
Standard Method of Test for

Determining Dynamic Modulus of Hot Mix Asphalt (HMA)



AASHTO Designation: TP 62-07 (2009)¹

1. SCOPE

- 1.1. This test method covers procedures for preparing and testing hot mix asphalt (HMA) to determine the dynamic modulus and phase angle over a range of temperatures and loading frequencies.
- 1.2. This standard is applicable to laboratory-prepared specimens of mixtures with nominal maximum size aggregate less than or equal to 37.5 mm (1.48 in.).
- 1.3. *This standard may involve hazardous material, 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 procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

- 2.1. *AASHTO Standards:*
- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
 - T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
 - T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
 - T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
 - T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyrotory Compactor
- 2.2. *ASTM Standard:*
- E 4, Standard Practices for Force Verification of Testing Machines
- 2.3. *Other Document:*
- Chapra, Steven C. and Raymond P. Canale. *Numerical Methods for Engineers*. The McGraw-Hill Companies, Inc., New York, NY, 1985, pp. 404–407.

3. DEFINITIONS

- 3.1. *complex modulus (E^*)*—a complex number that defines the relationship between stress and strain for a linear viscoelastic material.

- 3.2. *dynamic modulus* ($|E^*|$)—the normal value of the complex modulus calculated by dividing the maximum (peak-to-peak) stress by the recoverable (peak-to-peak) axial strain for a material subjected to a sinusoidal loading.
- 3.3. *phase angle* (ϕ)—the angle in degrees between a sinusoidal applied peak stress and the resulting peak strain in a controlled stress test.

4. SUMMARY OF METHOD

- 4.1. A sinusoidal (haversine) axial compressive stress is applied to a specimen of asphalt concrete at a given temperature and loading frequency. The applied stress and the resulting recoverable axial strain response of the specimen is measured and used to calculate the dynamic modulus and phase angle.
- 4.2. Figure 1 presents one schematic of the dynamic modulus test.

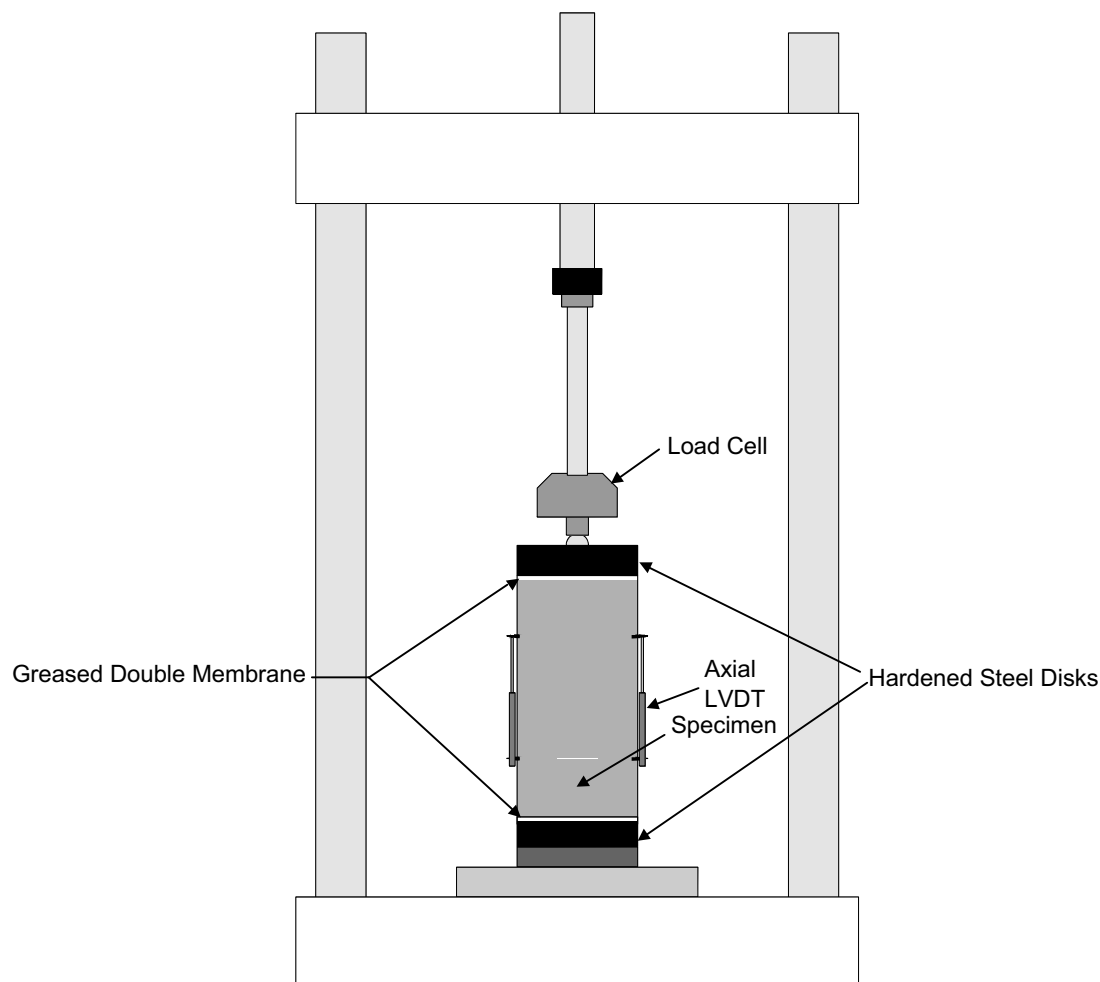


Figure 1—General Schematic of Dynamic Modulus Test

5. SIGNIFICANCE AND USE

- 5.1. Dynamic modulus values measured over a range of temperatures and frequencies of loading can be shifted into a master curve for characterizing asphalt concrete for pavement thickness design and performance analysis.
- 5.2. The values of dynamic modulus and phase angle can also be used as performance criteria for HMA design.

6. APPARATUS

- 6.1. *Dynamic Modulus Test System*—A dynamic modulus test system consisting of a testing machine, environmental chamber, and measuring system.
- 6.2. *Testing Machine*—A servo-hydraulic testing machine capable of producing a controlled haversine compressive loading. The testing machine should have a capability of applying load over a range of frequencies from 0.1 to 25 Hz and stress level up to 2800 kPa (400 psi). For sinusoidal loads, the standard error of the applied load shall be less than 5 percent. The standard error of the applied load is a measure of the difference between the measured load data and the best-fit sinusoid. The standard error of the load is defined in Equation 1.

$$se(P) = \sqrt{\frac{\sum_{i=1}^n (x_i - \hat{x}_i)^2}{n-4}} \left(\frac{100\%}{\hat{x}_o} \right) \quad (1)$$

where:

- $se(P)$ = standard error of the applied load,
 x_i = measured load at point i ,
 $\hat{x}_i$ = predicted load at point i from the best-fit sinusoid,
 n = total number of data points collected during test, and
 $\hat{x}_o$ = amplitude of the best-fit sinusoid.

- 6.2.1. *Environmental Chamber*—A chamber for controlling the test specimen at the desired temperature. The environmental chamber shall be capable of controlling the temperature of the specimen over a temperature range from -10 to 60°C (14 to 140°F) to an accuracy of $\pm 0.5^{\circ}\text{C}$ ($\pm 1^{\circ}\text{F}$). The chamber shall be large enough to accommodate the test specimen and a dummy specimen with thermocouple mounted at the center for temperature verification.
- 6.2.2. *Measurement System*—The system shall be fully computer-controlled, capable of measuring and recording the time history of the applied load and the axial deformations. The system shall be capable of measuring the period of the applied sinusoidal load and resulting deformations with a resolution of 0.5 percent. The accuracy and resolution of measurements are summarized in Table 1.

Table 1—Accuracy and Resolution of Measurement System

Measurement	Range	Accuracy	Resolution
Load	0.12 to 25 kN	Error ≤ 0.0 percent	≤ 0.0012 kN
Deformation	≥ 1 mm	Error ≤ 0.0025 mm	≤ 0.0002 mm
Inherent Phase Lag between Load and Deformation	Not specified	≤ 1 degree	Not specified

- 6.2.2.1. *Load*—The load shall be measured with an electronic load cell in contact with one of the specimen caps. The load cell shall be calibrated in accordance with ASTM E 4. The load measuring system shall have a minimum range of 0 to 25 kN (0 to 5600 lb) with a resolution of 1.2 N (0.24 lb).
- 6.2.2.2. *Axial Deformations*—Axial deformations shall be measured with linear variable differential transformers (LVDT) mounted between gauge points glued to the specimen, for example, as shown in Figure 2.
- The deformations shall be measured at two locations 180 degrees apart, three locations 120 degrees apart, or four locations 90 degrees apart. The measurement setup that calls for four locations set at 90 degrees apart has an advantage over the other two options in that, in case one LVDT does not function properly, LVDT and the LVDT on the opposite side can be dropped, and the remaining two LVDTs can be used to determine the average deformation. The LVDTs shall have a range of ± 0.5 mm (± 0.02 in.). The deformation measuring system shall have auto zero and selectable ranges as defined in Table 2.

Table 2—Deformation Measuring System Requirements

Range, mm (in.)	Resolution, mm (in.)
± 0.5 (0.01969)	0.0100 (0.00039)
± 0.25 (0.00984)	0.0050 (0.00020)
± 0.125 (0.00492)	0.0025 (0.00010)
± 0.0625 (0.00246)	0.0010 (0.00004)

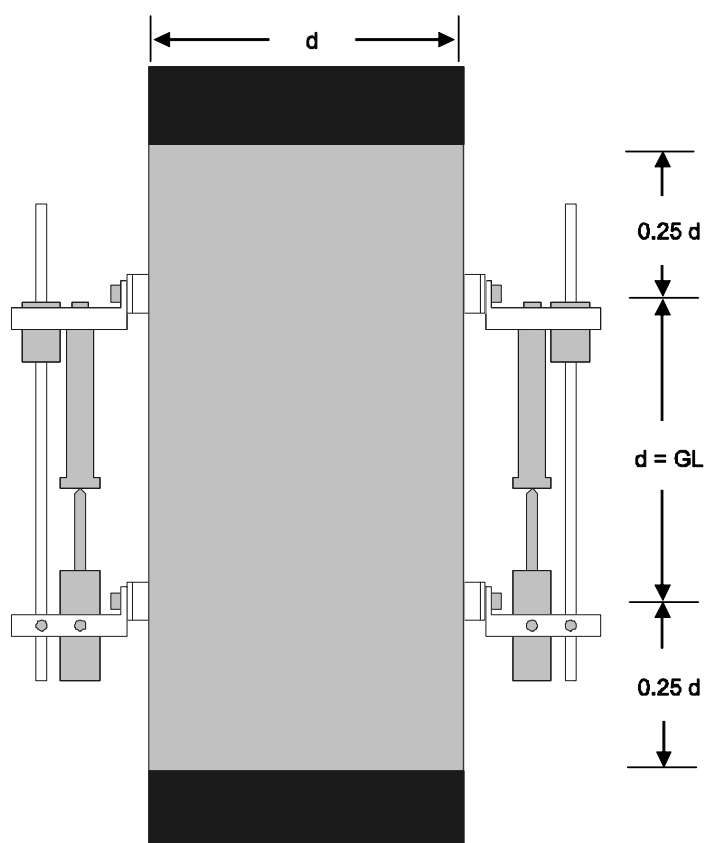


Figure 2—General Schematic of Gauge Points (Not to Scale)

- 6.2.3. *Loading Platens*—Loading platens, sized 104.5 ± 0.5 mm, are required above and below the specimen to transfer the load from the testing machine to the specimen. Generally, these platens should be made of hardened or plated steel, or anodized high-strength aluminum. Softer materials will require more frequent replacement. Materials that have linear elastic modulus properties and hardness properties lower than that of 6061-T6 aluminum shall not be used.
- 6.2.4. *End Treatment*—Friction-reducing end treatments shall be placed between the specimen ends and the loading platens. The end treatments shall consist of two Teflon[®] sheets or two 0.5-mm (0.02-in.) thick latex membranes separated with silicone grease.
- 6.3. *Superpave Gyratory Compactor*—A gyratory compactor and associated equipment for preparing laboratory specimens in accordance with T 312. The compactor shall be capable of compacting 170-mm (6.7-in.) high specimen.
- 6.4. *Saw*—A machine for sawing test specimen ends to the appropriate length is required. The saw shall have a diamond cutting edge and shall be capable of cutting specimens to the prescribed dimensions without excessive heating or shock.
- Note 1**—A diamond masonry saw greatly facilitates the preparation of test specimens with smooth, parallel ends. Both single- or double-bladed diamond saws should have feed mechanisms and speed controls of sufficient precision to ensure compliance with Sections 9.5 and 9.6 of this method. Adequate blade stiffness is also important to control flexing of the blade during thin cuts.
- 6.5. *Core Drill*—A coring machine with cooling system and a diamond bit for cutting nominal 101.6-mm (4.00-in.) diameter test specimens.
- Note 2**—A coring machine with adjustable vertical feed and rotational speed is recommended. The variable feeds and speeds may be controlled by various methods. A vertical feed rate of approximately 0.05 mm/rev (0.002 in./rev) and a rotational speed of approximately 450 RPM has been found to be satisfactory for several Superpave mixtures. Use of a standard electric core drill with a holder for the specimen is also acceptable.

7. HAZARDS

- 7.1. Observe standard laboratory safety precautions when preparing and testing hot mix asphalt (HMA) specimens.

8. TESTING EQUIPMENT CALIBRATION

- 8.1. The signal conditioning and data acquisition device of the testing system shall be checked to ensure that there is no excess phase shift between load and displacement channels.
- 8.2. The testing system shall be calibrated prior to initial use and at least once a year thereafter or per manufacturer requirements or per every 200 tests.
- 8.3. Verify the capability of the environmental chamber to maintain the required temperature within the accuracy specified.
- 8.4. Verify the calibration of all measurement components (such as load cell and specimen deformation measurement device) of the testing system.
- 8.5. If any of the verifications yield data that do not comply with the accuracy specified, correct the problem prior to proceeding with testing.

9. TEST SPECIMENS

- 9.1. *Size*—Dynamic modulus testing shall be performed on test specimens cored from gyratory 150-mm (4-in.) compacted mixtures. The average diameter of the test specimens shall be between 100 and 104 mm (3.94 and 4.1 in.) with a standard deviation of 1.0 mm (0.04 in.). The average height of the test specimen shall be between 147.5 and 152.5 mm (5.81 and 6.00 in.).
- 9.2. *Aging*—Laboratory-prepared mixtures shall be temperature-conditioned in accordance with the 4-hour short-term oven conditioning procedure in R 30. Field mixtures need not be aged prior to testing.
- 9.3. *Gyratory Specimens*—Prepare 170-mm (6.7-in.) tall specimens to the required air void content in accordance with T 312.
- Note 3**—Testing should be performed on test specimens (101.6-mm (4.0-in.) diameter) meeting specific air void tolerances. The gyratory specimen (152.4-mm (6.0-in.) diameter) air void content required to obtain a specified test specimen air void content must be determined by trial and error, achieved by using less or more mixture and compacted to the same height in the gyratory compactor. Generally, the test specimen air void content is 1.5 to 2.5 percent lower than the air void content of the gyratory specimen when the test specimen is removed from the middle as specified in this test method.
- 9.4. *Coring*—Core the nominal 101.6-mm (4.0-in.) diameter test specimens from the center of the gyratory specimens. Both the core drill and the gyratory specimen should be adequately supported to ensure that the resulting test specimen is cylindrical with sides that are smooth, parallel, and free from steps, ridges, and grooves.
- 9.5. *Diameter*—Measure the diameter of the test specimen at the mid-height and third points along axes that are 90 degrees apart. Record each of the six measurements to the nearest 1 mm (0.04 in.). Calculate the average and the standard deviation of the six measurements. If the standard deviation is greater than 2.5 mm (0.10 in.), discard the specimen. For acceptable specimens, the average diameter reported to the nearest 1 mm (0.04 in.) shall be used in all material property calculations.
- 9.6. *End Preparation*—The ends of all test specimens shall be smooth and perpendicular to the axis of the specimen. Prepare the ends of the specimen by sawing with a single- or double-bladed saw. The prepared specimen ends shall meet the tolerances described below. Reject test specimens not meeting these tolerances.
- 9.6.1. The specimen ends shall have a cut surface waviness height within a tolerance of ± 0.05 mm (± 0.002 in.) across any diameter. This requirement shall be checked in a minimum of three positions at approximately 120-degree intervals using a straightedge and feeler gauges approximately 8.1 to 12.5 mm (0.32 to 0.49 in.) wide or an optical comparator.
- 9.6.2. The specimen end shall not depart from perpendicular to the axis of the specimen by more than 1 degree, equivalent to 2.7 mm in 152.4 mm (0.11 in. in 6.10 in.). This requirement shall be checked on each specimen using a machinist's square and feeler gauges.
- 9.7. *Air Void Content*—Determine the air void content of the final test specimen in accordance with T 269. Reject specimens with air voids that differ by more than 0.5 percent from the target air voids.
- Note 4**—Considerable time can be saved if the cored test specimens were treated as wet, and the weights in water and saturated surface dry were measured immediately or within a short time