Testing

- If an automatic plot was produced by the device, record the peak load and flow from the peak of the curve
Stability & Flow Testing

- If a manual device was used, the stability dial reading may need to be converted to a pounds of force measurement based on a machine specific conversion chart.
- This measured stability may also need to be corrected based on its height or volume.
- The measured stability is multiplied by a correlation ratio derived from the Stability Correlation Ratio table in order to determine the corrected stability.

Maximum Theoretical Specific Gravity (ASTM D 2041)

- The maximum theoretical specific gravity is the ratio of the mass of a given volume of separated and cooled hot mix asphalt at 25°C (77°F) to the mass of an equal volume of water at the same temperature.
Maximum Theoretical Specific Gravity (ASTM D 2041)

- The sample is subjected to a partial vacuum (required to be $3.7 \pm 0.3$ kPa (25.5 to 30 mm Hg) for $15\pm2$ minutes) in order to remove the air trapped between the particles of the sample.

- This mass to volume measurement expresses the density of the mixture as if it had no air voids.

- The maximum Specific Gravity ($G_{mm}$) is used in conjunction with Bulk Specific Gravity ($G_{mb}$) to determine Percent Air Voids ($P_a$) in compacted bituminous materials.
**Density and Voids Analysis**

- Average the bulk specific gravity values ($G_{mb}$) for all test specimens of a given asphalt content.
- Values obviously in error shall not be included in the average (consult ASTM D 2726 for advice on outliers).
- Determine the unit weight for each average $G_{mb}$ by multiplying the $G_{mb}$ by 62.4 for pcf or 1000 for kg/m³.

**Air Void ($P_a$) Calculation**

- Air Voids ($P_a$) are determined using the following formula:
- $P_a = 100 - [100(G_{mb}/G_{mm})]$
Air Void ($P_a$) Calculation

- $G_{mb} = 2.334$
- $G_{mm} = 2.416$
- $P_a = 100 - [100(2.334/2.416)]$
- $P_a = 100 - (100 \times 0.9661)$
- $P_a = 100 - 96.61$
- $P_a = 3.39$

VMA (Voids in Mineral Aggregate) Calculation

- VMA is determined using the following formula:

$$VMA = 100 - \left[ \frac{(G_{mb} \times P_s)}{G_{sb}} \right]$$
VMA (Voids in Mineral Aggregate) Calculation

- \( G_{mb} = 2.344 \)
- \( P_s = 93.04 \)
- \( G_{sb} = 2.651 \)
- \( VMA = 100 - \frac{(2.344 \times 93.04)}{2.651} \)
- \( VMA = 100 - \frac{218.1}{2.651} \)
- \( VMA = 100 - 82.26 \)
- \( VMA = 17.74 \)
Preparation of Graphs

• Create a graphical plot for each of the following:
  – Stability (corrected) vs. Asphalt content
  – Flow vs. Asphalt Content
  – Unit weight vs. Asphalt Content
  – Percent air voids vs. Asphalt Content
  – Percent VMA vs. Asphalt Content
• For each plot connect the values with a smooth curve that best fits all values
### Test Property

<table>
<thead>
<tr>
<th>Test Property</th>
<th>Aircraft Gross Weight ≥60,000 lbs</th>
<th>Aircraft Gross Weight &lt;60,000 lbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Blows</td>
<td>75</td>
<td>50</td>
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<tr>
<td>Stability, minimum pounds (newtons)</td>
<td>2,150 (9564)</td>
<td>1,350 (6005)</td>
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<tr>
<td>Flow range, 0.01 in (0.25 mm)</td>
<td>10-14</td>
<td>10-18</td>
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<tr>
<td>Air Voids, percent</td>
<td>2.8-4.2</td>
<td>2.8-4.2</td>
</tr>
<tr>
<td>Percent VMA, minimum</td>
<td>Dependent on maximum particle size of HMA mixture, see below</td>
<td>16</td>
</tr>
<tr>
<td>1/2 in (12.5 mm) maximum size</td>
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<td>15</td>
</tr>
<tr>
<td>3/4 in (19.0 mm) maximum size</td>
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<td>14</td>
</tr>
<tr>
<td>1 in (25.0 mm) maximum size</td>
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<td>13</td>
</tr>
<tr>
<td>1 1/4 in (31.25 mm) maximum size</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Analysis of Graphs

- Optimum asphalt content is determined as the asphalt content that produces a void level in the HMA at the mid point of the specified range (2.8 to 4.2 percent air)
- If the other plotted values do not meet the required criteria, or are marginal, or if the mixture meets parameters but is not compactable in the field, the aggregate blend must be revised or a new source of aggregates secured and a new JMF developed
Verification of JMF

- When the selected optimum asphalt content does not coincide with the asphalt content used in the trial specimens, and additional set of specimens shall be prepared.
- The optimum asphalt content is added to the specimens and they are tested as described to verify the actual results duplicate those anticipated from the curves.
Once the optimum asphalt content has been determined and verified, samples need to be prepared and tested for moisture sensitivity and the potential for stripping.

These tendencies can be gauged using ASTM D 4867, Standard Test for Effect of Moisture on Asphalt Concrete Paving Mixtures, otherwise known as the TSR (Tensile Strength Ratio) test.

This procedure subjects samples specially prepared at specific void level, saturated with water under vacuum, and “tortured” with some combination of hot water exposure (140°F for 24 hrs) and possibly freeze/thaw cycles (see Note 5 in ASTM).
**TSR (Tensile Strength Ratio)**

- Using a set of specimens as a control, the tortured specimen’s ability to withstand cracking in a special TSR head used in the stability press is compared to the non-tortured specimens.
- This number (TSR) is required by the FAA to be at least 75% (that is, the tortured specimens must have at least 75% of the tensile strength as the non-tortured specimens).

- In addition, the surface of the specimens is examined for any evidence of asphalt cement stripping from the surface of the aggregates.
- If the mixture fails this procedure, anti-stripping agent needs to be added to the mixture to produce the desired result.