Appendix I

Proposed revision to Standard Method of Test for Tensile Creep Compliance, Tensile Failure Limits and Energy Ratio of Asphalt Mixtures Using the Superpave Indirect Tension (IDT) Test

Standard Method of Test for

Tensile Creep Compliance, Tensile Failure Limits and Energy Ratio of Asphalt Mixtures Using the Superpave Indirect Tension (IDT) Test

AASHTO Designation:

1. SCOPE

1.1.   This standard provides distinct procedures for determining the tensile creep compliance, tensile failure limits and energy ratio of asphalt mixtures using the Superpave Indirect Tension (IDT) test.

1.2.   The procedures described in this standard provide tensile properties of asphalt mixtures for evaluation of cracking performance at intermediate temperatures (i.e., 0-25 ℃). These procedures apply to dense graded, gap graded and open graded test specimens prepared from either field cores or laboratory compacted samples. Test specimens under these procedures are nominally 150 mm (6 in) in diameter.

1.3.   *These tests may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1.   *AASHTO Standards:*

- M 323 Superpave Volumetric Mix Design.
- R 30-02 Mixture Conditioning of Hot Mix Asphalt (HMA).
- R 35 Superpave Volumetric Design for Asphalt Mixtures.
- T 166 Bulk Specific Gravity (Gmb) of Compacted Hot Mix Asphalt (HMA) Using Saturated
- Surface-Dry Specimens.
- T 168-03 Sampling Bituminous Paving Mixtures.
- T 209 Theoretical Maximum Specific Gravity (Gmm) and Density of Hot Mix Asphalt (HMA).
- T 269 Percent Air Voids in Compacted Dense and Open Asphalt Mixtures.

- T 275 Bulk Specific Gravity (Gmb) of Compacted Hot Mix Asphalt (HMA) Using Paraffin-
- Coated Specimens.
- T 312 Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the
- Superpave Gyratory Compactor.
- T 331 Bulk Specific Gravity (Gmb) and Density of Compacted Hot Mix Asphalt (HMA) Using
- Automatic Vacuum Sealing Method.

2.2. *ASTM Standards:*

- D1188 Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Coated Samples.
- D2041 Test Method for Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures.
- D2726 Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures.
- D3203/D3203M Standard Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures.
- D 3549/3549M Standard Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens.
- D 5361/D 5361M Standard Practice for Sampling Compacted Bituminous Mixtures for Laboratory Testing.
- D6752 Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Automatic Vacuum Sealing Method.
- D6857 Test Method for Maximum Specific Gravity and Density of Bituminous Paving Mixtures Using Automatic Vacuum Sealing Method.

2.3. *Other Document:*

- The Superpave Mix Design Manual for New Construction and Overlays.

3. TERMINOLOGY

3.1. *Gage length*—Reference distance to record displacement during testing.

3.2. *Seating load*—Minimum load that remains on a specimen throughout a test. Seating load is applied to test specimens to ensure proper contact to the loading head.

3.3. *Creep strain*—Time-dependent component of strain resulting from stress.

3.4. *Creep compliance (D)*—Ratio of creep strain to applied stress.

3.5.   *Tensile strength (S_T)*—Maximum stress that a material can take before failure when subjected to tension.

3.6.   *Elastic energy (EE)*—Recoverable potential energy that is stored when a body is deformed.

3.7.   *Fracture*—For the purposes of this standard method, fracture is defined as the instant at which local failure occurs.

3.8.   *Fracture energy density (FE)*—Area under the stress-strain curve.

3.9.   *Fracture energy density failure limit (FE_f)*—Total energy required to induce fracture (i.e., local failure) under a large single load.

3.10.   *Dissipated creep strain energy density (DCSE)*—Energy dissipated by way of the non-recoverable (permanent) component of the time-dependent strain. DCSE is associated with damage accumulation under repeated loading conditions.

3.11.   *Dissipated creep strain energy density failure limit ($DCSE_f$)*—Total energy required to induce fracture (i.e., local failure) under repeated load.

3.12.   *Minimum dissipated creep strain energy density ($DCSE_{min}$)*—Dissipated creep strain energy required to initiate and propagate a crack for 50 mm (2 in) after 6000 loading cycles.

3.13.   *Energy ratio (ER)*—Ratio of DCSE*f* to DCSE*min*. It is a parameter derived from cracking performance analysis of field sections throughout the State of Florida. ER was found to be able to accurately discriminate between field sections that exhibited cracking and those that did not.

4.   SUMMARY OF METHOD

4.1.   This standard describes the procedure for determining the tensile creep compliance, tensile failure limits and energy ratio of asphalt mixtures. These material properties and parameters are determined using the following Superpave IDT tests: tensile creep test and tensile fracture test.

4.2.   *Tensile creep test*—The tensile creep test is performed in a load controlled mode. Creep compliance is determined by applying a static load in the form of a step function along the vertical diametral axis of a test specimen and then holding it for 1000 seconds. The resulting horizontal and vertical deformations measured near the center of the specimen are used to calculate tensile creep compliance as a function of time. The magnitude of the load applied is selected to maintain the material response within the linear viscoelastic range throughout the test. This is typically accomplished by keeping the horizontal deformation between 0.0025 and 0.0040 mm (100-150 micro-inches) at 100 seconds and below 0.0200 mm (750 micro-inches) at 1000 seconds. However, for stiffer and more

brittle materials, such as highly aged field specimens or mixtures with high RAP/RAS content, limit the maximum horizontal deformation to levels that may cause failure during this test (e.g., 0.0050 mm or 200 micro-inches). By measuring both horizontal and vertical deformations in regions where stresses are relatively constant and away from the localized non-linear effects induced by the steel loading heads, Poisson's ratio can be accurately determined. Note that creep compliance is sensitive to Poisson's ratio measurements.

4.3. Note 1—Ruggedness testing indicated that the asphalt mixtures had statistically equal energy ratios when the rest period between the Mr test and the creep test ranges from 5 to 15 min.

4.4. *Tensile fracture test*—The tensile fracture test is performed in a displacement controlled mode. The test specimen is loaded along its vertical diametral axis at a constant displacement rate of 50±2.5 mm/minute (2±0.1 in/minute) until failure occurs.

Note 2—For open graded mixtures, displacement rate shall be increased to 100 mm/minute (4 in/minute).

4.5. *Testing sequence*—Each test can be performed as a stand-alone routine or test specimens can be subjected to the following testing sequence:
1. Tensile creep test
2. Tensile fracture test

4.6. *Testing temperature*—Superpave IDT tests shall be performed at 10 ℃.

4.7. *Test specimen dimensions*—Test specimens shall nominally be 150 mm (5.9 in) in diameter and 38 to 50 mm (1.5-2 in) in thickness (i.e., disk-shaped specimens).

Note 3—Recommended specimen thickness is 38 mm (1.5 in) for dense graded and gap graded mixtures and 50 mm (2 in) for open graded mixtures.

4.8. *Number of replicates*—Three replicate test specimens are recommended for any asphalt mixture under evaluation. Results from the three replicates are analyzed as a group.

5.   SIGNIFICANCE AND USE

5.1. Tensile creep compliance, tensile failure limits and energy ratio allow for the evaluation of asphalt mixture cracking performance at intermediate temperatures (i.e., 0-25 ℃). Tensile creep compliance and tensile failure limits can also be implemented into a model for analysis of crack progression.

5.2. The tensile creep test is used to capture the permanent strain associated with the time-dependent response of asphalt mixtures. Tensile creep compliance parameters can be used to estimate the rate of damage accumulation of asphalt mixtures subjected to

repeated loads. The test can also be used to investigate the effect of temperature, load magnitude and loading time on the response of asphalt mixtures. Creep compliance can also be used to generate stiffness estimates for pavement design and evaluation models.

5.3.   The tensile fracture test is used to determine the failure limits of asphalt mixtures, namely FE_f and $DCSE_f$. These material properties can be used for estimating the fracture tolerance of asphalt mixtures. Additional properties such as tensile strength and failure strain are also obtained as part of this test.

5.4.   ER is a cracking performance comparison parameter derived from the evaluation of field sections. It accounts for the effect of material properties and pavement structural characteristics on cracking performance. The higher the value of the ER, the better the expected cracking performance of a pavement section at intermediate temperatures.

5.5.   This procedure is suitable for any asphalt mixture gradation. Nominal maximum aggregate size (NMAS) shall not exceed 19 mm for 38-mm (1.5-in) thick specimens or 25 mm for 50-mm (2-in) thick specimens.

5.6.   The values stated in either SI units or U.S. customary units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

6.   APPARATUS

6.1.   *Loading device*—The loading device shall be capable of providing a fixed or constant load with a resolution of at least 5 N (1 lbf) and a constant rate of ram displacement between 12 to 75 mm/min (0.5-3 in/minute). The load frame should be capable of handling a minimum load of 22 kN (5,000 lbf).

6.2.   *Loading heads*—Loading strip heads shall be 20 mm (0.75 in) wide. Further details on loading head dimensions can be found in Appendix 1.

6.3.   *Gage points*—Four targets or gage points shall be glued onto both faces of the specimen along the vertical and horizontal axes. These gage points shall be either aluminum or steel depending on the measurement system that will be used. Reference dimensions for gage points are 8 mm (5/16'') in diameter and 3 mm (1/8'') in height.

6.4.   *Gage point mounting system*—A gage point mounting system is required to precisely attach the gage points on test specimens. The system may have two adjustable heads that hold the four gage points that are placed on either face of the specimen by vacuum. This system guarantees that the gage points on one face of the specimen are perfectly aligned with the gage points on the other face. Further details are presented in Appendix 2.

6.5.   *Contact point template*—A template shall be used for marking the exact contact point of loading heads so that loading heads are perfectly aligned with gage points. Dimensions can be found in Appendix 3.

6.6.   *Temperature control system*—The temperature control system shall be capable of maintaining temperature control within ±0.5 ºC (measured near the center of the chamber), at settings ranging from 0 to 25 ºC. The system shall include a temperature-controlled cabinet large enough to house the loading heads and specimen constraint system as well as three test specimens. A thermally sealed access port for thermocouple or electrical feed through is also required.

6.7.   *Measuring and recording system*—The measuring and recording system shall include sensors for measuring and simultaneously recording horizontal and vertical deformations on both faces of a test specimen as well as the load applied to the specimen. The system shall be capable of recording horizontal deformations with a resolution of 0.00025 mm (0.000010 in). The system shall also be capable of recording vertical deformation with a resolution of 0.00050 mm (0.000020 in). Load cells shall be accurately calibrated with a resolution of 5 N (1 lbf) or better. In all cases, the noise in the recording system should be less than the accuracy of the deformation measurement devices being used.

6.7.1. *Recorder*—The measuring or recording devices must provide real time deformation and load information and should be capable of monitoring readings at a minimum of 500 points/second. These parameters shall be recorded on an analog to digital or digital data acquisition system. The data acquisition system must be able to record time, load, and four deformation measurement devices.

6.7.2. *Deformation measurement*—The values of vertical and horizontal deformation shall be measured with 38 mm (1.5 in) gage point mounted extensometers with a full scale travel of 0.5 mm (0.02 in). The extensometers must be capable of performing within the temperature range prescribed in the test procedure.

6.7.3. *Load measurement*—Load shall be measured with an electronic load cell with a capacity of 22 kN (5,000 lbf) and a sensitivity of ± 5 N (±1 lbf). The capacity of the load cell shall be matched as closely as possible to the expected testing load ranges to allow adequate feedback response.

6.8.   *Specimen sawing apparatus*—A specimen sawing device will be used to cut parallel, smooth and plane top and bottom faces for preparation of test specimens. A water-cooled masonry saw has been found to perform this function adequately.

6.9.   *Humidity cabinet*—A chamber that can control to ±5 % relative humidity is necessary to condition specimens. This cabinet or chamber must be large enough to accommodate the number of specimens expected to be tested over 2 days.

7.   HAZARDS

7.1.   Observe standard laboratory safety precautions when preparing and testing asphalt mixture specimens.

8.   STANDARDIZATION

8.1.   Calibrate the testing system prior to initial use and at least once a year thereafter.

8.1.1.   Calibrate the environmental control component to maintain the required temperature within the specified accuracy.

8.1.2.   Calibrate all measurement components (such as load cells and displacement transducers) of the testing system.

8.1.3.   If any of the verifications yield data that do not comply with the accuracy specified, correct the problem prior to proceeding with testing. Appropriate action may include correction of menu entries, maintenance on system components, calibration of system components (using an independent calibration agency, or service by the manufacturer, or in-house resources), and replacement of system components.

9.   SAMPLING

9.1.   *Laboratory compacted samples*

9.1.1.   *Sample preparation—*Prepare 4500 g, 150-mm diameter Superpave gyratory compacted pills in accordance with AASHTO T 312. Target air void content of dense graded asphalt mixtures shall be 7±0.5 % to simulate the upper end of acceptable compaction level in the field. Note that up to two test specimens can be obtained by slicing a single Superpave pill. Therefore, two Superpave pills are required for a minimum of three replicate test specimens.

9.1.2.   *Conditioning—*Asphalt mixture may be subjected to short-term and long-term oxidative conditioning following the standard practice in AASHTO R 30-02. Additional conditioning may be introduced at user's discretion. The purpose of this process is to evaluate how material properties and expected performance change with conditioning level.

9.2.   *Field cored samples—*Obtain field cores from a pavement section in accordance with ASTM D 5361/D 5361M. Extracted cores, which may contain one or more testable layers, must have smooth and uniform vertical (curved) surfaces. Cores that are obviously deformed or have any visible cracks must be rejected. Irregular top and bottom surfaces shall be trued up as necessary. Individual layer specimens shall be obtained by slicing. Prepare a minimum of three replicate test specimens per individual layer.

10. SPECIMEN PREPARATION AND PRELIMINARY DETERMINATIONS

10.1. Laboratory compacted samples or field cored samples shall be sliced to the appropriate test specimen dimensions using the apparatus described in 6.8. Smooth and parallel surfaces must be obtained after slicing. A minimum of three test specimens shall be obtained from slicing a series of laboratory compacted samples or field cored samples.

Note 4—Measurements taken on cut faces yield more consistent results, and gage points can be attached with much greater bonding strength.

10.2. *Test specimen dimensions—*Prepare test specimens with a nominal diameter of 150 mm (5.9 in) and a thickness between 38 and 50 mm (1.5-2.0 in).

Note 5—Recommended specimen thickness is 38 mm (1.5 in) for dense graded and gap graded mixtures and 50 mm (2 in) for open graded mixtures.

10.3. *Determining specimen diameter (Φ)—*Determine and report the diameter of each test specimen to the nearest 0.1 mm (0.01 in) by averaging two diameters measured at right angles to each other at about mid-thickness of the specimen.

10.4. *Determining specimen thickness (h)—*Determine and report the thickness of each test specimen to the nearest 0.1 mm (0.01 in) by averaging four measurements located at approximately quarter points around the perimeter and 15 to 25 mm (0.5-1 in) in from the specimen edge, in accordance with ASTM D 3549.

10.5. *Determining specimen bulk specific gravity (G_{mb})—*Determine the specific gravity of each specimen in accordance with AASHTO T 166, AASHTO T 275 or AASHTO T 331.

10.6. *Determining specimen air void content—* Determine the air void content of each specimen according to AASHTO T 269. This procedure requires prior determination of the theoretical maximum specific gravity of the mixture (G_{mm}).

10.7. *Specimen drying—*If specimens were immersed directly into water (e.g., for sawing and/or determining the bulk specific gravity), allow each specimen to dry at room temperature to a constant mass. Dehumidifiers can be used to expedite the drying process.

10.8. *Test specimen selection—*If more than three specimens are available, specimens are sorted by their air void content and grouped for testing. The average air void content per group shall be kept as close as possible to minimize the effect of air void content on properties measured.

10.9. *Additional mixture conditioning—*Additional conditioning may be performed at this stage to account for factors other than oxidative aging, such as cycle pore water pressure, UV radiation, freeze/thaw, etc.

10.10. *Gage point attachment—*Attach four gage points with a toughened cyanoacrylate adhesive to each flat face of the specimen by means of the mounting system described in 6.4. Gage points shall be centered at the middle quartile of both faces along two perpendicular directions, at a gage length of 38 mm (1.5 in). The placement and location of the gage points on each face shall produce a mirror image of each other.

10.11. *Marking contact points for loading heads—*Use the template described in 6.5 to mark the contact points where loading heads would be perfectly aligned with a pair of gage points on each face. This action defines the vertical diametral axis along which load will be applied. A test specimen with attached gage points and marked contact points is shown in Appendix 4.

10.12. *Test specimen storage—*All specimens shall be stored in an environment where the temperature is maintained between 5 and 20 ℃ until they are to be conditioned for testing.

10.13. *Test specimen conditioning—*Lower the temperature of the environmental chamber to the test temperature and, once the test temperature ± 0.5 ℃ is achieved, allow each specimen to remain at the test temperature from 3 ± 1 h prior to testing. Under no circumstances shall the specimen be kept at 0 ℃ or less for more than 24 h.

10.14. *Mounting extensometers—*Extensometers shall be used to measure horizontal and vertical deformations on both faces of a test specimen. There are currently two extensometer systems widely used. One of these systems uses aluminum gage points on which knife edges are fixed by a set screw. The extensometers are then clipped onto these knife edges, one over the other. Another extensometer system have built-in magnets in both legs for attachment to steel gage points.

11. TESTING

11.1. *Alignment and stability—*Insert the test specimen into the loading device and position it so that the load alignment marks on the test specimen line up with the loading heads. The alignment between the specimen and loading heads is important for proper test results. Prior to performing the test, the extensometers shall be stable. For creep compliance testing, stability is defined as the horizontal extensometers not drifting by more than 10 micro-strain over 100 seconds. For fracture testing, stability is defined as the horizontal extensometers not drifting by more than 50 micro-strain over 100 seconds. If these tolerances are not met, it is an indication that the specimen has not stabilized at the test temperature.

11.2. *Seating load—*After stability is achieved, zero or rebalance the deformation measurement devices and apply a seating load of 50 N (10 lbf).

11.3. *Data baseline—*All tests included in this standard method are preceded by one second worth of data just prior to starting the test, sampled at 10 Hz (10 data points per second), to establish a baseline or zero from which to reference the data.

11.4. *Replicates—*Each test is performed in triplicate, i.e., three specimens are required for any material and the results are analyzed as a group. The experience gained testing the first specimen can be used with any additional specimens of the same material.

11.5. *Tensile creep test*

11.5.1. *Load function*—Apply a static step/ramp load of fixed magnitude for a duration of 1000 seconds. The load shall rise from the seating load to the operator selected maximum load.

11.5.2. *Selection of load magnitude*—The magnitude of the load is adjusted so that the horizontal deformation at 100 seconds is between 0.0025 and 0.0040 mm (100-150 micro-inches), and the horizontal deformation at 1000 seconds does not exceed 0.0200 mm (750 micro-inches). For stiffer and more brittle materials, such as highly aged field specimens or mixtures with high RAP/RAS content, limit the maximum horizontal deformation to levels that do cause failure during this test (e.g., 0.0050 mm or 200 micro-inches). If the horizontal deformation falls outside these limits, stop the test and allow a minimum recovery time of 5 minutes before reloading at a different level. These limits prevent both non-linear response, characterized by exceeding the upper limit, and significant problems associated with noise and drift inherent in sensors when violating the lower limit. Unequal response between specimen faces may require adjustment to the gages or re-seating of the specimen due to eccentric loading condition.

11.5.3. *Data acquisition*—The data acquisition rate for the tensile creep test changes or varies with time after the application of the load. For the first 10 seconds of the test, the data acquisition rate is set at 10 Hz (10 data points per second), for a total of 100 data points. For the next 290 seconds, the data acquisition rate is set at 1 Hz (one data point per second), for a total of 290 data points. The last 700 seconds of the test require only one data point every five seconds (0.2 Hz), for a total of 140 data points. In total, the creep test data acquisition generates 540 lines of data, including the 10 pre-load data points.

11.6. *Tensile fracture test*—This test shall normally be run immediately following the tensile creep test, but it can also be used as a stand-alone routine. For the latter scenario, follow 11.1 to 11.4 prior to testing.

Note 6—Ruggedness testing indicated that the asphalt mixtures had statistically equal energy ratios when the rest period between the creep test and the strength test varied from 5 to 15 min.

11.6.1. *Load function*—Load the specimen a constant rate of 50±2.5 mm (2±0.1 in) of ram displacement per minute. The test is terminated when the load response falls or yields by 20% of the peak value.

Note 7—For open graded mixtures, displacement rate shall be increased to 100 mm/minute (4 in/minute).

11.6.2. *Data acquisition*—The data acquisition rate can either be set to take data readings for every 100 N (25 lbf) change in load, or it can be a combination time-dependent and load-crossing data.

12.   DATA ANALYSIS

12.1.   *Data analysis for tensile creep test*

12.1.1. *Subscript convention*—For the purpose of clarity, subscript convention was developed. The subscript 'i' represents the specimen number in each test group (i = 1, 2 or 3), the subscript 'k' represents the specimen face (k = 1 or 2) and the subscript 't' represents the time data recording (t = 0 to t_end). Thus, a variable may have up to three subscripts of the following form: $X_{i,k,t}$.

12.1.2. *Data acquisition*—For each specimen, loading and deformation data are recorded by transducers. Deformations are measured independently on each face of the specimen. Test data acquisition is summarized in Table 1.

Table 1. Data acquisition for tensile creep test

Data Point	Time	Force	Horizontal Deformation		Vertical Deformation	
			Face 1	Face 2	Face 1	Face 2
	(s)	(N)	(mm)	(mm)	(mm)	(mm)
1st	t_1	P_{i,t_1}	$H_{i,1,t_1}$	$H_{i,2,t_1}$	$V_{i,1,t_1}$	$V_{i,2,t_1}$
2nd	t_2	P_{i,t_2}	$H_{i,1,t_2}$	$H_{i,2,t_2}$	$V_{i,1,t_2}$	$V_{i,2,t_2}$
3rd	t_3	P_{i,t_3}	$H_{i,1,t_3}$	$H_{i,2,t_3}$	$V_{i,1,t_3}$	$V_{i,2,t_3}$
… … …	… … …	… … …	… … …	… … …	… … …	… … …
Last	t_{end}	$P_{i,t_{end}}$	$H_{i,1,t_{end}}$	$H_{i,2,t_{end}}$	$V_{i,1,t_{end}}$	$V_{i,2,t_{end}}$

12.1.3. *Determination of absolute deformation*—Absolute deformation ΔH and ΔV shall be calculated from the accumulated displacement recorded by extensometers using the following equations:

$$\Delta H_{i,j,k} = H_{i,k,t} - H_{i,k,t_1} \qquad (1)$$

$$\Delta V_{i,j,k} = V_{i,k,t} - V_{i,k,t_1} \qquad (2)$$

where:

$\Delta H_{i,j,k}$ = absolute horizontal deformation of specimen i for face k at time data recording t.

$\Delta V_{i,j,k}$ = absolute vertical deformation of specimen i for face k at time data recording t.

$H_{i,k,t}, H_{i,k,t_1}$ = accumulated horizontal displacement of specimen i for face k at time t and t_1, respectively.

$V_{i,k,t}, V_{i,k,t_1}$ = accumulated vertical displacement of specimen i for face k, at time t and t_1, respectively.

12.1.4. *Data normalization*—In order to minimize the effect of specimen dimensions, a normalization factor C_{norm_i} shall be applied to each specimen:

$$C_{norm_i} = \left(\frac{h_i}{h_{avg}}\right) \times \left(\frac{\Phi_i}{\Phi_{avg}}\right) \times \left(\frac{P_{avg}}{P_i}\right) \tag{3}$$

where:

C_{norm_i} = normalization factor for specimen i (dimensionless) in the tensile creep test.

h_i = thickness of specimen i.

h_{avg} = average thickness of the three specimens in the test group:

$$H_{avg} = \frac{\sum_{i=1}^{3} h_i}{3} \tag{4}$$

Φ_i = diameter of specimen i.

Φ_{avg} = average diameter of the three specimens in the test group:

$$\Phi_{avg} = \frac{\sum_{i=1}^{3} \Phi_i}{3} \tag{5}$$

$P_{i,}$ = creep load of of specimen i.

P_{avg} = average creep load of the three specimens in the test group:

$$P_{avg} = \frac{\sum_{i=1}^{3} P_i}{3} \tag{6}$$

The normalized absolute horizontal and vertical deformations, $\Delta H_{norm_{i,k,t}}$, $\Delta V_{norm_{i,k,t}}$, for each specimen, face and time instant shall be calculated as follows:

$$\Delta H_{norm_{i,k,t}} = C_{norm_i} \times \Delta H_{i,k,t} \tag{7}$$

$$\Delta V_{norm_{i,k,t}} = C_{norm_i} \times \Delta V_{i,k,t} \tag{8}$$

12.1.5. *Determination of the trimmed average deformation*—There is a total of 6 sets of data (3 specimens, 2 faces/specimen) for each deformation and time instant. In the trimming process, deformation data are sorted, the highest and the lowest deformation values are removed and the remaining four deformation values are averaged as follows:

$$\Delta H_{trim\ avg,t} = \frac{\sum_{i=1}^{3}\sum_{k=1}^{2}\Delta H_{norm_{i,k,t}} - \Delta H_{norm_{t,max}} - \Delta H_{norm_{t,min}}}{2n-2} \tag{9}$$

$$\Delta V_{trim\ avg,t} = \frac{\sum_{i=1}^{3}\sum_{k=1}^{2}\Delta V_{norm_{i,k,t}} - \Delta V_{norm_{t,max}} - \Delta V_{norm_{t,min}}}{2n-2} \tag{10}$$

in which n is the total number of specimens (i.e., three).

12.1.6. *Determination of creep compliance curve*—The creep compliance curve expresses the relationship between the time dependent strain and the corresponding stress. Creep compliance at any time instant t is computed by the following equation:

$$D_t = \frac{\Delta H_{trim\ avg,t} \times h_{avg} \times \Phi_{avg}}{P_{avg} \times GL} \times C_{compliance,t} \tag{11}$$

where:

D_t = creep compliance at time t (GPa^{-1}, psi^{-1}).

GL = gage length (38 mm, 1.5 in).

$C_{compliance,t}$ = creep compliance correction factor at time t (dimensionless), defined as:

$$C_{compliance,t} = 0.6354 \times \left(\frac{\Delta V_{trim\ avg,t}}{\Delta H_{trim\ avg,t}}\right) - 0.332 \tag{12}$$

Once creep compliance values are calculated, mixture parameters D_0, D_1 and m-value are obtained by fitting a power-law equation to the creep compliance vs. time data points, as shown in Figure 1. D_0, D_1 and m-value are determined by minimizing the squared error during the fitting process.
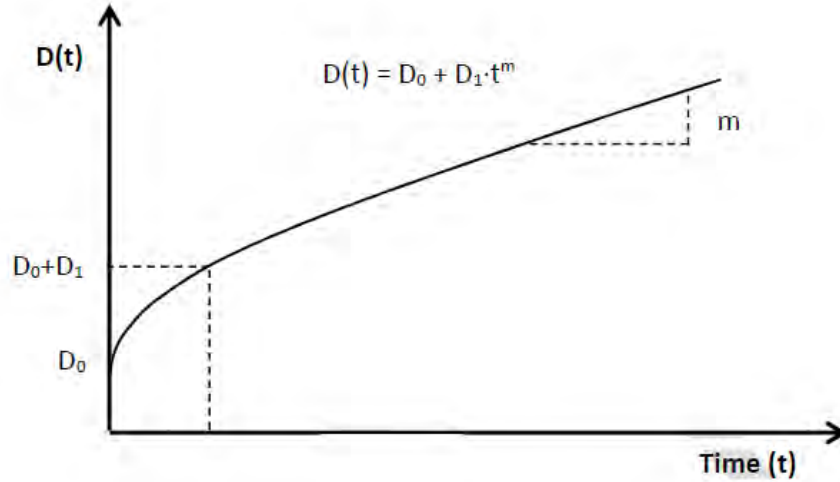
Figure 1. Schematic representation of the creep compliance curve

12.1.7. *Poisson's ratio*—The calculation of creep compliance presented in the previous section had Poisson's ratio inherently built into the solution. If a measure of Poisson's ratio is desired (it is recommended the use of deformations at t=500 s), it can be computed from Equation 13, which is valid within the range $0.05 \leq v \leq 0.50$:

$$v = -0.10 + \left[1.480 - 0.778 \times \left(\frac{h_{avg}}{\Phi_{avg}}\right)^2\right] \times \left(\frac{\Delta H_{trim\ avg,t}}{\Delta V_{trim\ avg,t}}\right)^2 \qquad (13)$$

12.2. *Data analysis for tensile fracture test*

12.2.1. *Subscript convention*—For the purpose of clarity, subscript convention was developed. The subscript 'i' represents the specimen number in each test group (i = 1, 2 or 3), the subscript 'k' represents the specimen face (k = 1 or 2) and the subscript 't' represents the time data recording (t = 0 to t_{end}). Thus a variable may have up to three subscripts of the following form: $X_{i,k,t}$.

12.2.2. *Data acquisition*—For each specimen, loading and deformation data are recorded by transducers. Deformations are measured independently on each face of the specimen. Test data acquisition is summarized in Table 2.

Table 2. Data acquisition for tensile fracture test

Data Point	Time	Force	Horizontal Deformation		Vertical Deformation	
			Face 1	Face 2	Face 1	Face 2
	(s)	(N)	(mm)	(mm)	(mm)	(mm)
1st	t_1	P_{i,t_1}	$H_{i,1,t_1}$	$H_{i,2,t_1}$	$V_{i,1,t_1}$	$V_{i,2,t_1}$
2nd	t_2	P_{i,t_2}	$H_{i,1,t_2}$	$H_{i,2,t_2}$	$V_{i,1,t_2}$	$V_{i,2,t_2}$

3rd	t_3	P_{i,t_3}	$H_{i,1,t_3}$	$H_{i,2,t_3}$	$V_{i,1,t_3}$	$V_{i,2,t_3}$
… … …	… … …	… … …	… … …	… … …	… … …	… … …
Last	t_{end}	$P_{i,t_{end}}$	$H_{i,1,t_{end}}$	$H_{i,2,t_{end}}$	$V_{i,1,t_{end}}$	$V_{i,2,t_{end}}$

12.2.3. *Determination of absolute deformation*—Absolute deformation ΔH and ΔV shall be calculated from the accumulated displacement recorded by extensometers using the following equations:

$$\Delta H_{i,k,t} = H_{i,k,t} - H_{i,k,t_1} \tag{14}$$

$$\Delta V_{i,k,t} = V_{i,k,t} - V_{i,k,t_1} \tag{15}$$

where:

$\Delta H_{i,k,t}$ = absolute horizontal deformation of specimen i for face k at time data recording t.

$\Delta V_{i,k,t}$ = absolute vertical deformation of specimen i for face k at time data recording t.

$H_{i,k,t}, H_{i,k,t_1}$ = accumulated horizontal displacement of specimen i for face k at time t and t_1, respectively.

$V_{i,k,t}, V_{i,k,t_1}$ = accumulated vertical displacement of specimen i for face k, at time t and t_1, respectively.

12.2.4. *Data normalization*—In order to minimize the effect of specimen dimensions, a normalization factor C_{norm_i} shall be applied to each specimen:

$$C_{norm_i} = \left(\frac{h_i}{h_{avg}}\right) \times \left(\frac{\Phi_i}{\Phi_{avg}}\right) \tag{16}$$

where:

C_{norm_i} = normalization factor for specimen i (dimensionless) in the tensile fracture test.

h_i = thickness of specimen i.

h_{avg} = average thickness of the three specimens in the test group:

$$h_{avg} = \frac{\sum_{i=1}^{3} h_i}{3} \tag{17}$$

Φ_i = diameter of specimen i.

Φ_{avg} = average diameter of the three specimens in the test group:

$$\Phi_{avg} = \frac{\sum_{i=1}^{3} \Phi_i}{3} \tag{18}$$

The normalized absolute horizontal and vertical deformations, $\Delta H_{norm_{i,k,t}}$, $\Delta V_{norm_{i,k,t}}$, for each specimen, face and time instant shall be calculated as follows:

$$\Delta H_{norm_{i,k,t}} = C_{norm_i} \times \Delta H_{i,k,t} \tag{19}$$

$$\Delta V_{norm_{i,k,t}} = C_{norm_i} \times \Delta V_{i,k,t} \tag{20}$$

12.2.5. *Detection of specimen instant of fracture*—Data from the two faces of a test specimen are analyzed in order to determine the instant of fracture, i.e., local failure of the specimen. This is accomplished by plotting the difference between absolute vertical and absolute horizontal deformation ($\Delta V_{i,k,t} - \Delta H_{i,k,t}$) over time for each face and selecting the point in time at which this difference peaks. The first 'peak' point in time, whether from face 1 or face 2, is determined to be the instant of fracture (t_f).

12.2.6. *Poisson's ratio*—Trimmed average deformations required for calculating Poisson's ratio are obtained at half the average failure load of the three specimens.

12.2.6.1. *Determination of the trimmed average deformation*—There is a total of 6 sets of data (3 specimens, 2 faces/specimen) for each deformation and time instant. In the trimming process, deformation data are sorted, the highest and the lowest deformation values are removed and the remaining four deformation values are averaged as follows:

$$\Delta H_{trim\ avg,t} = \frac{\sum_{i=1}^{3}\sum_{k=1}^{2} \Delta H_{norm_{i,k,t}} - \Delta H_{norm_{t,max}} - \Delta H_{norm_{t,min}}}{2n-2} \tag{21}$$

$$\Delta V_{trim\ avg,t} = \frac{\sum_{i=1}^{3}\sum_{k=1}^{2} \Delta V_{norm_{i,k,t}} - \Delta V_{norm_{t,max}} - \Delta V_{norm_{t,min}}}{2n-2} \tag{22}$$

in which n is the total number of specimens (i.e., three).

12.2.6.2. *Calculation of Poisson's ratio*—It can be computed from Equation 23, which is valid within the range 0.05≤ν≤0.50:

$$\nu = -0.10 + \left[1.480 - 0.778 \times \left(\frac{h_{avg}}{\Phi_{avg}}\right)^2\right] \times \left(\frac{\Delta H_{trim\ avg,0.5P_{tf}}}{\Delta V_{trim\ avg,0.5P_{tf}}}\right)^2 \tag{23}$$

12.2.7. *Tensile stress*

12.2.7.1.   *Specimen tensile stress*—Tensile stress at any time t can be determined as follows:

$$\sigma_{i,t} = \frac{2 \times P_{i,t}}{\pi \times h_i \times \Phi_i} \times C_{SX,i} \tag{24}$$

where:

$\sigma_{i,t}$ = tensile stress for specimen i at time t.

$P_{i,t}$ = load for specimen i at time t.

h_i = thickness of specimen i.

Φ_i = diameter of specimen i.

$C_{SX,i}$ = stress correction factor for specimen i (dimensionless):

$$C_{SX,i} = 0.984 - 0.01114 \times \left(\frac{h_i}{\Phi_i}\right) - 0.2693 \times v + 1.436 \times \left(\frac{h_i}{\Phi_i}\right) \times v \tag{25}$$

12.2.7.2.   *Specimen indirect tensile strength*—The tensile strength of each specimen is equal to the tensile stress at the instant of fracture (t$_f$):

$$S_{T,i} = \frac{2 \times P_{i,t_f}}{\pi \times h_i \times \Phi_i} \times C_{SX,i} \tag{26}$$

where:

$S_{T,i}$ = indirect tensile strength of specimen i.

P_{i,t_f} = load at instant of fracture t$_f$ for specimen i.

h_i = thickness of specimen i.

Φ_i = diameter of specimen i.

$C_{SX,i}$ = stress correction factor for specimen i (Eq. 25).

12.2.7.3.   *Average indirect tensile strength*—Average tensile strength (S$_T$) is calculated using the following equation:

$$S_T = \frac{\sum_{i=1}^{3} S_{T,i}}{3} \tag{27}$$

12.2.8. *Tensile strain*

12.2.8.1.   *Face tensile strain*—The tensile strain at any time t can be calculated as follows as:

$$\varepsilon_{i,k,t} = \frac{\Delta H_{norm_{i,k,t}}}{GL} \times 1.072 \times C_{BX,i} \tag{28}$$

where:

$\varepsilon_{i,k,t}$ = tensile strain of specimen i for face k at time t.

$\Delta H_{norm_{i,k,t}}$ = normalized absolute horizontal deformation of specimen i for face k at time t.

GL = gage length (38 mm, 1.5 in).

$C_{BX,i}$ = buldging correction factor for specimen i, expressed as:

$$C_{BX,i} = 1.03 - 0.189 \times \left(\frac{h_i}{\Phi_i}\right) - 0.081 \times v + 0.089 \times \left(\frac{h_i}{\Phi_i}\right)^2 \tag{29}$$

12.2.8.2.   *Face failure strain*—The failure strain of each face is equal to the strain at the instant of fracture (t_f):

$$\varepsilon_{f,k,t} = \frac{\Delta H_{norm_{i,k,t_f}}}{GL} \times 1.072 \times C_{BX,i} \tag{30}$$

where:

$\varepsilon_{f,k,t}$ = failure strain of specimen i for face k.

$\Delta H_{norm_{i,k,t_f}}$ = normalized absolute horizontal deformation of specimen i for face k at the instant of fracture (t_f).

GL = gage length (38 mm or 1.5 in).

$C_{BX,i}$ = buldging correction factor for specimen i (Eq. 29).

12.2.8.3.   *Average failure strain*—Failure strain data are sorted, the highest and the lowest values are removed and the remaining four values are averaged as follows:

$$\varepsilon_f = \frac{\sum_{i=1}^{3}\sum_{k=1}^{2} \epsilon_{f,i,k} - \epsilon_{f,max} - \epsilon_{f,min}}{2n - 2} \tag{31}$$

12.3. *Determination of failure limits (FE_f and DCSE_f)*—Asphalt mixture failure limits are schematically defined in Figure 2.
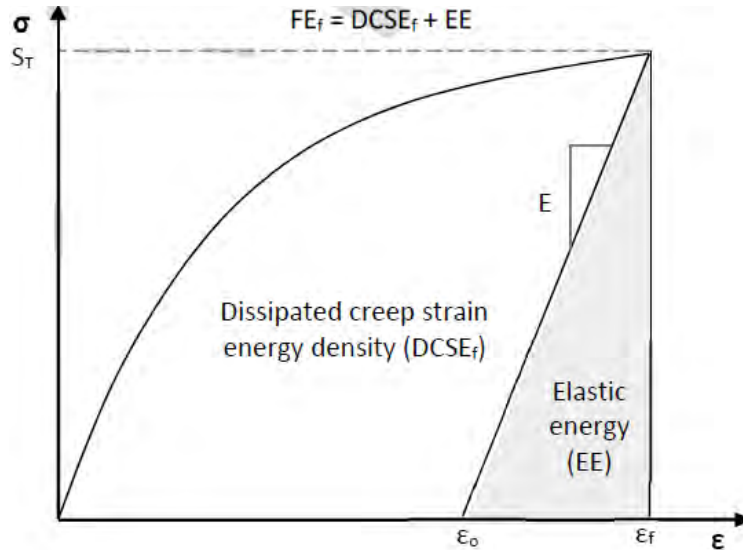

Figure 2. Schematic representation of mixture failure limits (FE_f and DCSE_f)

12.3.1. *Fracture Energy Density Failure Limit (FE_f)*—Fracture energy density failure limit is determined as the area under the stress-strain curve up to the instant of fracture (i.e., local failure):

$$FE_{f,i,k} = \int_0^{\varepsilon_{f,i}} \sigma_{i,k}(\varepsilon) \cdot d\varepsilon \tag{32}$$

where $FE_{f,i,k}$ is the fracture energy density failure limit of specimen i for face k. Note that computation of $FE_{f,i,k}$ requires previous calculation of tensile stress and strain as a function of time.

12.3.1.1.   *Determination of specimen fracture energy density failure limit*—Use numerical integration to determine the area under the stress-strain curve ($\sigma_{i,t}$—$\varepsilon_{i,k,t}$) up to the instant of fracture.

12.3.1.2.   *Determination of average fracture energy density failure limit*—$FE_{f,i,k}$ data are sorted, the highest and the lowest values are removed and the remaining four values are averaged as follows:

$$FE_f = \frac{\sum_{i=1}^{3}\sum_{k=1}^{2} FE_{f,i,k} - FE_{f,max} - FE_{f,min}}{2n - 2} \tag{33}$$

12.3.2. *Determination of Elastic Energy (EE)*—Elastic energy is not a failure limit, but it is needed to determine DCSE_f.

12.3.2.1.   *Determination of specimen elastic energy*—The elastic energy stored in a specimen at the instant of fracture t$_f$ can be calculated as follows:

$$EE_i = \frac{1}{2}\frac{(S_{T,i})^2}{E_i} \tag{34}$$

where:

EE_i = elastic energy of specimen i.

$S_{T,i}$ = indirect tensile strength of specimen i.

E_i = predicted or measured modulus (e.g., dynamic modulus, resilient modulus, tangent modulus, etc.) of specimen i at the testing temperature and a frequency of 10 Hz.

12.3.2.2.   *Determination of average elastic energy*—The average elastic energy (EE) is obtained as:

$$EE = \frac{\sum_{i=1}^{3} EE_i}{3} \tag{35}$$

12.3.3. *Dissipated Creep Strain Energy Density Failure Limit (DCSEf)*—Dissipated creep strain energy density failure limit is determined as the difference between fracture energy density failure limit and elastic energy:

$$DCSE_f = FE_f - EE \tag{36}$$

where:

$DCSE_f$ = dissipated creep strain energy density failure limit.

FE_f = fracture energy density failure limit (from 12.3.1.2).

EE = elastic energy (from 12.3.2.2).

12.4.   *Determination of Energy Ratio (ER)* —Energy ratio is calculated from mixture parameters obtained from the aforementioned set of testing:

$$ER = \frac{DCSE_f}{DCSE_{min}} = \frac{DCSE_f}{\dfrac{m^{2.98} \times D_1}{A}} \tag{37}$$

where:

ER = Energy ratio (dimensionless).

D_1, m = tensile creep compliance parameters.

A = parameter that takes into account the tensile strength of the asphalt mixture (S_T) and the tensile stress in the pavement structure (σ). If the tensile stress is unknown, a value of 1 MPa (150 psi) is suggested.

For stress and strength reported in MPa, DCSE$_f$ in kJ/m^3 and D$_1$ in GPa-1, A (in MPa^{-2}) is determined as:

$$A = 8.64 \times 10^{-4} \cdot \frac{(6.36 - S_T)}{\sigma^{3.1}} + 3.57 \times 10^{-3} \tag{38}$$

For stress and strength reported in psi, DCSE$_f$ in lbf-in/in^3 and D$_1$ in psi^{-1}, A (in psi^{-2}) is determined as:

$$A = 1.42 \times 10^{-3} \cdot \frac{(922.5 - S_T)}{\sigma^{3.1}} + 1.70 \times 10^{-7} \tag{39}$$

Note 8—Mixture properties for determination of ER should be obtained from mixtures conditioned to simulate field-aged materials. Roque et al. (2012) have determined that oxidative aging alone using the long-term oven aging (LTOA) procedure does not satisfactorily simulate long-term field aging as reflected by mixture failure limits. This work showed that cyclic pore pressure conditioning of mixture is required after LTOA to more properly simulate field aging. In addition, ER should not be used to evaluate brittle mixtures as reflected by a fracture energy density failure limit lower than 0.75 kJ/m^3.

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13.   REPORT

13.1.   *General information*
13.1.1. Maximum specific gravity of the asphalt mixture (Gmm) to the nearest 0.001.
13.1.2. Bulk specific gravity (Gmb) of each test specimen to the nearest 0.001.
13.1.3. Air void content of each test specimen to the nearest 0.1 percent.
13.1.4. Thickness (h) and diameter (Φ) of each test specimen to the nearest 0.1 mm (0.01 in).
13.1.5. Test temperature to the nearest 0.5 ºC.
13.2.   *Tensile Creep Test*
13.2.1. Load used during the test to the nearest 5 N (1 lbf).
13.2.2. Tensile creep compliance parameter m to the nearest 0.001.
13.2.3. Tensile creep compliance parameter D0 to the nearest 10-4 GPa-1 (10-9 psi-1).
13.2.4. Tensile creep compliance parameter D1 to the nearest 10-4 GPa-1 (10-9 psi-1).
13.3.   *Tensile Fracture test*
13.3.1. Tensile strength (ST) to the nearest 0.01 MPa (1 psi).
13.3.2. Failure strain (εf) to the nearest 10-6 or µε.
13.4.   *Failure Limits*
13.4.1. Fracture energy density failure limit (FEf) to the nearest 0.01 kJ/m3 (0.001 lbf-in/in3).

13.4.2. Dissipated creep strain energy density failure limit (DCSEf) to the nearest 0.01 kJ/m3 (0.001 lbf-in/in3).

13.5. *Energy Ratio*

13.5.1. Tensile stress in the pavement structure (σ) to the nearest 0.1 MPa (1 psi)

13.5.2. Energy ratio (ER) to the nearest 0.1.

14. PRECISION AND BIAS

14.1. *Precision*—The research required to develop precision estimates has not been conducted.

14.2. *Bias*—The test methods described in this standard have no bias because the values determined can be defined only in terms of the test methods.

15. KEYWORDS

15.1. Cracking performance, fracture energy density; creep compliance; failure limit; rate of damage; energy ratio.
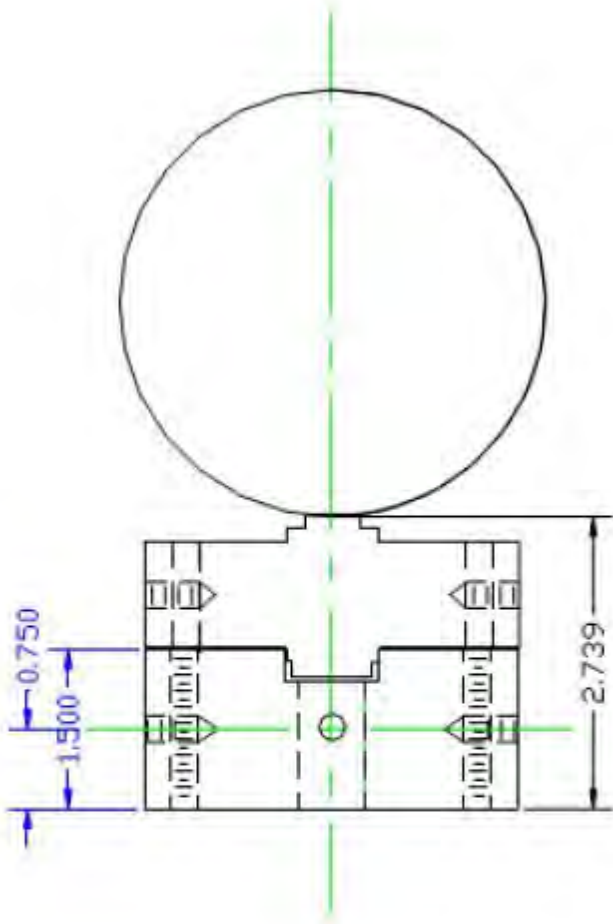
APPENDIXES

APPENDIX 1. Loading Heads

APPENDIX 1.A. Bottom Loading Head
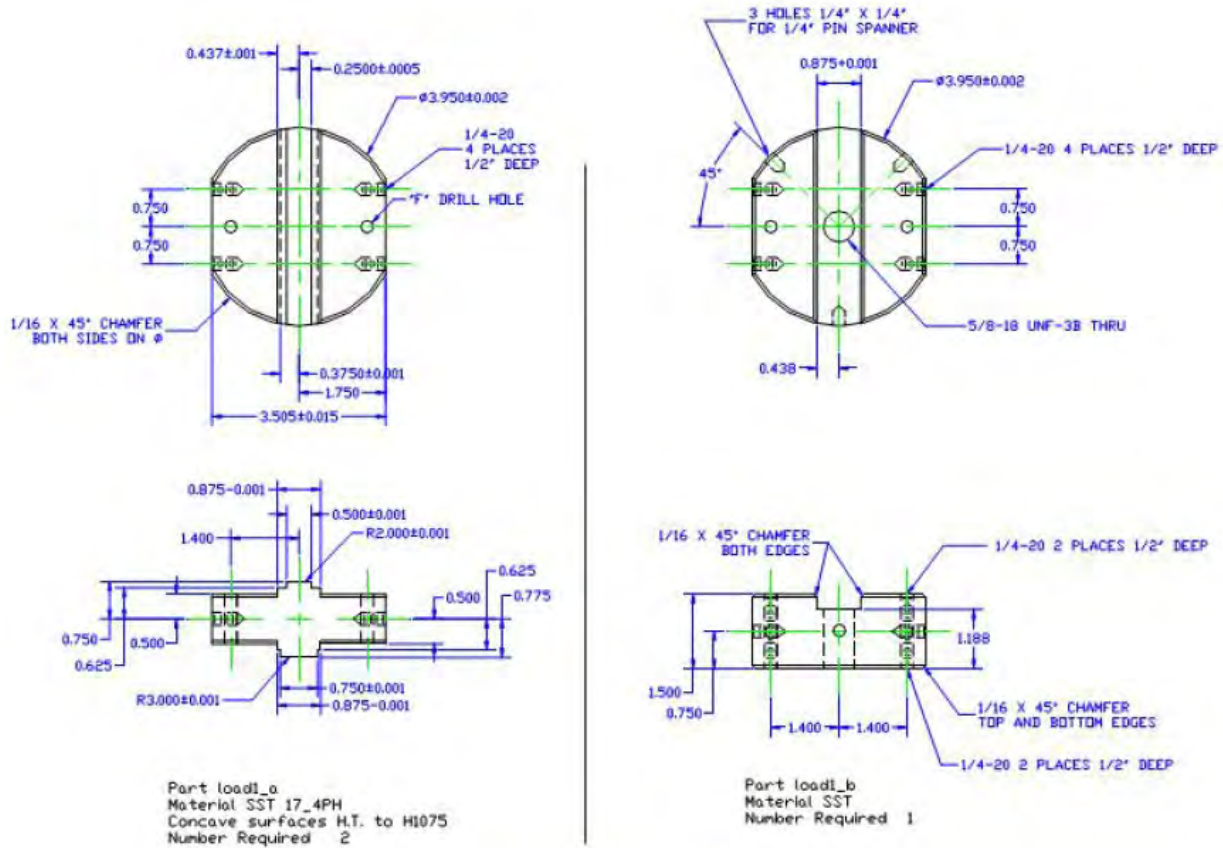
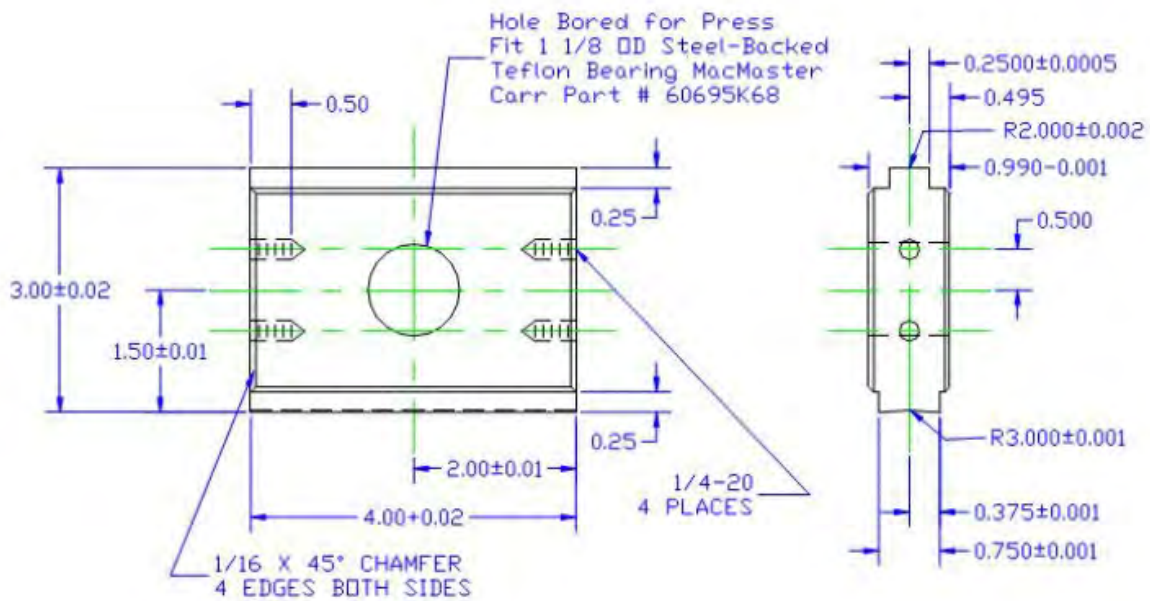APPENDIX 1.B. Bottom Loading Head Subassembly

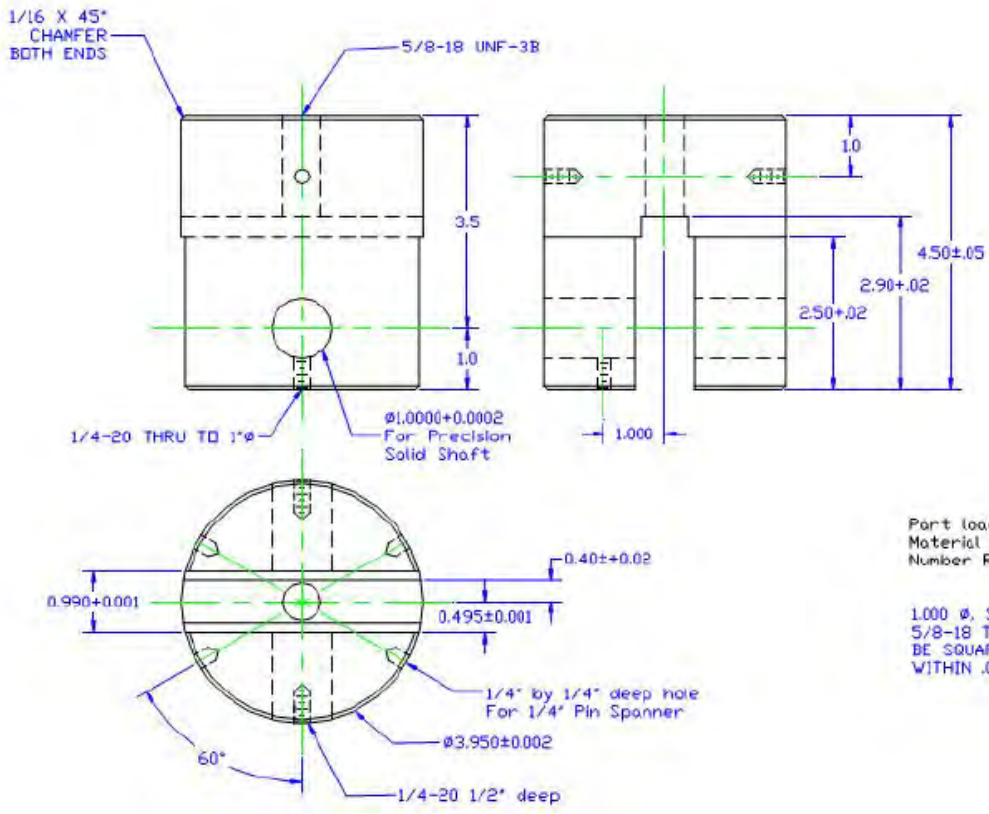Part load1_b
Material SST
Number Required 1

APPENDIX 1.C. Top Loading Head

Part load2_a
Material SST 17_4PH
Comcave Surfaces H.T. to H1075
Number Required 2

Drill and Tap 4 - 1/4-20 Holes
and Rough Bore 1.125 Hole
Before Heat Treating

Hole Bored for Press
Fit 1 1/8 OD Steel-Backed
Teflon Bearing MacMaster
Carr Part # 60695K68

0.2500±0.0005
0.495
R2.000±0.002
0.990-0.001
0.500

0.50
0.25

3.00±0.02

1.50±0.01

0.25

2.00±0.01

4.00+0.02

R3.000±0.001

1/4-20
4 PLACES

1/16 X 45° CHAMFER
4 EDGES BOTH SIDES

0.375±0.001
0.750±0.001

APPENDIX 1.D. Top Loading Head Swivel Block

1/16 X 45°
CHANFER
BOTH ENDS

5/8-18 UNF-3B

1.0

3.5

4.50±.05

2.90+.02

2.50+.02

1.0

1.000

1/4-20 THRU TO 1"Ø

Ø1.0000+0.0002
For Precision
Solid Shaft

0.40±+0.02

0.990+0.001

0.495±0.001

60°

1/4" by 1/4" deep hole
For 1/4" Pin Spanner
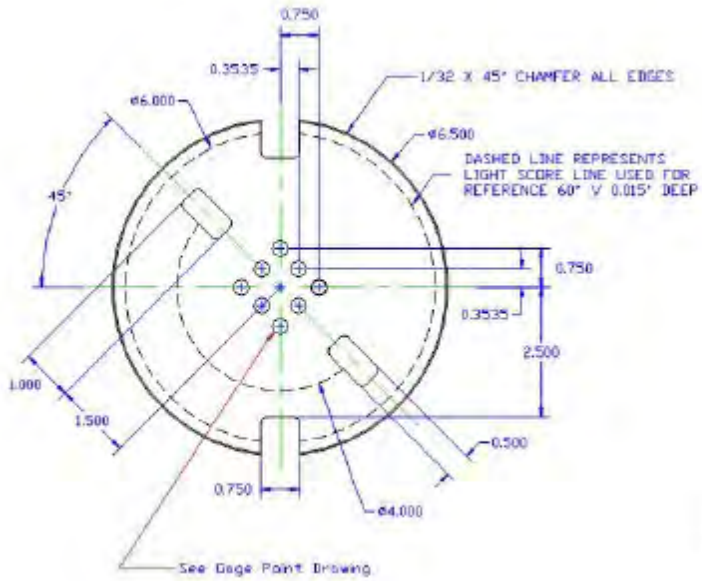
Ø3.950±0.002

1/4-20 1/2" deep

Part load3_a
Material SST
Number Required 1

1.000 Ø, SLOT AND
5/8-18 TAPPED END TO
BE SQUARE AND PARALLEL
WITHIN .002"

APPENDIX 2. Gage Point Mounting System (Is this for Φ=100 mm or Φ=150 mm?)
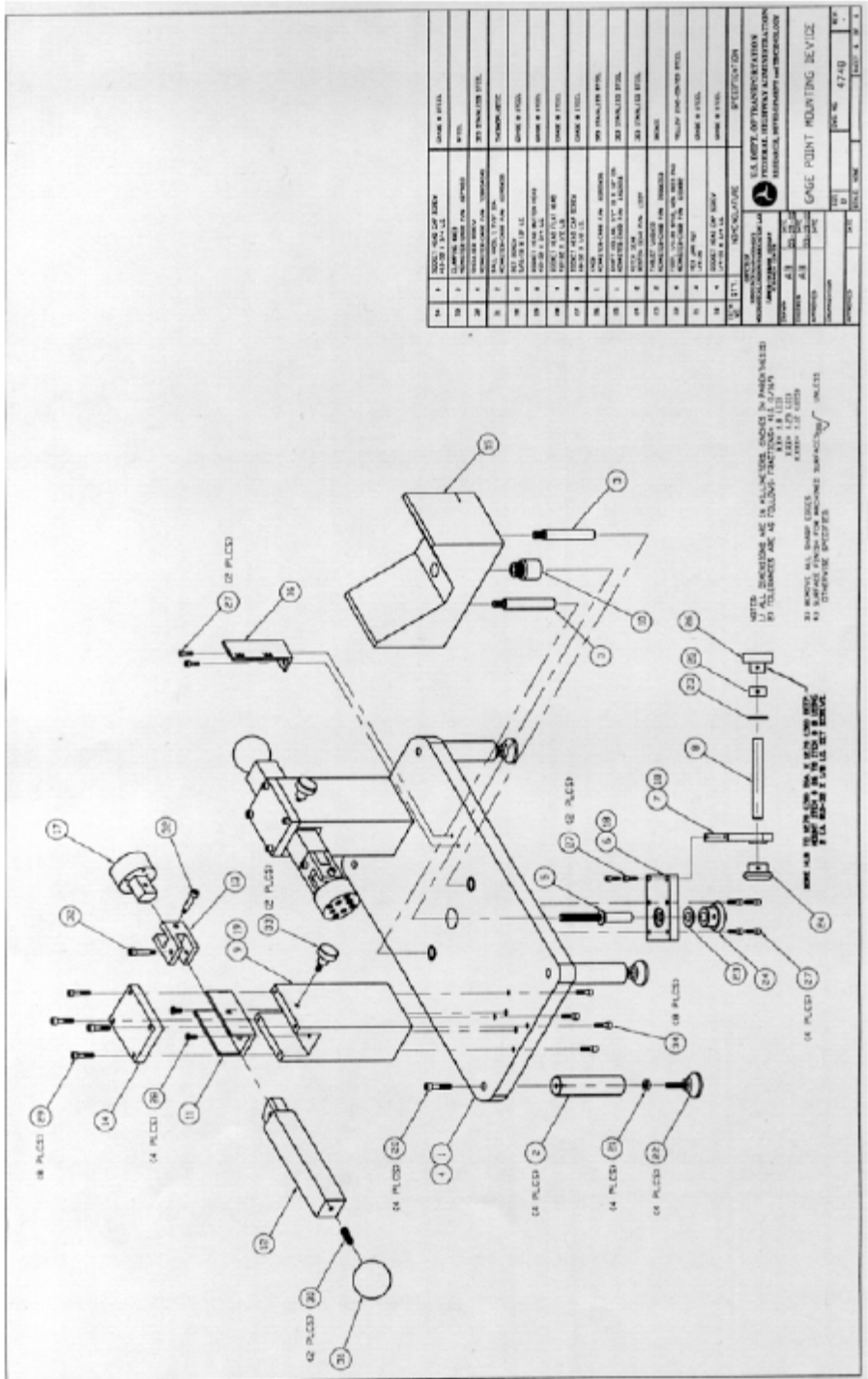
APPENDIX 3. Contact Point Template

APPENDIX 4. Test Specimen with Attached Gage Points and Marked Contact Points