MAXAM AQUABlack Warm Mix Asphalt Technology

Submitted in Accordance with

*Caltrans Approval Process for Warm Mix Asphalt Technologies (23 March 2011)*

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# Table of Contents

Chapter 1  Contact Details .................................................................................................................. 1

Chapter 2  Technology Details ............................................................................................................ 2

Chapter 3  Laboratory Test Results ..................................................................................................... 4
  3.1  Walla Walla, Washington Project .......................................................................................... 4
    3.1.1  Mix Design ............................................................................................................... 4
    3.1.2  Laboratory Testing................................................................................................... 4
      3.1.2.1  Dynamic Modulus ..................................................................................... 4
      3.1.2.2  Moisture-Susceptibility and Rutting ......................................................... 5
      3.1.2.3  Beam Fatigue .......................................................................................... 10
      3.1.2.4  Flow Number .......................................................................................... 11
      3.1.2.5  Effect on Blinder Grade........................................................................... 11

Chapter 4  Field Projects ................................................................................................................... 14
  4.1  Caltrans I-80 Emigrant Gap .................................................................................................. 14
    4.1.1  Background ........................................................................................................... 14
    4.1.2  Mix Design ............................................................................................................. 15
    4.1.3  Production and Placement .................................................................................... 15
    4.1.4  Field Sampling and Testing .................................................................................... 15
    4.1.5  Field Performance ................................................................................................. 17
  4.2  Arizona DOT Projects ........................................................................................................... 22
    4.2.1  Background ............................................................................................................ 22
    4.2.2  Mix Design ............................................................................................................. 23
    4.2.3  Production and Placement .................................................................................... 23
    4.2.4  Field sampling and Testing .................................................................................... 24
    4.2.5  Field Performance ................................................................................................. 24

References ....................................................................................................................................... 33

## List of Figures

- Figure 2.1 — AQUABlack WMA System: Mixing Chamber and Pressure Valve ......................... 2
- Figure 2.2 — AQUABlack Control Box......................................................................................... 3
- Figure 2.3 — AQUABlack Touch Screen Control Panel................................................................. 3
- Figure 3.1 — Dynamic Modulus Comparison of HMA and WMA............................................. 6
- Figure 3.2 — AAHTO T283 Test Results .................................................................................... 7
- Figure 3.3a — Hamburg Wheel Tracking Results: Rutting Rate ............................................ 8
- Figure 3.3b — Hamburg Wheel Tracking Results: Rut Depth at 20,000.................................. 9
- Figure 3.3c — Stripping Inflection Point...................................................................................... 9
- Figure 3.4 — Fatigue Resistance Curves...................................................................................... 10
Figure 3.5 — Box Plot of Flow Number Results ................................................................................................................................. 12
Figure 4.1 — Schematic of I-80 Emigrant Gap Project .......................................................................................................................... 14
Figure 4.2 — Emigrant Gap Project QA Density Data ............................................................................................................................ 16
Figure 4.3 — Emigrant Gap Project QA Hveem Stability Data .................................................................................................................. 16
Figure 4.4 — WMA at Yuba Gap Exit (WB Lane 2) ............................................................................................................................... 18
Figure 4.5 — WMA at Yuba Gap Exit Close-up (WB Lane 2) ..................................................................................................................... 18
Figure 4.6 — WMA at Yuba Gap Exit (WB Lane 1 Shoulder) .................................................................................................................... 19
Figure 4.7 — WMA at Yuba Gap Exit Close-up (WB Lane 1 Shoulder) ................................................................................................. 19
Figure 4.8 — WMA at Lang Road Exit .................................................................................................................................................. 20
Figure 4.9 — WMA at Lang Road Exit Close-up (WB Lane2) .................................................................................................................. 20
Figure 4.10 — HMA at Rainbow Exit (WB Lane 1) ............................................................................................................................. 21
Figure 4.11 — HMA at Rainbow Exit Close-up (WB Lane 1) ................................................................................................................ 21
Figure 4.12 — Location of AZDOT WMA Projects with AQUABlack ................................................................................................. 22
Figure 4.13 — Schematic of AZDOT Field Projects with HMA Control and WMA Test Sections ................................................................ 26
Figure 4.14a — Typical Appearance of Surface Texture in Field Project #1 ....................................................................................... 29
Figure 4.14b — Typical Appearance of Surface Texture in Field Project #2 ....................................................................................... 29
Figure 4.15a — Straight-Edge Placement in Wheelpath of WMA Section of Field Project #1 ........................................................................ 30
Figure 4.15b — Straight-Edge Placement in Wheelpath of WMA Section of Field Project #2 ........................................................................ 30
Figure 4.16a — Full-Width Cracking in HMA of Field Project #2 ........................................................................................................ 31
Figure 4.16b — Cracking in Shoulder of WMA of Field Project #1 .................................................................................................... 32

List of Tables

Table 3.1 — Aggregate Proportions ...................................................................................................................................................... 4
Table 3.2 — Job Mix Formula and Volumetric Properties .................................................................................................................. 5
Table 3.3 — Tests Conducted on Plant-Produced Materials ............................................................................................................. 5
Table 3.4 — Tests Conducted on Plant-Produced Materials ............................................................................................................. 6
Table 3.5 — AAHOT T283 Test Results ........................................................................................................................................... 7
Table 3.6 — Hamburg Wheel Tracking Tests Results ....................................................................................................................... 8
Table 3.7 — Flexural Fatigue Results ............................................................................................................................................. 10
Table 3.8 — Tukey-Kramer Statistical Groupings for Flow Number Test Results .................................................................................... 13
Table 3.9 — Statistical Comparison of Confined Flow Number Test Data .......................................................................................... 13
Table 3.10 — True Grade of Binders from Plant-Produced Materials ............................................................................................... 13
Table of Contents

Table 4.1 – Emigrant Gap Mix Design Summary ................................................................. 15
Table 4.2 – Layer Thicknesses ......................................................................................... 22
Table 4.3 – AZDOT Mix Design Summary ................................................................. 23
Table 4.4 – AZDOT HMA Control and WMA Test Section Summary ......................... 25
Table 4.5 – Summary Data for Field Project #1 .............................................................. 27
Table 4.6 – Summary Data for Field Project #2 .............................................................. 28
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Chapter 2 — Technology Details (1)

There are a number of ways to classify warm mix asphalt (WMA) technologies: by degree of temperature reduction and/or by the means of achieving that temperature reduction; i.e., by additive (organic, wax, chemical, and surfactant) or by mechanical foaming. MAXAM’s AQUABlack® fits into the latter category. It is a process in which a small amount of water is introduced into hot asphalt via a foaming nozzle. When a given volume of water turns to steam at atmospheric pressure, it expands by several orders of magnitude. When the water is dispersed in hot asphalt and turns to steam (from contact with the hot asphalt), it results in an expansion of the binder phase and corresponding reduction in the mix viscosity.

The Maxam AQUABlack® system consists of a small mixing chamber containing a high velocity water nozzle that foams the asphalt when the two streams (water and asphalt cement) are combined. The mixing chamber is inserted into the existing asphalt cement feed line just prior to the asphalt cement entering the drum (Figure 2.1). Typical water pressure is 700 to 1000 lb/in². When the asphalt cement is foamed it initially expands 12 to 14 times, but almost instantly collapses to 65% to 80% of the volume. Any water that is not entrained in the bubbles is dissipated. Approximately one pint of water is retained in a 25-ton load of WMA.

Figure 2.1 – AQUABlack WMA System: Mixing Chamber and Pressure Valve

Valves, gauges and filters for the water injection system are contained in a control box (Figure 2.2) that is located close to the mixing chamber. The control box equipment is monitored and controlled by a touch-screen control panel (Figure 2.3) that is mounted in the control house. The operator sets the feed rate for the plant on the control panel and the system automatically calculates the amount of water to be injected into the warm mix asphalt, and sets the water pump drive to the proper output rate. The flexible system retrofits onto any plant and can be installed over a weekend. The unit comes completely assembled and installation requires attachment to the asphalt cement line and water source. System components include the following:

PLC (Programmable Logic Controller) Based Touch Screen Control Panel
The touch-screen Control Panel is mounted in the control house and easily connected to the metering system using multi-conductor cable. When the operator sets the maximum tons on the control panel, the system automatically calculates the correct amount of water to be injected and sets the water pump drive to the proper output rate. A mass flow meter (Endress & Hauser) monitors the flow rate and sounds a warning if it goes beyond the optimum range. The control system interfaces directly with the main plant to control to enact a “hot stop” if needed.
High-pressure Variable Speed Metering System
The high-pressure variable speed metering system comes completely pre-piped and prewired, and is enclosed in a weather tight enclosure. The enclosure is heated for cold weather operation. The system is equipped with an automatic compressed air purge that cleans water from the delivery line upon shutdown to prevent freezing.

AQUABlack® Foaming Gun
The AQUABlack® all stainless Foaming Gun comes with all required water hose and hot oil jumpers for installation. It is inserted into the existing asphalt cement line just prior to entering the drum. Access nozzle service ports means that no disassembly is required for inspection.

MSDS – not applicable
Chapter 3 — Laboratory Test Results (2)

3.1 Walla Walla, Washington Project

As part of NCHRP Project 09-47A (Properties and Performance of Warm Mix Asphalt Technologies), a warm-mix asphalt field demonstration was conducted in Walla Walla, Washington, to compare conventional hot-mix asphalt (HMA) with WMA produced using the AQUABlack® asphalt foaming system. The National Center for Asphalt Technology (NCAT) documented the demonstration and evaluated both mixes.

3.1.1 Mix Design

The material used for this trial consisted of a 12.5-mm nominal maximum aggregate size (NMAS) Superpave mix design with a compactive effort of 100 gyrations. The mix design used for the HMA was also used for the WMA without any changes. The aggregate used for the design was basalt and natural sand blend including 20% reclaimed asphalt pavement (RAP). The materials percentages used for mix design submittal and production are presented in Table 3.1. The Washington State Department of Transportation (WSDOT) allows the substitution of up to 20% RAP without the use of blending charts. The binder, provided by Idaho Asphalt was a PG 64-28. A liquid anti-stripping agent, Unichem 8162, manufactured by BJ Services Company, was added to the asphalt binder at a rate of 0.25% by weight of liquid binder. The job mix formula and volumetric properties are shown in Table 3.2. For this field trial, water was added at a rate of 2.5% by weight of asphalt binder.

<table>
<thead>
<tr>
<th>Aggregate Type</th>
<th>%, Mix Design</th>
<th>%, Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Chips</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>Fine Chips</td>
<td>76</td>
<td>62</td>
</tr>
<tr>
<td>Natural Sand</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>RAP</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

3.1.2 Laboratory Testing

Laboratory testing of plant-produced material, as shown in Table 3.3, was undertaken to allow a comparison of the HMA and WMA properties.

3.1.2.1 Dynamic Modulus

The stiffness of the mixes was evaluated using AASHTO TP 79-09, Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Hot-Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT). Three specimens per mix were prepared from re-heated plant-produced material in accordance with AASHTO PP60-09, Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC). These specimens were then cored with a 100-mm core drill and cut to yield 150-mm tall specimens. The target air-void content of the final prepared samples was 7 ± 0.5%. There is no standard pass/fail criterion for AASHTO TP 79; therefore, the master curves of the dynamic modulus developed from the testing were used to compare WMA stiffness to that of HMA. Results of the dynamic modulus testing are shown in Table 3.4 and Figure 3.1. As illustrated in Figure 3.1, the HMA and WMA stiffnesses are virtually identical. Admittedly, the use of re-heated materials for testing may not represent the ideal circumstance. However, because specimens for dynamic modulus testing require coring (to 100-mm diameter) and cutting (to 150-mm height), the challenges of doing so in a mobile lab are obvious. Furthermore, the emphasis is on relative performance. Since both HMA and WMA specimens were subjected to the same re-heating protocol, though not ideal, it is logical to conclude that the effects on both, particularly in terms of binder hardening, are comparable.
3.1.2.2 Moisture-Susceptibility and Rutting

AASHTO T 283-07, Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage, is the most commonly used moisture-susceptibility test used by state agencies. The standard acceptance criterion is a tensile-strength ratio that is greater than or equal to 0.80 per AASHTO M 323. Specimens were compacted in the NCAT mobile laboratory from plant-produced mix without reheating the mix.

### Table 3.2 – Job Mix Formula and Volumetric Properties

<table>
<thead>
<tr>
<th>Sieve Size, mm (in)</th>
<th>JMF Specifications</th>
<th>Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.0 (¾”)</td>
<td>100</td>
<td>99-100</td>
</tr>
<tr>
<td>12.5 (½”)</td>
<td>94</td>
<td>90-100</td>
</tr>
<tr>
<td>9.5 (%)</td>
<td>81</td>
<td>90 Max</td>
</tr>
<tr>
<td>4.75 (#4)</td>
<td>52</td>
<td>47-57</td>
</tr>
<tr>
<td>2.36 (#8)</td>
<td>34</td>
<td>28-58</td>
</tr>
<tr>
<td>1.18 (#16)</td>
<td>23</td>
<td>30-38</td>
</tr>
<tr>
<td>0.6 (#30)</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>0.3 (#50)</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>0.15 (#100)</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>0.075 (#200)</td>
<td>5.6</td>
<td>2.0-7.0</td>
</tr>
<tr>
<td>AC, %</td>
<td>5.2</td>
<td>0-10</td>
</tr>
<tr>
<td>Air Voids, %</td>
<td>3.7</td>
<td>2.5-5.5</td>
</tr>
<tr>
<td>VMA, %</td>
<td>14.7</td>
<td>12.5 Min</td>
</tr>
<tr>
<td>VFA, %</td>
<td>75</td>
<td>65-75</td>
</tr>
<tr>
<td>D/A Ratio</td>
<td>1.2</td>
<td>0.6-1.6</td>
</tr>
</tbody>
</table>

### Table 3.3 – Tests Conducted on Plant-Produced Materials

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Outcome</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Modulus (AASHTO TP 79)</td>
<td>Stiffness</td>
<td>3 Specimens per Mix</td>
</tr>
<tr>
<td>Moisture Susceptibility (AASHTO T 283)</td>
<td>Moisture Susceptibility</td>
<td>3 Unconditioned, 3 Conditioned per Mix</td>
</tr>
<tr>
<td>Hamburg Wheel-Tracking Test (AASHTO T 324)</td>
<td>Moisture Susceptibility and Rutting Resistance</td>
<td>Two Twin Sets per Mix</td>
</tr>
<tr>
<td>Flexural Fatigue (AASHTO T 321-07)</td>
<td>Fatigue Resistance</td>
<td>6 per mix</td>
</tr>
<tr>
<td>Flow Number Confined (AASHTO TP 79)</td>
<td>Permanent-Deformation Resistance</td>
<td>3 Specimens per Mix</td>
</tr>
<tr>
<td>Flow Number Unconfined (NCHRP 09-43 Method)</td>
<td>Permanent-Deformation Resistance</td>
<td>3 Specimens per Mix</td>
</tr>
</tbody>
</table>
### Table 3.4 – Tests Conducted on Plant-Produced Materials

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Frequency (Hz)</th>
<th>HMA</th>
<th>WMA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Modulus (k/in²)</td>
<td>Phase Angle (deg)</td>
<td>Modulus (k/in²)</td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
<td>1116.7</td>
<td>18.8</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1639.8</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>2192.0</td>
<td>10.7</td>
</tr>
<tr>
<td>20</td>
<td>0.1</td>
<td>323.0</td>
<td>30.6</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>635.0</td>
<td>26.5</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1088.7</td>
<td>21.2</td>
</tr>
<tr>
<td>40</td>
<td>0.01</td>
<td>87.4</td>
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<td></td>
<td>0.1</td>
<td>111.2</td>
<td>22.8</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>178.5</td>
<td>28.4</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>358.8</td>
<td>31.3</td>
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### Figure 3.1 – Dynamic Modulus Comparison of HMA and WMA
Table 3.5 and Figure 3.2 summarize the results of the moisture susceptibility testing conducted in accordance with AASHTO T 283. The whiskers in Figure 3.2 represent ± one standard deviation. The tensile strength ratios (TSR) for the HMA and WMA were 0.89 and 0.86, respectively, both of which exceed the AASHTO R 35 criterion of 0.80.

Table 3.5 – AAHTO T283 Tests Results

<table>
<thead>
<tr>
<th>Mix</th>
<th>Conditioned</th>
<th>Saturation (%)</th>
<th>Air Voids, (%)</th>
<th>Tensile Strength (lb/in²)</th>
<th>TSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMA</td>
<td>Yes</td>
<td>71.1</td>
<td>6.6</td>
<td>96.6</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70.1</td>
<td>6.8</td>
<td>106.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>78.0</td>
<td>7.2</td>
<td>102.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0.0</td>
<td>6.7</td>
<td>121.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0</td>
<td>6.9</td>
<td>119.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0</td>
<td>6.9</td>
<td>115.4</td>
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<tr>
<td>HMA</td>
<td>Yes</td>
<td>70.1</td>
<td>6.9</td>
<td>102.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>71.6</td>
<td>6.6</td>
<td>129.8</td>
<td></td>
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<td></td>
<td></td>
<td>72.6</td>
<td>6.9</td>
<td>126.9</td>
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<td></td>
<td>No</td>
<td>0.0</td>
<td>6.9</td>
<td>138.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0</td>
<td>6.5</td>
<td>132.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0</td>
<td>7.0</td>
<td>134.2</td>
<td></td>
</tr>
</tbody>
</table>

AASHTO T 324, *Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)*, is a loaded wheel test used to evaluate the stripping and rutting potential of a mix. Some state agencies and researchers use this test in lieu of, or in conjunction with, AASHTO T283 to evaluate moisture susceptibility. Specimens were compacted to 6 inches in diameter by 3.75 inches in height in the NCAT mobile lab without reheating. The target air-void content was 7 ± 0.5%. Specimens were conditioned and tested at 122°F (50°C). The stripping inflection point, rutting rate, and total rut depth were determined for each mix.
The results of the Hamburg testing are shown in Table 3.6 and Figure 3.3. The average rutting rate (Figure 3.3a) of the WMA was slightly higher than that of the HMA; however, the variability of the HMA rutting rate was greater than that of the WMA. A t-test indicated that there was no statistical difference between the two mean rutting rates at a significance level of 0.05. The WMA rut depth was slightly greater than the HMA rut depth (Figure 3.3b); however, both were less than the commonly used criterion of 10mm at 20,000 passes.

Table 3.6 – Hamburg Wheel Tracking Tests Results

<table>
<thead>
<tr>
<th>Mix</th>
<th>Air Voids of Cut Sample (%)</th>
<th>Rutting Rate (mm/hr)</th>
<th>Total Rut Depth (mm) (Based on Rate)</th>
<th>Stripping Inflection Point (cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMA</td>
<td>6.6</td>
<td>2.969</td>
<td>11.8</td>
<td>9000</td>
</tr>
<tr>
<td></td>
<td>7.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.8</td>
<td>2.283</td>
<td>9.1</td>
<td>8100</td>
</tr>
<tr>
<td></td>
<td>6.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.7</td>
<td>1.315</td>
<td>5.2</td>
<td>7400</td>
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<td></td>
<td>5.9</td>
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<td></td>
<td></td>
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<tr>
<td>HMA</td>
<td>7.0</td>
<td>1.709</td>
<td>6.8</td>
<td>5700</td>
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<td></td>
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<td></td>
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<td>7.1</td>
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<td></td>
<td>7.4</td>
<td></td>
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<td></td>
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</tbody>
</table>

Figure 3.3a – Hamburg Wheel Tracking Results: Rutting Rate
The stripping inflection points (Figure 3.3c) were determined in accordance with AASHTO T 324. The average stripping inflection point of the WMA was greater than that of the HMA. The HMA showed higher moisture susceptibility than the WMA, though the HMA still exceeded the minimum acceptable stripping inflection point (5000 cycles or 10,000 passes) for moisture resistance during the Hamburg Wheel-Track testing.

3.1.2.3 Beam Fatigue

Flexural fatigue testing was performed in accordance with AASHTO T 321-07. Six specimens were tested for each mix: three each at 300 and 600 microstrain at a temperature of 20 ± 0.5°C. The specimens were compacted in a kneading beam compactor, and then trimmed to the dimensions of 380 ± 6 mm in length, 63 ± 2 mm in width, and 50 ± 2 mm in height. The target void content was 7 ± 1 percent. The samples were compacted from re-heated plant-produced material.
Data acquisition software was used to record load cycles, applied loads, strain levels and beam deflection. The software calculates the beam stiffness with each loading iteration. At the beginning of each test, the initial beam stiffness was calculated by the data acquisition software after 50 conditioning cycles. AASHTO T 321-07 was used to define beam failure as a 50% reduction in beam stiffness in terms of number of cycles until failure. The fatigue endurance limit was determined in accordance with the procedure developed in NCHRP project 09-38. Test results are shown in Table 3.7 and Figure 3.4.

<table>
<thead>
<tr>
<th>Mix</th>
<th>Microstrain Level</th>
<th>Beam ID</th>
<th>Cycles to Failure</th>
<th>Endurance Limit (Microstrain)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMA</td>
<td>600</td>
<td>W3</td>
<td>9,420</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>W5</td>
<td>9,560</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>W6</td>
<td>12,730</td>
<td></td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>H57</td>
<td>411,050</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H58</td>
<td>637,530</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>H59</td>
<td>420,910</td>
<td></td>
</tr>
<tr>
<td>HMA</td>
<td>600</td>
<td>H51</td>
<td>11,600</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H52</td>
<td>11,140</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>H53</td>
<td>13,560</td>
<td></td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>W7</td>
<td>451,280</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>W8</td>
<td>378,610</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>W9</td>
<td>241,410</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.4 — Fatigue Resistance Curves
As shown in Figure 3.4 there is little difference in the fatigue resistance of the WMA and the HMA. To compare the data statistically, a two-sample t-test ($\alpha = 0.05$) was performed to compare the WMA and HMA cycles to failure at the different strain levels. There was no statistical difference between the WMA and HMA fatigue life at either 300 microstrain or 600 microstrain. As shown in Table 3.7 the WMA had a slightly higher fatigue endurance limit which indicates that the WMA can endure a higher strain level than the HMA without accruing permanent damage. Therefore, the bending beam fatigue results indicate that the WMA should have equal or better fatigue performance than the HMA.

### 3.1.2.4 Flow Number

Flow Number testing is conducted to determine when tertiary flow occurs. The greater the number of loading cycles that occur before tertiary flow initiates, the more resistant the mix to permanent deformation. Specimen fabrication and testing were conducted in accordance with AASHTO PP 60-09, *Standard Practice for Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)*, and AASHTO TP 79-09, *Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)*, respectively. Since AASHTO TP 79-09 does not specify whether to test the specimens confined or unconfined, a set of samples for each mix was tested confined and another set was tested unconfined. The confined specimens were compacted from plant-produced mix re-heated materials. Two sets of unconfined specimens were available. A limited number of AMPT samples compacted in the field were available in addition to samples that were re-heated for compaction.

One set of flow number specimens was tested in accordance with the recommendations from NCHRP 09-43; i.e., unconfined with a deviator stress of 87 lb/in$^2$. The target testing temperature was 53°C, which is the LTPP 50% reliability high temperature for Walla Walla, WA, adjusted to a depth of 20 mm in the pavement structure. The other specimens were tested with a confining pressure of 10 lb/in$^2$ and a deviator stress of 100 lb/in$^2$. The testing temperature was 53°C. Each confined flow number test ran the full 20,000 cycles before being terminated by the software. To determine the relative deformation resistance of these mixes, two parameters were measured: the permanent deformation of each sample after 20,000 loading cycles; and the slope of the steady-state portion of the rutting curve (after initial consolidation). For consistency, this was calculated as the slope of the sample deformation between cycle 10,000 and cycle 20,000.

Figure 3.5 shows a box plot of the unconfined flow number test results. The results of a Tukey-Kramer statistical analysis are shown in Table 3.8. While the average flow number values for the re-heated mixes were higher than those compacted in the field lab, the statistical analysis indicates that the results were not statistically different results for either the WMA or HMA. The statistical analysis also indicated that for the lab-compacted samples, the HMA had a statistically higher flow number than the WMA, indicating the HMA would be more resistant to rutting than the WMA. However, for the field-compacted samples, the flow number results for WMA and HMA were not statistically different.

Table 3.9 shows the statistical comparisons of the confined flow number data. The data show no statistical difference between the WMA and HMA microstrain (at 20,000 testing cycles) or for the slope of the steady-state portion of the deformation curves. Recall that these samples were fabricated in the laboratory from re-heated plant-produced mix. The statistical comparisons from the confined flow number testing do not agree with those from the unconfined flow number testing.

Considering all of the flow number results, the evidence is not conclusive with regard to the relative potential for rutting of WMA compared to HMA. This finding is consistent with the results of the Hamburg testing.

### 3.1.2.5 Effect on Binder Grade

To determine the effect of the WMA technology process on the binder grade, recovered binders from both HMA and WMA mixes were tested and classified in accordance with AASHTO M-320. The results are shown in Table 3.10.
Figure 3.5 ─ Box Plot of Flow Number Results
Table 3.8 — Tukey-Kramer Statistical Groupings for Flow Number Test Results

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Mix Compaction</th>
<th>Mean Flow Number</th>
<th>Tukey-Kramer Statistical Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>Lab Re-heated</td>
<td>426.3</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Field-Compacted</td>
<td>331.7</td>
<td>A, B</td>
</tr>
<tr>
<td>WMA</td>
<td>Lab Re-heated</td>
<td>226.7</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>Field-Compacted</td>
<td>199.7</td>
<td>B</td>
</tr>
</tbody>
</table>

(α = 0.05)

Table 3.9 — Statistical Comparison of Confined Flow Number Test Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mix Type</th>
<th>WMA</th>
<th>HMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Microstrain at 20,000 cycles</td>
<td></td>
<td>47219</td>
<td>45020</td>
</tr>
<tr>
<td>Standard Deviation of Microstrain at 20,000 Cycles</td>
<td></td>
<td>4202.0</td>
<td>2222.6</td>
</tr>
<tr>
<td>Average Steady-State Rutting Slope</td>
<td></td>
<td>0.688</td>
<td>0.670</td>
</tr>
<tr>
<td>Standard Deviation of Steady-State Rutting Slope</td>
<td></td>
<td>0.071</td>
<td>0.059</td>
</tr>
</tbody>
</table>

(α = 0.05)

Table 3.10 — True Grade of Binders from Plant-Produced Materials

<table>
<thead>
<tr>
<th>Section</th>
<th>HMA</th>
<th>WMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Temperature (°F)</td>
<td>max 340</td>
<td>294</td>
</tr>
<tr>
<td></td>
<td>min 314</td>
<td>276</td>
</tr>
<tr>
<td></td>
<td>avg 324.6</td>
<td>284.6</td>
</tr>
<tr>
<td></td>
<td>std dev 8.6</td>
<td>5.4</td>
</tr>
<tr>
<td>Temperature of Sampled Mix (°F)</td>
<td>avg 310</td>
<td>270</td>
</tr>
<tr>
<td>Temperature Behind Screed (°F)</td>
<td>max 287</td>
<td>255</td>
</tr>
<tr>
<td></td>
<td>min 251</td>
<td>246</td>
</tr>
<tr>
<td>In-Place Density (%Gmm)</td>
<td>avg 94.7</td>
<td>94.4</td>
</tr>
<tr>
<td></td>
<td>std dev 0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Core Tensile Strengths (lb/in²)</td>
<td>avg 160.9</td>
<td>165.4</td>
</tr>
<tr>
<td></td>
<td>std dev 10.7</td>
<td>8.3</td>
</tr>
<tr>
<td>Recovered Binder True Grade (production mix)</td>
<td>77.9 + 21.6 - 26.0</td>
<td>75.3 + 20.6 - 27.9</td>
</tr>
<tr>
<td>Recovered Binder True Grade (cores)</td>
<td>72.9 + 22.2 - 26.1</td>
<td>75.7 + 19.2 - 25.9</td>
</tr>
</tbody>
</table>
Chapter 4 – Field Projects

Field projects submitted for consideration include one from Caltrans and two from Arizona DOT (AZDOT). The Caltrans project is addressed in section 4.1. The AZDOT projects are addressed in section 4.2.

4.1  Caltrans I-80 Emigrant Gap (3)

4.1.1  Background

The Emigrant Gap project, on Interstate 80 (I-80) in Placer and Nevada Counties between the Emigrant Gap and the Rainbow Interchanges (PM 56.1-66.3), rehabilitates pavement, structures, drainage, and updates signing and lighting. The Traffic Index (TI) is 12.5; AADT is 53,500 with 13% trucks. A schematic of this portion of I-80 showing the project limits may be seen in Figure 4.1. Construction, in accordance with Caltrans QC/QA Section 39-4, was undertaken by Teichert. Construction began in Spring 2010 and is expected to be complete in Fall 2013.

![Figure 4.1 – Schematic of I-80 Emigrant Gap Project](image)

The asphalt concrete layer placed on this project serves as a bond-breaker between the severely distressed existing PCC the 1.15 feet of new PCC. Prior to the final two-inch lift of asphalt concrete (HMA or WMA), leveling courses of varying thickness were placed. The compaction requirement for the leveling courses was waived. Between June and late October 2010 approximately 65,000 tons of mix were placed, about 6,000 tons of which was WMA produced with the Maxam AQUABlack system. The HMA was placed between June and September 2010; the WMA during October 2010. Because of the nearly 2½-hour haul from Teichert’s Marysville plant, WMA was chosen for the late season paving.

4.1.2  Mix Design

A ¾-inch Type A mix with 15% (RAP) was used for the HMA and WMA. Table 4.1 presents a summary of the Hveem mix design information. The PG 64-28 binder was supplied by Paramount. Aggregate was from Teichert’s Hallwood plant.
4.1.3 Production and Placement

Plant Production
Both HMA and WMA were produced in a Cedar Rapids dryer-drum plant at temperatures which varied from 310 to 325°F. The WMA was produced with Maxam AQUABlack system. The production capacity of the plant is 350 tons per hour. The plant utilized a 111 million BTU burner that dried and heated aggregates in an 8-ft x 32-ft-drum. The liquid asphalt was controlled using a Micro Motion device and was introduced in the dual drum configuration manufactured by Gencor. The plant is equipped with a 65,000 cubic feet per minute bag house for pollution control.

Delivery, Placement & Compaction
The following is a general description of the placement process used for both the WMA and HMA sections. The asphalt delivery trucks were single-trailer belly-dumps. The surface was milled to the depth required by the plans and a tack coat was applied to the milled surface. The WMA and the HMA were placed in a single windrow directly on the milled surface. Typical temperature in the windrow was 270°F, though compaction of the WMA was achieved at temperatures of approximately 220°F to 240°F. The paving equipment consisted of a Blaw-Knox PF200B paver and a Cedar Rapids Model MS-2 transfer vehicle directly in front of the paver. Initial compaction was achieved using a pair of dual steel wheel rollers, a CAT CB64 rolled the outside of the lane, while a CAT CB564D rolled the inside portion of the lane. Intermediate compaction was achieved using a CAT PS360C seven-wheel pneumatic roller with tire pressure approximately 100 lb/in². Finish rolling was done with a CAT CB564D steel wheel roller. The rolling pattern was established by quality control personnel and typically consisted of the following: breakdown – three to five passes with vibratory; intermediate compaction with pneumatic; and the finish rolling with static steel-wheel.

Weather
During HMA paving (June through September) the weather was warm and the skies were clear with temperatures ranging from 72°F to 88°F. During the WMA paving (October), skies were clear with temperatures ranging from 47°F to 60°F. The average temperature during WMA paving was 54°F.

4.1.4 Field Sampling and Testing

Caltrans QA data, provided by Transportation Engineering Technician Bob Treadwell, have been summarized as shown in Figures 4.2 and 4.3. Note that HMA data are from Lots 1 to 7; no QA data for lot 6 were provided. WMA data are from Lot 7. In both figures, the average value for each lot is shown by the heavy blue line. The range in average lot density (percent of theoretical maximum) for the HMA was 92.5% to 94.6%; for the WMA the average lot density was 92.5%. The range in average lot Hveem stability for the HMA was 42 to 44; for the WMA the average lot Hveem stability was 41. Both density and stability data meet the project criteria.
Figure 4.2 – Emigrant Gap Project QA Density Data

Figure 4.3 – Emigrant Gap Project QA Hveem Stability Data
4.1.5 Field Performance

A visual, field-performance assessment was made on 6 February 2012, about 16 months after opening to traffic, by Bob Treadwell of Caltrans, and Mike Ray and Willy Gruenthal of Teichert. The visual assessment was limited to the westbound lanes of the project as PCC has already been placed on the eastbound lanes. Additionally, because of safety concerns the visual survey focused on the WMA placed at the Yuba Gap and Lang Road exits, post miles 59.05 and 56.22, respectively. For the HMA, the survey was done at the Rainbow exit, post mile 66.22. Of particular interest was the presence of rutting, cracking and raveling. Typical conditions of the HMA and WMA sections are shown in Figures 4.4 to 4.12.

Rutting
A 10-ft straight edge was placed at the aforementioned locations to identify possible wheelpath rutting. As is evident from close-ups of the pavement surface shown in Figures 4.5, 4.7, 4.9 and 4.11 to 4.12, there is no rutting in either the WMA or HMA sections.

Cracking
As noted previously, both HMA and WMA section were carefully inspected for visual signs of cracking. As may be seen in Figures 4.4 to 4.12, there is no evidence of cracking in either the WMA or HMA sections.

Raveling
There was very limited, minor severity raveling observed in the wheelpaths of both the HMA and WMA sections (Figures 4.5, 4.9 and 4.11). This minor loss of material is attributed to tire-chain wear rather. Note the surface texture of the westbound (WB) lane 1 shoulder shown Figures 4.6 and 4.7. Despite the fact that the WMA material in the WB lane 1 shoulder carried the eastbound traffic for approximately 6 months, there is no evidence of raveling.
Figure 4.4 – WMA at Yuba Gap Exit (WB Lane 2)

Figure 4.5 – WMA at Yuba Gap Exit Close-up (WB Lane 2)
Figure 4.6 – WMA at Yuba Gap Exit (WB Lane 1 Shoulder)

Figure 4.7 – WMA at Yuba Gap Exit Close-up (WB Lane 1 Shoulder)
Figure 4.8 – WMA at Lang Rd Exit (WB Lane 2)

Figure 4.9 – WMA at Lang Rd Exit Close-up (WB Lane 2)
Figure 4.10 – HMA at Rainbow Exit (WB Lane 1)

Figure 4.11 – HMA at Rainbow Exit Close-up (WB Lane 1)
4.2 Arizona DOT Projects (4)

4.2.1 Background

Significant sampling and testing were undertaken by Arizona DOT to document the construction and performance of a mill and inlay project on the Interstate 10 (I-10). The Tucson-Benson Highway portion of I-10, shown in Figure 4.12, from Houghton Road (~ MP 276) to Mountain View Ranch (~ MP 281) was built by Granite Construction using the Maxam AQUABlack WMA technology. The ten year one way traffic level is 37 million ESALs; AADT is 40,000 with 23% trucks (4).

Data were collected by AMEC Earth and Environmental (formerly MACTEC) on production and laydown temperatures, aggregate properties, mix quality control and compaction testing. Also samples were taken from the roadway (cores) and from the windrow to compare the moisture susceptibility of the WMA technology to that of conventional HMA. All the test data may be found in the AMEC report submitted to Arizona DOT; i.e., reference 4. The project consisted of five WMA test sections and five control, i.e., conventional HMA. The test sections were selected so that the WMA and the HMA pavements had equal thicknesses. This would allow a comparison of the compaction characteristics of each mix and relative performance.

Paving took place between August 4 and September 23, 2010.

Table 4.2 shows the structural pavement thicknesses for the mainline portion of the project.

<table>
<thead>
<tr>
<th>Mileposts on I-10 (EB and WB)</th>
<th>Highway Section</th>
<th>Mill Depth (inches)</th>
<th>HMA &amp; WMA (inches)</th>
<th>AR-ACFC (inches)</th>
<th>Fog Coat</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.P. 276.00 to 281.30</td>
<td>Travel Lanes</td>
<td>5</td>
<td>4½</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Passing Lanes</td>
<td>3 ½</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inside Shoulder</td>
<td>3</td>
<td>3</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Outside Shoulder</td>
<td>½</td>
<td></td>
<td>½</td>
<td>Yes</td>
</tr>
</tbody>
</table>
4.2.2 Mix Design

The HMA and WMA used 20% Recycled Asphalt Pavement (RAP) and 1% Portland Cement as an admixture. Table 4.3 presents a summary of the Marshall mix design information. The asphalt binder used on the project was a PG 70-10 supplied by Western Refining. The aggregate for the project was a crushed stone produced by Granite Construction from its Swan pit. When 20 % RAP is used, AZDOT requires that the mix design include the recovered properties of the combined asphalt cement. The results of that testing as well as the complete mix design information may be found in the AMEC report.

<table>
<thead>
<tr>
<th>% Asphalt</th>
<th>% Effective Asphalt</th>
<th>Dust to Eff Asphalt Ratio</th>
<th>VMA %</th>
<th>Voids Filled %</th>
<th>Effective Air Voids %</th>
<th>Corrected Marshall Stability (lb)</th>
<th>Flow (0.25 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>4.1</td>
<td>0.92</td>
<td>16.1</td>
<td>67.6</td>
<td>6.8</td>
<td>4433</td>
<td>12</td>
</tr>
<tr>
<td>5.0</td>
<td>4.5</td>
<td>0.82</td>
<td>16.2</td>
<td>65.2</td>
<td>5.6</td>
<td>4850</td>
<td>13</td>
</tr>
<tr>
<td>5.5</td>
<td>5.2</td>
<td>0.74</td>
<td>16.4</td>
<td>71.4</td>
<td>4.7</td>
<td>4540</td>
<td>14</td>
</tr>
</tbody>
</table>

The volumetric properties at the design binder content meet all the criteria outlined in Section 416-2 of Arizona DOT’s standard specifications (5).

4.2.3 Production and Placement

Both HMA and WMA were produced in a Cedar Rapids dryer-drum with a production capacity of 350 tons per hour. Three, 300-ton capacity hot storage silos were on site during production. The aggregates were introduced to the plant by way of a 30-inch conveyor that transports the stockpiled crushed aggregates over a tunnel feed layout. Washed products were introduced via alternate cold feed bins which intersect the main tunnel feed. The plant utilized a 111 million BTU burner that dried and heated aggregates in an 8-ft x 32-ft-drum. The liquid asphalt was controlled using a Micro Motion device and was introduced in the dual drum configuration manufactured by Gencor. The plant is equipped with a 65,000 cubic feet per minute bag house for pollution control.

The following is a general description of the placement process used for both the WMA and HMA sections. The asphalt delivery trucks were single-trailer belly-dumps. The surface was milled to the depth required by the plans and a tack coat was applied to the milled surface. The WMA and the HMA were placed in a single windrow directly on the milled surface. The paving equipment consisted of a Blaw-Knox PF200B paver and a Cedar Rapids Model MS-2 transfer vehicle directly in front of the paver. On those sections where the paving thickness was five inches (travel lanes), the first lift of WMA or HMA was placed in a single ribbon approximately 3½ inches in depth with a final compacted depth at approximately 3 inches. The second lift had an uncompacted depth of 2½ inches and the compacted depth was approximately 2 inches. On other sections WMA and HMA were placed in one lift with the uncompacted depth ½ thicker than the compacted depth (3 inches for the inside shoulder and the passing lane). Initial compaction was achieved using a pair of dual steel wheel rollers, a CAT CB64 rolled the outside of the lane, while a CAT CB564D rolled the inside portion of the lane. Intermediate compaction was achieved using a CAT PS360C seven-wheel pneumatic roller with tire pressure approximately 100 lb/in$^2$. Finish rolling was done with a CAT CB564D steel wheel roller. The rolling pattern was established by quality control personnel and typically consisted of the following: breakdown – three to five passes with vibratory; intermediate compaction with pneumatic; and the finish rolling with static steel-wheel.

Typically the milling operation began about 7pm and paving began about 10pm. During paving the weather was warm and skies were clear. Ambient temperature during paving was 72°F to 88°F.
4.2.4 Field Sampling and Testing

As noted in section 4.2.1, five control (HMA) and test (WMA) sections were included in AZDOT’s study. These five control and test sections correspond to five nights of paving as shown in Table 4.4. Field projects # 1 and # 2 are located in the eastbound and westbound lanes, respectively. The field projects, outlined in heavy black lines, are shown schematically in Figure 4.13. The HMA is shaded in grey; the WMA in green. As may be seen in Figure 4.13, both field projects include the travel and passing lanes.

Tables 4.5 and 4.6 present a summary of the data from Field Project #1 and # 2, respectively. Each table contains the basic information about each night’s paving: mix type; date paved, and tons placed. Also, these summary tables include the results of the acceptance testing conducted by AZDOT. The average in-place air void contents for the WMA for Field Project 1 were 6.9% and 6.7%; for the corresponding HMA, the average air void contents were 6.6% and 7.3%. The average in-place air void contents for the WMA for Field Project 2 were 6.3% and 5.8%; for the corresponding HMA, the average air void contents were 6.4% and 7.0%.

The last section of the tables contains information on the placement operation - the production and placement temperatures, and the compaction sequence. The average production temperatures for the WMA and HMA for Field Project # 1 were 263°F to 267°F and 297°F to 310°F, respectively. The average production temperatures for the WMA and HMA for Field Project # 2 were 263°F to 268°F and 295°F to 297°F, respectively. The average temperatures were based on daily plant pyrometer traces at 9 pm, 11 pm, 1 am and 3 am. Placement temperatures for the WMA and HMA for Field Project # 1 ranged from 247°F to 280°F and 247°F to 280°F, respectively. Placement temperatures for the WMA and HMA for Field Project # 2 were 255°F to 280°F and 280°F to 303°F, respectively.

4.2.5 Field Performance

A visual, field-performance assessment was made on 7 December 2011 by Sadar Chalabe (AZDOT) and Rita Leahy, about 15 months after opening to traffic. Mr. Chalabe and Dr. Leahy walked the entire length of both field projects to inspect for rutting, cracking, and raveling. The typical appearance of the wearing course (½-inch AR-ACRFC [asphalt rubber-asphalt concrete friction course]) of Field Projects # 1 and # 2 is shown in Figure 4.14.

Rutting
A 10-ft straight edge was used at random locations to identify possible wheelpath rutting. As is evident from Figure 4.15 there is no evidence of rutting in the WMA sections of either Field Project # 1 or # 2.

Cracking
As noted previously, each HMA control and WMA test section was carefully inspected for visual signs of cracking. As shown in Figure 4.16, there was some cracking observed in the HMA Section of Field Project # 2 and the WMA section of Field Project # 1. However, as is evident from Figure 4.9, this cracking is related to the concrete bridge structure, not the HMA or WMA. There was no other evidence of cracking in either the HMA control or WMA test sections in Field Projects # 1 and # 2.

Raveling
There was very limited, minor severity raveling observed in the longitudinal joint of both the HMA and WMA sections of Field Project # 2. This is attributed to workmanship rather than materials.
# Table 4.4 — AZDOT HMA Control and WMA Test Section Summary

<table>
<thead>
<tr>
<th>Field Project</th>
<th>Paving Date</th>
<th>WMA Milepost</th>
<th>Lane</th>
<th>Tons</th>
<th>Paving Date</th>
<th>HMA Milepost</th>
<th>Lane</th>
<th>Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>August 11-12</td>
<td>276.0 to 279.6</td>
<td>EB Outside Shoulder (2 inches)</td>
<td>2194</td>
<td>August 12-13</td>
<td>279.6 to 281.2 EB; 281.2 to 279.2 WB EB &amp; WB Outside Shoulders (2 inches)</td>
<td>2046</td>
<td></td>
</tr>
<tr>
<td># 1</td>
<td>August 18-19</td>
<td>277.0 to 277.4 and 277.5 to 278.1</td>
<td>EB Travel Lane (4½ inches)</td>
<td>1859</td>
<td>August 19-20</td>
<td>278.1 to 279.1</td>
<td>EB Travel Lane (4½ inches)</td>
<td>1771</td>
</tr>
<tr>
<td># 2</td>
<td>September 8-9</td>
<td>278.1 to 277.8</td>
<td>WB Travel Lane (4½ inches)</td>
<td>1623</td>
<td>September 9-10</td>
<td>277.8 to 276.7</td>
<td>WB Travel Lane (4½ inches)</td>
<td>1968</td>
</tr>
<tr>
<td># 1</td>
<td>September 14-15</td>
<td>277.2 to 278.2</td>
<td>EB Passing Lane and Inside Shoulder (3 inches)</td>
<td>2395</td>
<td>September 15-16</td>
<td>278.2 to 281.4</td>
<td>EB Inside Shoulder &amp; Passing Lane (3 inches)</td>
<td>2480</td>
</tr>
<tr>
<td># 2</td>
<td>September 20-21</td>
<td>278.7 to 277.7</td>
<td>WB Passing Lane and Inside Shoulder (3 inches)</td>
<td>1486</td>
<td>September 22-23</td>
<td>277.0 to 276.0</td>
<td>WB- Inside Shoulder &amp; Passing Lane (3 inches)</td>
<td>2507</td>
</tr>
</tbody>
</table>

*NB: The cells highlighted in [YELLOW](#) and [BLUE](#) represent AZDOT Field Projects #1 and #2, respectively.*
Figure 4.13 — Schematic of AZDOT Field Projects with HMA Control and WMA Test Sections
Table 4.5 – Summary Data for Field Project # 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Warm Mix Asphalt</th>
<th>Hot Mix Asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date Paved</td>
<td>August 18-19</td>
<td>August 19-20</td>
</tr>
<tr>
<td>Tons</td>
<td>1859</td>
<td>1771</td>
</tr>
<tr>
<td><strong>Date Paved</strong></td>
<td><strong>Average</strong> (Standard Deviation)</td>
<td><strong>Average</strong> (Standard Deviation)</td>
</tr>
<tr>
<td>3/8</td>
<td>68.8 (4.57)</td>
<td>70.3 (2.22)</td>
</tr>
<tr>
<td>#8</td>
<td>39.3 (2.87)</td>
<td>39.0 (1.41)</td>
</tr>
<tr>
<td>#40</td>
<td>14.8 (0.96)</td>
<td>14.3 (0.50)</td>
</tr>
<tr>
<td>#200</td>
<td>3.9 (0.22)</td>
<td>3.7 (0.10)</td>
</tr>
<tr>
<td>% Asphalt</td>
<td>4.60 (0.31)</td>
<td>4.74 (0.23)</td>
</tr>
<tr>
<td>Lab Compacted Air Voids (%)</td>
<td>5.2 (0.47)</td>
<td>5.2 (0.54)</td>
</tr>
<tr>
<td>In-place Air Voids (%)</td>
<td>6.9 (1.01)</td>
<td>6.6 (0.76)</td>
</tr>
<tr>
<td>Range of in-place Air Voids (%)</td>
<td>5.2 to 8.4 (1.01)</td>
<td>5.2 to 7.4 (7.6)</td>
</tr>
<tr>
<td>Marshall Stability (lb)</td>
<td>5335 (136)</td>
<td>4605 (117)</td>
</tr>
<tr>
<td>Average Plant Temp (°F)</td>
<td>263</td>
<td>310</td>
</tr>
<tr>
<td><strong>Field Notes</strong></td>
<td>Rolling pattern</td>
<td>Rolling pattern</td>
</tr>
<tr>
<td></td>
<td>• 3 Vibratory;</td>
<td>• 3 Vibratory;</td>
</tr>
<tr>
<td></td>
<td>• 6 9-wheeler</td>
<td>• 6 9-wheeler</td>
</tr>
<tr>
<td></td>
<td>• 2 steady</td>
<td>• 2 steady</td>
</tr>
<tr>
<td></td>
<td>Laydown Temp Range (°F): 247 to 259</td>
<td>Laydown Temp Range (°F): 247 to 300</td>
</tr>
<tr>
<td>Date Paved</td>
<td>September 14-15</td>
<td>September 15-16</td>
</tr>
<tr>
<td>Tons</td>
<td>2395</td>
<td>2480</td>
</tr>
<tr>
<td><strong>Date Paved</strong></td>
<td><strong>Average</strong> (Standard Deviation)</td>
<td><strong>Average</strong> (Standard Deviation)</td>
</tr>
<tr>
<td>3/8</td>
<td>69.5 (2.52)</td>
<td>70.0 (5.48)</td>
</tr>
<tr>
<td>#8</td>
<td>41.8 (2.99)</td>
<td>42.3 (4.86)</td>
</tr>
<tr>
<td>#40</td>
<td>15.0 (1.15)</td>
<td>15.5 (1.73)</td>
</tr>
<tr>
<td>#200</td>
<td>3.8 (0.18)</td>
<td>3.9 (0.34)</td>
</tr>
<tr>
<td>% Asphalt</td>
<td>4.95 (0.20)</td>
<td>4.90 (0.37)</td>
</tr>
<tr>
<td>Lab Compacted Air Voids (%)</td>
<td>5.2 (0.56)</td>
<td>5.2 (0.60)</td>
</tr>
<tr>
<td>In-place Air Voids (%)</td>
<td>6.7 (1.02)</td>
<td>7.3 (0.94)</td>
</tr>
<tr>
<td>Range of in-place Air Voids (%)</td>
<td>4.8 to 8.1</td>
<td>5.4 to 8.1</td>
</tr>
<tr>
<td>Marshall Stability (lb)</td>
<td>4607 (45)</td>
<td>4662 (218)</td>
</tr>
<tr>
<td>Average Plant Temp (°F)</td>
<td>267</td>
<td>297</td>
</tr>
<tr>
<td><strong>Field Notes</strong></td>
<td>Rolling pattern</td>
<td>Rolling pattern</td>
</tr>
<tr>
<td></td>
<td>• 5 Vibratory</td>
<td>• 3 Vibratory</td>
</tr>
<tr>
<td></td>
<td>• 6 9-wheeler</td>
<td>• 6 9-wheeler</td>
</tr>
<tr>
<td></td>
<td>• 2 steady</td>
<td>• 2 steady</td>
</tr>
<tr>
<td></td>
<td>Laydown Temp Range (°F): 255 to 280</td>
<td>Laydown Temp Range (°F): 280 to 290</td>
</tr>
</tbody>
</table>
Table 4.6 – Summary Data for Field Project # 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Warm Mix Asphalt</th>
<th>Hot Mix Asphalt (Control)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date Paved</td>
<td>September 8-9</td>
<td>September 9-10</td>
</tr>
<tr>
<td>Tons</td>
<td>1623</td>
<td>1968</td>
</tr>
<tr>
<td>Average (Standard Deviation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/8</td>
<td>70.8 (1.26)</td>
<td>72.8 (1.89)</td>
</tr>
<tr>
<td>#8</td>
<td>43.8 (1.26)</td>
<td>44.8 (2.50)</td>
</tr>
<tr>
<td>#40</td>
<td>15.8 (0.50)</td>
<td>16.0 (0.82)</td>
</tr>
<tr>
<td>#200</td>
<td>3.6 (0.45)</td>
<td>3.8 (0.15)</td>
</tr>
<tr>
<td>% Asphalt</td>
<td>4.99 (0.12)</td>
<td>5.10 (0.20)</td>
</tr>
<tr>
<td>Lab Compacted Air Voids (%)</td>
<td>4.5 (0.32)</td>
<td>4.4 (0.25)</td>
</tr>
<tr>
<td>In-place Air Voids (%)</td>
<td>6.3 (0.88)</td>
<td>6.4 (1.02)</td>
</tr>
<tr>
<td>Range of in-place Air Voids (%)</td>
<td>5.4 to 7.9</td>
<td>4.7 to 8.3</td>
</tr>
<tr>
<td>Marshall Stability (lb)</td>
<td>4632 (122)</td>
<td>5612 (363)</td>
</tr>
<tr>
<td>Average Plant Temp (°F)</td>
<td>268</td>
<td>295</td>
</tr>
</tbody>
</table>

Field Notes
- Rolling pattern
  - 5 Vibratory
  - 6 9-wheeler
  - 2 steady
- Laydown Temp Range (°F): 255 to 280

Date Paved: September 20-21
Tons: 1486
average (standard deviation)

<table>
<thead>
<tr>
<th>Parameter</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8</td>
<td>72.0 (2.58)</td>
<td>71.5 (3.11)</td>
</tr>
<tr>
<td>#8</td>
<td>43.8 (3.30)</td>
<td>41.5 (3.42)</td>
</tr>
<tr>
<td>#40</td>
<td>16.0 (1.41)</td>
<td>13.3 (1.26)</td>
</tr>
<tr>
<td>#200</td>
<td>4.3 (0.25)</td>
<td>3.8 (0.17)</td>
</tr>
<tr>
<td>% Asphalt</td>
<td>5.05 (0.25)</td>
<td>4.94 (0.22)</td>
</tr>
<tr>
<td>Lab Compacted Air Voids (%)</td>
<td>5.1 (0.37)</td>
<td>5.6 (0.39)</td>
</tr>
<tr>
<td>In-place Air Voids (%)</td>
<td>5.8 (1.15)</td>
<td>7.0 (0.75)</td>
</tr>
<tr>
<td>Range of in-place Air Voids (%)</td>
<td>4.0 to 7.2(1.15)</td>
<td>6.0 to 8.5 (1.15)</td>
</tr>
<tr>
<td>Marshall Stability (lb)</td>
<td>4965 (261)</td>
<td>4560 (361)</td>
</tr>
<tr>
<td>Average Plant Temp (°F)</td>
<td>263</td>
<td>297</td>
</tr>
</tbody>
</table>

Field Notes
- Rolling pattern
  - 5 Vibratory
  - 6 9-wheeler
  - 2 steady
- Laydown Temp Range (°F): 272 to 279

Laydown Temp Range (°F): 281 to 303
Figure 4.14a — Typical Appearance of Surface Texture in Field Project # 1

Figure 4.14b — Typical Appearance of Surface Texture in Field Project # 2
Figure 4.15a — Straight-Edge Placement in Wheelpath of WMA Section of Field Project # 1

Figure 4.15a — Straight-Edge Placement in Wheelpath of WMA Section of Field Project # 2
Figure 4.16a — Full-Width Cracking in HMA of Field Project # 2
Figure 4.16b—Cracking in Shoulder of WMA of Field Project #1
References