**Final HMA Characterization Plan (Indoor Phase VI and Outdoor Phase I)**

**Delivery Order 015: Reflective Cracking Support**

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## 1. Material Sampling

- Collect at least six 5-gallon buckets of loose mix from Outdoor Phase I and four 5-gallon buckets from Indoor Phase VI for hot mix asphalt (HMA) characterization tests in NextGen Pavement Materials Laboratory.
- Collect at least 45 6-inch (inner diameter of core bit = 6 inch) HMA cores from the transition test area of Outdoor Phase I and at least 38 6-inch (inner diameter of core bit = 6 inch) HMA cores from Indoor Phase VI test.

## 2. Laboratory Tests

### 2.1 Mix Design Verification using Loose Mix

Table 1 shows the proposed testing matrix for the collected loose mix. These tests shall be conducted on loose mix collected from both Outdoor Phase I and Indoor Phase VI test areas. In addition to verify the HMA mix design, Tensile Strength Ratio (TSR) test and dynamic modulus test will be conducted.

Table 1. Mix Design Verification

| Test | Standard | Replicates |
|---|---|---|
| Theoretical Maximum Specific Gravity | ASTM D2041 | 1 |
| Bulk Specific Gravity | ASTM D2726 | 1 |
| Asphalt Content | ASTM D6307 | 1 |
| Gradation | ASTM D5444 | 1 |

#### *2.1.1 Tensile Strength Ratio (TSR) Test*

TSR test is conducted as per ASTM D4867 "*Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures*" for moisture damage. The test involves two sets of HMA samples which are subjected to a split tensile test (or indirect tensile test). One set is conditioned by partial vacuum saturation with water, soaking in water for 24 hours. The other set is used as a control and tested dry at room temperature. The ratio of the average split tensile strength of the conditioned samples over the average split tensile strength of the unconditioned (control) samples is reported as the TSR. As the Outdoor Phase I test area is subjected to moisture change, three replicate specimens shall be tested for each set (conditioned and unconditioned) from the loose mix collected form Outdoor Phase I.

*2.1.2 Dynamic Modulus Test*

Dynamic modulus test is conducted as per AASHTO TP79 "*Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester*". The test applies a repeated load at varying frequencies to the asphalt mixture specimen over a relatively short period of time and measures the specimen's recoverable strain and permanent deformation. This provides an insight into the asphalt mixture's viscous properties. The test specimens shall be prepared in the laboratory using the loose mix, as extracted HMA cores will not be tall enough. The mix verification conducted on both the collected loose mixes (indoor and outdoor) shall be compared. If the data is significantly different, both sets shall be tested for three replicate specimens; if not significant differences can be found in between the two loose mixes, three replicates specimens shall be tested using the Indoor Phase VI test

2.2 Testing from HMA Cores

The 6-inch HMA cores will be used for advanced characterization tests as described below.

*2.2.1 Disc-shaped Compact Tension (DCT) Test*

The DCT test is conducted as per ASTM D7313 "*Standard Test Method for Determining Fracture Energy of Asphalt-Aggregate Mixtures Using the Disk-Shaped Compact Tension Geometry*". The test is generally used to obtain the fracture energy of asphalt mixture lab or field specimens, which can be used in performance-type specifications to control various forms of cracking, such as thermal, reflective, and block cracking of pavements surfaced with asphalt mixtures. The test data is also required for future finite element modeling effort. Three replicate specimens shall be tested using cores from Outdoor Phase I.

*2.2.2 Texas Overlay Tester (OT)*

The Texas Overlay Tester (OT) will be used to evaluate the compaction effort. This test is proposed to reduce testing time and specimen preparation as regardless of the testing condition (as compared to customized OT).

**Compaction Effort**

The Texas OT is a fatigue-type test, and currently represents the best laboratory method to truly simulate horizontal joint movements in the joint/crack vicinity of PCC pavements. The OT is generally run in a displacement-controlled mode (triangular waveform) at a specific displacement rate with a fixed maximum horizontal displacement. While the tester operates at a very slow opening and closing movement (about 0.1 Hz) compared to that due to aircraft loading, it is comparable to that due to daily temperature fluctuations. In order to evaluate the compaction effort, HMA cores from Indoor Phase VI and Outdoor Phase I shall be used as the lift thickness is different. Table 2 shows the HMA core locations along with replicates for each set.

Table 2. Evaluate the Effect of Compaction Effort using the Texas OT

| Test | Standard | HMA Core Location | Replicates |
|---|---|---|---|
| Texas OT | (*1*) | Indoor Phase VI (Bottom Lift) | 3 |
| | | Indoor Phase VI (Top Lift) | 3 |
| | | Outdoor Phase I (Bottom) | 3 |

*2.2.3 Customized Overlay Tester (OT)*

In support of the testing objectives of Outdoor Phase I and Indoor Phase VI, customized OT will be used to evaluate the effect of crack propagation and the effect of occurrence of an extreme cooling cycle.

**Effect of Crack Propagation**

There are many causes for asphalt pavement cracking such as the temperature changes and the traffic load induced from vehicles. A mixture's resistance to crack propagation gives a direct influence on the cracking performance of asphalt pavements. Crack propagation is important towards the understanding of the cracking mechanism since it can be studied over a period of time, unlike crack initiation and the total failure criteria, which are instantaneous. There are two types of traditional methods used for analyzing the stress-strain behavior of asphalt mixtures to resist cracking: 1) the continuous approach, which does not consider any flaws in the analysis, and 2) the fracture mechanics approach, which includes a pre-determined flaw/crack (*2*). Continuous approach offers a much more fundamental explanation of damage than conventional fracture mechanics approach. On the contrary, fracture mechanics initiates with the hypothesis that there are integral flaws or cracks in the material. Therefore, fracture mechanics by itself is incapable of properly addressing the mechanism of crack initiation. The use of fracture mechanics is necessary to fundamentally and accurately account for the different factors that affect the development and propagation of cracks.

The customized OT is proposed to evaluate the effect of different crack lengths in the overlay specimen. The customized OT shall be tested for the control set per Yin and Mandal (*3*). The testing shall be conducted at a test temperature of 32 °F with an opening of 12 mils and a 150-s rest period. Several studies (*4-14*) investigating the crack growth behavior of asphalt pavements using different fracture test specimens were conducted in the past. The crack length in these studies were selected based on the ratio of 'crack length ($a$) to thickness ($t$)/height ($H$) of the sample'. Typically, the ratios were reported between 0.13 and 0.75 for ratio of '$a/H$' and between 0.2 to 1.2 for ratio of '$a/t$'. As listed in Table 3, it is proposed to use four notch lengths with the ratios of $a/H$ as 0.2, 0.4, 0.6, and 0.8 giving a notch length of 0.30-inch, 0.60-inch, 0.90-inch, and 1.20-inch, respectively.

Further, strain gages shall be glued directly on top of the crack/notch on both the sides of the specimen to measure initial strain. For the specimen with no-notch (notch length = 0 inch), strain gages shall be used at three locations (bottom, middle, and top) on both sides of the specimen. This set (i.e., no-notch) of testing will be used to compare to the 'Temperature Only' section for Outdoor Phase I test pavement. Every set of specimens shall be tested for at least three replicate specimens using the cores from Outdoor Phase I test pavement. The specimens shall be fabricated from the bottom of the HMA cores.

Table 3. Laboratory Test Plan to Study the Crack Propagation Effect using the Customized OT

| Test | Standard | Notch Length (inch) | Replicates |
|---|---|---|---|
| Customized OT | (*3*) | 0 | 4 |
| | | 0.30 | 3 |
| | | 0.60 | 3 |
| | | 0.90 | 3 |
| | | 1.20 | 3 |

**Occurrence of an Extreme Cooling Cycle**

A transfer function is an important feature of a mechanistic-based pavement design procedure. This function converts the stress or strain response value to a number of load repetitions to failure. In the past few decades, a considerable number of fatigue transfer functions have been proposed, but there are widespread discrepancies in their respective predictions (*15*). However, Miner's law has been widely used for the accumulation of different damages (*16-20*). For HMA pavements, the current mechanistic-based approaches incorporate some version of Miner's linear cumulative fatigue hypothesis. Based on cyclic uniaxial tensile/compression tests on aluminum samples, Miner introduced the following hypothesis (*21*):

$$\sum_i \frac{n_i}{N_i} = 1 \tag{1}$$

where $n_i$ is the number of load cycles applied at stress $i$ and $N_i$ is the load cycles to failure at stress $i$. Miner's law is also used within the analytical pavement design process for asphalt pavements. The customized OT tests results will be used to study if the crack behavior is affected by the order or sequence of load application. Three sets of data are proposed, as shown in Table 4. The 'Extreme cooling condition' is simulated to occur in 1 month of a typical year; for every 12 loading cycles, there would be 11 cycles of 0.16 mil/sec and 1 cycle of 0.32 mil/sec. Set 1 assumes the extreme cooling to occur at the year end, whereas, Set 2 assumes the extreme cooling to occur at the beginning of the year. Set 3 assumes extreme cooling to occur in middle of the year. It should be

noted that the Testquip software would need to be modified in order to run Set 3. Strain gages shall be used at three locations (bottom, middle, and top) on both sides of the specimen. The testing shall be conducted at a test temperature of 32 °F with an opening of 12 mils and a 150-s rest period. Every set of specimens shall be tested for four replicate specimens using the bottom portion of the HMA cores from Indoor Phase VI test pavement.

Table 4. Laboratory Test Plan to Study Occurrence of an Extreme Cooling Cycle using the Customized OT

| Testing Suite | Standard | Cycles | Cycle Time (sec) | Displacement Rate (mils/sec) | Replicates |
|---|---|---|---|---|---|
| **Extreme Set 1*** | (*3*) | 1st – 11th Cycle | 150 | 0.16 | 4 |
| | | 12th Cycle | 70 | 0.32 | |
| **Extreme Set 2** | | 1st Cycle | 70 | 0.32 | 4 |
| | | 2nd – 12th Cycle | 150 | 0.16 | |
| **Extreme Set 3** | | 1st – 6th Cycle | 150 | 0.16 | 4 |
| | | 7th Cycle | 70 | 0.32 | |
| | | 8th - 12th Cycle | 150 | 0.16 | |

**Simulates Indoor Phase VI Full-scale Test*

## 3. Time Estimate

### 3.1 Mix Verification

The time table for completion of all mix verification tests is provided in Table 5.

Table 5. Estimated Time for Completion of Mix Verification

| Test | Number of tests to be completed | Total time required for completion (days) |
|---|---|---|
| Theoretical Maximum Specific Gravity | 2 | 4 |
| Bulk Specific Gravity | 2 | |
| Asphalt Content | 2 | |
| Gradation | 2 | |

### 3.2 TSR Test

The time table for completion of all TSR tests is provided in Table 6.

Table 6. Estimated Time for Completion of TSR Test

| Test | Number of tests to be completed | Total time required for completion (days) |
|---|---|---|
| Sample Preparation | 6 | 4 |
| Sample Testing | 6 | |

3.3 Dynamic Modulus Test

Assuming:

a) Test sample preparation and instrumentation (pin attachments) is complete and acceptable
b) Test equipment is available and functional

The time table for completion of all dynamic modulus tests is provided in Table 7.

Table 7. Estimated Time for Completion of Dynamic Modulus Test

| Test Set | Number of tests to be completed | Time required for test sample conditioning (hrs) | Total time required for completion (days) |
|---|---|---|---|
| Compaction | 3 | - | 6 |
| 14 °F | 3 | 4 | |
| 39 °F | 3 | 3 | |
| 50 °F | 3 | 3 | |
| 70 °F | 3 | 3 | |
| 99 °F | 3 | 3 | |

3.4 DCT Test

Assuming:

a) Test sample instrumentation is complete and acceptable
b) Test equipment is available and functional

The time table for completion of DCT tests is provided in Table 8.

Table 8. Estimated Time for Completion of DCT Test

| Test Set | Recommended number of tests to be completed | Time required for conditioning (hrs) | Time required for (days) |
|---|---|---|---|
| 32 °F | 3 | 8 to 16 | 1 |

3.5 Texas OT

Assuming:

a) Test equipment is available and functional

*Data Collection*

Collected data for the overlay tests will be composed of:

a) Maximum load vs. maximum displacement (for each cycle) obtained from Testquip software
b) Strain gage data obtained from data acquisition system (LABView) [For effect of crack propagation only]

The time table for completion of Texas OT tests is provided in Table 9.

Table 9. Estimated Time for Completion of Texas OT (Compaction Effort)

| HMA Core Location | Number of tests to be completed | Total time required (days) |
|---|---|---|
| Indoor Phase VI (Bottom Lift) | 3 | 36 |
| Indoor Phase VI (Top Lift) | 3 | |
| Outdoor Phase I (Bottom Lift) | 3 | |

3.6 Customized OT

Assuming:

a) Test sample instrumentation is complete and acceptable
b) Test equipment is available and functional

*Data Collection*

Collected data for the overlay tests will be composed of:

a) Maximum load vs. maximum displacement (for each cycle) obtained from Testquip software
b) Strain gage data obtained from data acquisition system (LABView)

The time table for completion of customized OT tests is provided in Tables 10 and 11.

Table 10. Estimated Time for Completion of Texas OT (Crack Propagation)

| Notch Length (in.) | Number of tests to be completed | Total time required (days) |
|---|---|---|
| 0 | 4 | 50 |
| 0.30 | 3 | |
| 0.60 | 3 | |
| 0.90 | 3 | |
| 1.20 | 3 | |

Table 11. Estimated Time for Completion of Customized OT Tests

| Testing Suite | Number of tests to be completed | Total time required (days) |
|---|---|---|
| Extreme Set 1 | 4 | 48 |
| Extreme Set 2 | 4 | |
| Extreme Set 3 | 4 | |

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