Designation: D7312 – 10

Standard Test Method for Determining the Permanent Shear Strain and Complex Shear Modulus of Asphalt Mixtures Using the Superpave Shear Tester (SST)[1]

This standard is issued under the fixed designation D7312; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard provides performance-related test procedures for the determination of stiffness complex shear modulus and permanent shear strain of asphalt mixtures using the Superpave Shear Tester (SST). This standard is applicable to the testing and analysis of modified and unmodified asphalt mixtures.

1.2 This standard is applicable to specimens prepared in a laboratory or cored from a pavement for post-construction analysis. It is intended for use with specimens having the following minimum dimensions:

Nominal Maximum Aggregate Size in Asphalt Mixture	Specimen Diameter	Specimen Height
19 mm	150 mm	50 mm
12.5 mm, 9.5 mm, 4.75 mm	150 mm	38 mm

NOTE 1—Nominal maximum aggregate size is defined in AASHTO R35 as one sieve larger than the first sieve to retain more than 10 % of the total aggregate. Asphalt mixtures with a nominal maximum aggregate size greater than 19 mm can be tested using this procedure, but it is not recommended. The larger aggregate sizes may significantly interfere with the material response, thereby affecting the repeatability of the test.

NOTE 2—The SST shall accommodate test specimens of 150 mm in diameter and 50 mm in height. The specimen height of 50 mm is preferred, but may not be available in roadway cores where layer thickness may be less. If the specimen height is less than 50 mm, use platen to platen fixturing (Linear Variable Differential Transformers (LVDTs) or extensometers). Specimen heights less than 38 mm cannot be tested because of equipment constraints.

NOTE 3—The diameter-to-height ratio for shear test specimens should be 3:1 or greater. This effectively eliminates the use of 100 mm diameter specimens (because of minimum height requirement for testing discussed in Note 2).

1.3 The between laboratory reproducibility of this test method has not been determined, therefore this standard should not be used for acceptance or rejection of a material for purchasing purposes.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D75 Practice for Sampling Aggregates
D140 Practice for Sampling Bituminous Materials
D979 Practice for Sampling Bituminous Paving Mixtures
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 Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures
D3549 Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
D5361 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
D6925 Test Method for Preparation and Determination of the Relative Density of Asphalt Mix Specimens by Means of the Superpave Gyratory Compactor
E1 Specification for ASTM Liquid-in-Glass Thermometers
E4 Practices for Force Verification of Testing Machines

[1] This test method is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.26 on Fundamental/Mechanistic Tests.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

2.2 *AASHTO Standards:*[3]

AASHTO R35 Superpave Volumetric Design for Hot Mix Asphalt (HMA)

AASHTO R30 Short and Long Term Aging of Hot Mix Asphalt (HMA)

3. Terminology

3.1 *Definitions:*

3.1.1 *complex shear modulus*—a complex number that defines the relationship between shear stress and strain for a linear viscoelastic material, G*.

3.1.2 *permanent shear strain*—the non-recoverable shear strain resulting from a shear load.

3.1.3 *phase angle*—a measure of the time lag between the applied stress and resulting strain, or applied strain and resulting stress, in a viscoelastic material.

4. Summary of Test Method

4.1 This test method includes two procedures.

4.1.1 In the frequency sweep test, the test initiates from a zero shear load and zero shear strain. Repeated sinusoidal shear loading oscillates around zero through ten frequencies at a given temperature while a varying axial load is applied to prevent dilation of the specimen. The loads and deformations are used to calculate the complex shear modulus and phase angle of the specimen at each frequency.

4.1.2 In the repeated shear at constant height test, a repeated haversine shear stress is applied to the specimen while a varying axial load prevents dilation. The accumulated shear deformation at the end of the test is measured to determine the permanent shear strain.

5. Significance and Use

5.1 The test procedures and associated analysis techniques described in this method can be used to determine complex shear modulus and permanent shear strain of asphalt mixtures. The shear frequency sweep test at constant height can be used to determine the complex shear modulus of a mixture. The repeated shear test at constant height can be used to determine permanent shear strain under repeated loading.

NOTE 4—The complex shear modulus is used to characterize the shear behavior of the mixture, and the permanent shear strain relates to pavement rutting.

6. Apparatus

6.1 *Shear Test System*—The shear test system shall consist of a loading device, specimen deformation measurement equipment, an environmental chamber, and a control and data acquisition system. At a minimum, it shall accommodate test specimens 150 mm in diameter and 38 to 50 mm in height.

6.1.1 *Loading Device*—The loading device shall be capable of simultaneously applying both vertical and horizontal loads to a specimen. It shall also be capable of applying static, ramped (increasing or decreasing), and repetitive loads of various waveforms. At a minimum, the loading device shall be capable of applying horizontal shear load pulses in a haversine wave form with a load duration of 0.1 s with 0.6 s between load pulses. Loading shall be provided by two hydraulic actuators (one each horizontal and vertical) and shall be controlled by closed-loop feedback using either stress or strain control throughout the entire range of frequencies and temperatures. The loading device shall be capable of meeting the minimum requirements specified in Table A1.1.

6.1.2 *Environmental Chamber*—The environmental chamber shall be capable of maintaining the temperature of the test specimen as specified in Table A1.1 during the testing sequence.

6.1.3 *Data Acquisition and Control System*—The data acquisition and control system shall automatically control user-selected measurement parameters, within the accuracy specified in Table A1.1, during the testing sequence, and shall record load cycles, applied horizontal and vertical loads, specimen deformation in two directions (vertical and horizontal), environmental conditions, and the required frequency of data sampling. At the conclusion of the test, the data acquisition and control system shall provide all applicable test data. The load shall be measured by load cells, and the axial and shear deformations shall be measured by Linear Variable Differential Transformers (LVDTs) meeting the requirements of Table A1.1.

NOTE 5—The user can view the wave or pulse parameters on the oscilloscope during the test or plot the raw data after the test to confirm that the test met the user-selected load and strain levels.

6.2 *Conditioning Chamber*—The conditioning chamber shall be capable of maintaining the specimen conditioning temperatures as specified in Table A1.1.

6.3 *Platen-Specimen Assembly Device (Optional)*—The platen-specimen assembly device is used to facilitate bonding the specimen to the loading platens with adhesive. The device shall maintain the platens in a parallel position (relative to each other) during the gluing operation. The platens must remain parallel so that stresses do not develop in the specimen when the specimen-platen assembly is clamped in the test system. At a minimum, the device shall accommodate test specimens 150 mm in diameter with a height of 38 to 50 mm.

6.4 *Aluminum Loading Platens*—Top and bottom aluminum loading platens at least 6.35 mm greater in diameter than the diameter of the specimen to be tested and at least 20 mm thick. The bearing face of each platen shall be planar to 0.025 mm across the entire surface.

6.5 *Adhesive*—Quick-set adhesive with a minimum hardened modulus of 2000 MPa for bonding the platens to the specimen ends.

NOTE 6—Devcon[4] 10240 5-Minute Plastic Steel Epoxy Cement and Devcon[4] 10110 2-Hour Plastic Steel Epoxy Cement or equivalents have been used satisfactorily. A ruggedness experiment comparing these two epoxies showed that glue type was not significant[5]

[3] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, http://www.transportation.org.

[4] "Devcon" and all its related uses and terms are trademarked and copyright ITW Devcon, 685 Galt Industrial Blvd. City: St. Louis State: MO ZIP: 63132-1021.

[5] Anderson and McGennis, *Journal of the Association of Asphalt Paving Technologists*, Vol 72, 2003.

6.6 *Thermometer*—A calibrated liquid-in-glass thermometer of suitable range with subdivisions readable to 0.1°C (0.2°F) or any other thermometric device of equal accuracy, precision, and sensitivity shall be used. Thermometers shall conform to the requirements of Specification E1.

7. Test Specimens

7.1 Prepare test specimens according to 7.2, 7.3 or 7.4, as appropriate. Test at least three specimens for each procedure (A or B).

NOTE 7—Testing additional samples, typically five total, will produce a more accurate test result.

7.2 *Laboratory-Mixed, Laboratory-Compacted (LMLC) Specimens*—Sample asphalt binder and aggregates in accordance with Practices D140 and D75, respectively. Use the appropriate proportions of asphalt binder and aggregates according to the final asphalt mix design.

7.2.1 Prepare aggregate batches of the appropriate mass to produce a compacted specimen 150 mm in diameter and 135 ± 5 mm in height at the appropriate air void content. Heat the aggregate batches to the appropriate mixing temperature.

NOTE 8—Appendix X1 contains information on the calculation of the appropriate aggregate batch weight to achieve the correct specimen dimension at the proper percentage of air voids.

7.2.2 Heat the asphalt binder to the appropriate mixing temperature. Mix the correct proportions of asphalt binder and combined aggregates to match the asphalt mix design.

7.2.3 Condition the asphalt mixture for 4 h ± 5 min at 135 ± 3°C in accordance with AASHTO R30.

7.2.4 Compact the asphalt mixture specimen following Test Method D6925 to produce test specimens with the required air voids.

Test	Air Voids in Test Specimen
Shear Frequency Sweep (Procedure A)	7.0 ± 0.5 %
Repeated Shear at Constant Height (Procedure B)	3.0 ± 0.5 %

NOTE 9—Compaction procedures other than the Superpave gyratory compactor and other target air void percentages may be used. However, the user should be careful with comparing asphalt mixtures with different target air voids or compaction. The test procedures and analyses are sensitive to both the percentage of air voids and the compaction procedure.

NOTE 10—Specimens are often compacted to a target air void percentage that is higher than the anticipated percentage of air voids in the cut test specimen. This is done because cutting the top and bottom of a compacted specimen removes lower density material, thereby raising the density (lowering the air voids) of the test specimen. The magnitude of the difference between the target percentage of air voids for the compacted specimen and the target percentage of air voids for the test specimen is dependent upon the nominal maximum aggregate size of the mixture, mixture gradation and other factors. Coarse mixes, or mixes with a larger nominal maximum aggregate size, tend to have greater differences between the compacted specimen air voids and the test specimen air voids. In general, a 1.0 % offset (compact to a target of 4.0 % air voids or 8.0 % air voids) should be sufficient to achieve the appropriate percentage of air voids in the test specimen.

7.2.5 Allow the compacted mixture specimens to cool completely to room temperature. Cut the specimens to the proper test dimensions. Determine and record the height of the test specimens in accordance with Test Method D3549. To verify that the specimen faces are parallel, determine the minimum and maximum height of each individual specimen. If the difference between the minimum and maximum height is more than 2.0 mm, then discard that specimen and prepare another.

7.2.6 Determine the maximum specific gravity of the mixture in accordance with Test Method D2041 or D6857 and the bulk specific gravity of each test specimen in accordance with Test Method D2726 or D6752. Calculate the air void content of each specimen in accordance with Test Method D3203.

7.3 *Field-Mixed, Laboratory-Compacted (FMLC) Specimens*—Obtain HMA samples in accordance with Practice D979. Compact specimens according to Test Method D6925 to the appropriate percentage of air voids (see 7.2.4 and Notes 8-10).

7.3.1 Allow the compacted mixture specimens to cool completely to room temperature. Cut the specimens to the proper test dimensions. Determine and record the height of the test specimens in accordance with Test Method D3549. To verify that the specimen faces are parallel, determine the minimum and maximum height of each individual specimen. If the difference between the minimum and maximum height is more than 2.0 mm, then discard that specimen and prepare another.

7.3.2 Determine the maximum specific gravity of the mixture in accordance with Test Method D2041 or D6857 and the bulk specific gravity of each test specimen in accordance with Test Method D2726 or D6752. Calculate the air void content of each specimen in accordance with Test Method D3203.

7.4 *Field-Mixed, Field-Compacted (FMFC or Pavement Core) Specimens*—Obtain asphalt pavement specimens having a diameter of 150 mm and a minimum thickness of 38 mm in accordance with Practice D5361.

7.4.1 Cut the specimens to the proper test dimensions. Determine the height and diameter of the test specimens in accordance with Test Method D3549. To verify that the specimen faces are parallel, determine the minimum and maximum height of each individual specimen. If the difference between the minimum and maximum height is more than 2.0 mm, then discard that specimen and cut another.

7.4.2 Determine the maximum specific gravity of the mixture in accordance with Test Method D2041 or D6857 and the bulk specific gravity of each test specimen in accordance with Test Method D2726 or D6752. Calculate the air void content of each specimen in accordance with Test Method D3203.

7.5 *Preparing the Specimens for Testing*—The following steps discuss the bonding of the test specimen to the platens for testing in the shear tester.

7.5.1 Ensure that the platens are clean, aligned, and clamped in place in the Platen-Specimen Assembly Device (Optional) or Shear Test Device.

7.5.2 Proportion and mix the epoxy resin and hardener together in accordance with the manufacturer's instructions (Note 6).

7.5.3 Apply a thin coating of the epoxy cement to the top of the test specimen and to the bottom platen. Center the test specimen on the bottom platen and lower the top platen onto the specimen. Rotate the specimen slightly to ensure good bonding.

NOTE 11—Approximately 135 to 150 g of epoxy cement has been found suitable to provide bonding without excess waste. Half of the epoxy cement should be used on the bottom platen and the other half on the top of the specimen.

7.5.3.1 Bond the specimen to the platens using light pressure as recommended by the equipment manufacturer. Begin removing excess epoxy cement from the sides of the test specimen by trimming with a tongue depressor or other suitable tool as soon as the pressure is applied.

7.5.4 After the adhesive has stabilized, remove the test assembly (specimen with attached platens) from the Platen-Specimen Assembly Device (optional) or Shear Test Device and allow the epoxy to cure for the minimum time recommended by the manufacturer.

NOTE 12—For Devcon[4] 10240 5-Minute Plastic Steel Epoxy Cement, a minimum curing time of two hours at room temperature is satisfactory. For Devcon[4] 10110 2-Hour Plastic Steel Epoxy Cement curing overnight before testing is recommended.

NOTE 13—The adhesive has stabilized when the test assembly has reached a point, based on the operator's experience, that it will not deform with the release of pressure. This procedure is done to facilitate the more efficient production of test specimens with a single device.

8. Calibration and Standardization

8.1 The testing system shall be standardized prior to initial use and at least once every 12 to 18 months thereafter according to Practice E4.

8.1.1 Verify the capability of the environmental control chamber to maintain the required temperature within the accuracy specified in Table A1.1 by measuring the temperature in the chamber at several points near where the specimens will be conditioned using a thermometer as described in 6.6.

8.1.2 Verify the calibration of all measurement components (such as load cells and LVDTs) of the testing system as recommended by the manufacturer. If any of the verifications yield data that does not comply with the accuracy requirements specified in Table A1.1, correct the problem prior to proceeding with testing.

NOTE 14—Possible corrections include correction of menu entries, maintenance on system components, calibration of system components (using an independent calibration service, manufacturer service, or in-house resources), or replacement of system components.

NOTE 15—A dynamic system check may be performed to verify the machine calibration by testing a known material. Neoprene and urethane samples 150 mm in diameter and 50 mm high are affixed to platens using epoxy steel. When used to verify the machine calibration by testing at 20°C, neoprene rubber is suitable for simulating the stiffness of typical asphalt mixes at 60 to 70°C, and urethane simulates the stiffness of asphalt mixes at 10 to 30°C. These materials behave viscoelastically and do not degrade or change properties substantially over time. Procedures A and B may be conducted on these materials at 20°C to verify the machine calibration. The samples should be tested immediately after initial machine set-up or calibration, then tested periodically to verify the machine is in calibration as recommended by the manufacturer.

9. Procedure A—Shear Frequency Sweep Test

9.1 Turn on the hydraulic system at least one hour before starting the test to allow sufficient warm-up time. Warm-up the actuators and hydraulic oil by using a sinusoidal waveform in stroke control.

9.2 Determine the lowest temperature at which the specimen will be tested and pre-condition the test specimen for two to four hours at the required test temperature ±0.5°C. Set the temperature for the environmental chamber of the shear test device at the required test temperature.

NOTE 16—Many specimens are tested at multiple temperatures depending on the desired data. For example, the complex shear modulus at an intermediate temperature (such as 20°C) may be desired to provide inputs to a fatigue analysis procedure. Shear modulus at a higher temperature (such as 40°C) may be desired to provide an indication of the expected high temperature behavior of an asphalt mixture. Because of equipment constraints, testing can only be conducted at temperatures where the mixture shear modulus is less than approximately 3000 MPa (435 ksi). Because of non-linear responses, testing should also be confined to temperatures no higher than 12°C below the high temperature grade of the asphalt binder (that is, 52°C for a PG 64-22 asphalt binder).

NOTE 17—A conditioning chamber is preferred since it allows the shear test device to be free to perform tests rather than be occupied for temperature conditioning.

9.3 After the conditioning period, remove the specimen (attached to platens) from the conditioning chamber. Open the environmental chamber of the shear tester.

9.4 Quickly attach the shear and axial LVDTs to the specimen platens. Ensure that the LVDTs are plugged into the proper data acquisition ports within the shear tester's environmental chamber. Zero the shear and axial LVDTs.

9.5 Confirm that the vertical test system head is positioned to allow the platen-specimen assembly to slide between the bottom and top heads. Confirm that the horizontal test head is positioned such that the top and bottom test heads are aligned vertically. Center the specimen and clamp according to the manufacturers' directions. Close and secure the environmental chamber.

NOTE 18—There are differences in the clamping procedures used with different brands of SSTs.

9.6 Confirm that the environmental chamber temperature control is activated and on the proper setting to maintain the required test temperature within a tolerance of ±0.5°C. Allow the specimen temperature to stabilize for a minimum of 20 min and a maximum of 60 min.

NOTE 19—This stabilization time allows the specimen to reacquire the proper test temperature (lost during LVDT instrumentation) and for the LVDTs to stabilize after the temperature change. A dummy specimen with a thermocouple mounted at the center may be used to verify that the temperature has stabilized. The minimum time needed to ensure stabilization should be used.

9.7 Execute the shear frequency sweep test.

9.7.1 Precondition the specimen by applying a sinusoidal shear strain consisting of a peak-to-peak amplitude of 0.0001 mm/mm (0.01 %) at 10 Hz for 100 cycles. During the loading cycle, maintain the specimen height constant, within ±0.0013 mm by applying sufficient axial stress during the loading cycle. This is accomplished by controlling the vertical actuator using closed-loop feedback from the axial LVDT.

NOTE 20—A compressive preload of 125 ± 25 N may be applied before preconditioning to ensure that a compressive load is maintained throughout the test and no tensile force is applied to the specimen.

9.7.2 Perform the shear frequency sweep test by applying a sinusoidal shear strain of 0.0001 mm/mm (0.01 %) at each of the following frequencies: 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.02, and 0.01 Hz. Use 50 cycles each for the 10 Hz and 5 Hz frequencies. Use 20 cycles each for the 2 Hz and 1 Hz frequencies. Use 7 cycles each for the 0.5, 0.2, and 0.1 Hz frequencies. Use 4 cycles each for the 0.05, 0.02, and 0.01 Hz frequencies.

9.7.3 Record the axial and shear deformations (from the LVDTs) and axial and shear loads. Record at a minimum rate of 50 data points per cycle for the number of cycles specified for each frequency in 9.7.2.

9.7.4 At the conclusion of the test, unclamp the specimen according to the procedure recommended by the equipment manufacturer (see Note 18). Disconnect the LVDT's from the specimen.

NOTE 21—Since the shear frequency sweep test is executed in the (theoretically) linear viscoelastic region, the same specimen can be tested in frequency sweep at a higher temperature (up to 40°C) or according to the repeated shear test at constant height (Procedure B). The repeated shear test at constant height should always induce sufficient permanent shear strain to affect mixture properties and should be considered a destructive test. Therefore, it is recommended that shear frequency sweep testing not be conducted on specimens that have been subjected to destructive testing.

9.8 Remove the specimen from the test chamber.

NOTE 22—The shear frequency sweep test takes approximately 45 min to execute from the time the specimen is removed from the conditioning chamber until the test is completed and the specimen is removed from the shear tester.

9.9 If the complex shear modulus will be determined at other test temperatures either: *(1)* return the specimen to the conditioning chamber and change the temperature of the SST and conditioning chamber to the next desired temperature, or *(2)* set the specimen aside without cleaning and wait to test until the temperature of the SST chamber can be adjusted.

NOTE 23—Once the complex shear modulus has been determined at all desired temperatures, clean the specimen from the platens by placing the specimen-platen assembly in an oven at approximately 135°C for sufficient time (45 to 60 min or as needed) to debond the specimen and epoxy from the platens. Gently scrape the platens clean.

10. Procedure B—Repeated Shear Test at Constant Height

10.1 Turn on the hydraulic system at least one hour before starting the test to allow sufficient warm-up time. Warm-up the actuators and hydraulic oil by using a sinusoidal waveform in stroke control.

10.2 Determine the test temperature and pre-condition the test specimens for two to four hours at the required test temperature ±0.5°C (see Note 17). Set the temperature for the environmental chamber of the shear test device at the required test temperature.

NOTE 24—The test temperature can be determined in many ways, but is most commonly calculated as the seven-day maximum pavement temperature (at a depth of 50 mm) for the project location. If the mixture in question is the wearing (surface) course, and the thickness of the layer is less than 50 mm, then the actual layer thickness (for example, 38 mm) may be used as the depth for calculating the test temperature. Information on calculating pavement temperatures is available in SHRP A-648A and the LTPPBind software of the Long Term Pavement Performance (LTPP) Program.

10.3 After the conditioning period, remove the specimen (attached to platens) from the conditioning chamber. Open the environmental chamber of the shear tester.

10.4 Quickly attach the shear and axial LVDTs to the specimen platens. Ensure that the LVDTs are plugged into the proper data acquisition ports within the shear tester's environmental chamber. Zero the axial LVDT. Adjust the shear LVDT to near the far end of its range to allow the entire stroke length to be used during testing.

10.5 Confirm that the vertical test system head is positioned to allow the platen-specimen assembly to slide between the bottom and top heads. Confirm that the horizontal test head is positioned such that the top and bottom test heads are aligned vertically. Center and clamp the specimen following the manufacturer's recommendations (see Note 18). Close and secure the environmental chamber.

10.6 Confirm that the environmental chamber temperature control is activated and on the proper setting to maintain the required test temperature within a tolerance of ±0.5°C. Allow the specimen temperature to stabilize for a minimum of 20 min and a maximum of 60 min (see Note 19).

10.7 Execute the repeated shear test at constant height.

10.7.1 Apply a repeated haversine shear stress to the test specimen consisting of 69 ± 5 kPa (approximately 1220 N shear load for a 150 mm diameter test specimen) for 0.1 s followed by a 0.6 s rest period. During the loading cycle, maintain the specimen height constant, within ±0.0013 mm by applying sufficient axial stress during the loading cycle. This is accomplished by controlling the vertical actuator using closed-loop feedback from the axial LVDT.

10.7.2 Continue the test sequence until the shear LVDT exceeds its range (usually at 2.5 mm or 5 % shear strain) or for a fixed number of cycles (typically 5000 or 10 000).

10.7.3 Record the axial and shear deformations (from the LVDTs) and axial and shear loads. Record at a minimum rate of 50 data points per cycle during the intervals specified in Table A2.1 or Table A2.2.

10.7.4 At the conclusion of the test, unclamp the specimen according to the procedure recommended by the manufacturer (see Note 18). Disconnect the LVDTs.

10.8 Remove the specimen from the test chamber.

NOTE 25—The repeated shear test at constant height (5000 cycles) takes approximately 90 min to execute from the time the specimen is removed from the conditioning chamber until the test is completed and the specimen is removed from the shear tester.

NOTE 26—Clean the specimen from the platens by placing the specimen-platen assembly in an oven at approximately 135°C for 45 to 60 min to debond the specimen and epoxy from the platens. Gently scrape the platens clean.

11. Calculations

11.1 *Procedure A (Shear Frequency Sweep Test at Constant Height)*—For each specimen, determine the complex shear modulus (G*) and phase angle (δ) at each frequency. These values are calculated by software programs from the measured values of shear load and shear displacement recorded as a function of time.

11.2 *Procedure B (Repeated Shear Test at Constant Height)*—For each specimen, determine the permanent shear strain at the end of the test (nominally 5000 or 10 000 cycles). The permanent shear strain (γ_p) is calculated as the change in shear deformation from the start of the test to the end of the test divided by the gauge length (nominally 50 mm when using platen-to-platen measurement):

$$\gamma_p = \frac{\delta_{shear,\ final} - \delta_{shear,\ initial}}{h} \quad (1)$$

where:

γ_p = permanent shear strain,
$\delta_{shear,\ final}$ = final recorded deformation by the shear LVDT at the end of the test,
$\delta_{shear,\ initial}$ = initial shear deformation at the start of the test (nominally zero), and
h = specimen height (platen-to-platen measurement only).

11.2.1 The permanent shear strain can also be expressed as a percentage by multiplying by 100.

12. Report

12.1 For each test specimen report the following:

12.1.1 Mixture identification,

12.1.2 Percentage of air voids in the test specimen or bulk specific gravity,

12.1.3 Conditioning time and temperature (within 0.1°C),

12.1.4 Equilibration or stabilization time, min, and

12.1.5 Measured temperature during the test (within 0.1°C).

12.2 *Procedure A (Shear Frequency Sweep Test at Constant Height)*—For each specimen, report the complex shear modulus (G*) and phase angle (δ) at each frequency.

12.3 *Procedure B (Repeated Shear Test at Constant Height)*—For each specimen, report the permanent shear strain obtained at the end of test and the number of cycles applied.

TABLE 1 Between and Within Laboratory Variability[A]

Test and Type Index	Standard Deviation (1s) (1s%)	Acceptable Range of Two Test Results (d2s) (d2s%)
Frequency Sweep G*[B]		
Single-operator precision	39 MPa (11 %)	108 MPa (30 %)
Multilaboratory precision	55 MPa (16 %)	154 MPa (44 %)
Repeated Shear at Constant Height[C]		
Single-operator precision	0.28 % (10 %)	0.79 % (29 %)
Multilaboratory precision	0.69 % (25 %)	1.91 % (70 %)

[A] From "Precision of Shear Tests Used for Evaluating Asphalt Mixtures," by Anderson, Huber, Steger and Romero, *Transportation Research Record 1832*, 2002.

[B] Four labs, using two different brands of SST, tested three replicates of one mixture at three temperatures and ten loading frequencies. The results shown here represent the precision of the results at 10 Hz and 40°C.

[C] Four labs, using two different brands of SST, tested three replicates of one mixture at 50°C.

12.4 Note any deviations from the test procedures for each specimen (that is, shear loads out of tolerance, etc.).

13. Precision and Bias

13.1 The within laboratory repeatability standard deviation and the between-laboratory reproducibility have been determined to be as shown in Table 1 based on four labs, three test replicates and one mixture sample. The between laboratory reproducibility of this test method is being determined and will be available on or before July 1, 2011. Therefore, this test method should not be used for acceptance or rejection of a material for purchasing purposes.

13.2 No information can be presented on the bias of the procedures in this test method for measuring bituminous mixture shear properties because no material, having an accepted reference value, has been established.

14. Keywords

14.1 complex shear modulus; frequency sweep; permanent strain; repeated shear; shear testing

ANNEXES

(Mandatory Information)

A1. MINIMUM TEST SYSTEM REQUIREMENTS

TABLE A1.1 Minimum Test System Requirements

Measurement and Control Parameters	Range	Resolution	Accuracy
Axial Load	±25 000 N	±25 N	±50 N
Shear Load	±25 000 N	±25 N	±50 N
Axial LVDT	±0.5 mm	±0.005 mm	±0.05 mm
Shear LVDT			
Procedure A. Frequency Sweep	±0.5mm	±0.005 mm	±0.05 mm
Procedure B. Repeated Shear	±2.5mm	±0.025 mm	±0.25 mm
Temperature	0–80ºC	0.25ºC	0.5ºC
Frequency	0.01–10 Hz	0.005 Hz	0.01 Hz

A2. REQUIRED INTERVAL RANGES FOR RECORDING DATA FOR PROCEDURE B

TABLE A2.1 Required Interval Ranges for Recording Data for Procedure B for Nominal 5000 Cycle Test

NOTE 1—Collect data during the cycles indicated at minimum rate of 50 data points per cycle during specified intervals.

NOTE 2—Software with some SST machines collects data for one additional cycle at the end of the test in order to ensure a full cycle of data is collected for the last specified cycle (cycle 5000 or 10 000, typically).

1 through 10	1599 through 1601
19 through 21	1799 through 1801
29 through 31	1999 through 2001
49 through 51	2249 through 2251
79 through 81	2499 through 2501
99 through 101	2749 through 2751
199 through 201	2999 through 3001
299 through 301	3249 through 3251
399 through 401	3499 through 3501
499 through 501	3749 through 3751
599 through 601	3999 through 4001
799 through 801	4249 through 4251
999 through 1001	4499 through 4501
1199 through 1201	4749 through 4751
1399 through 1401	4999 through 5000

TABLE A2.2 Required Interval Ranges for Recording Data for Procedure B for Nominal 10 000 Cycle Test

NOTE 1—Collect data during the cycles indicated at minimum rate of 50 data points per cycle during specified intervals.

NOTE 2—Software with some SST machines collects data for one additional cycle at the end of the test in order to ensure a full cycle of data is collected for the last specified cycle (cycle 5000 or 10 000, typically).

1 through 10	2699 through 2701
19 through 21	2999 through 3001
29 through 31	3299 through 3301
39 through 41	3699 through 3701
49 through 51	3999 through 4001
59 through 61	4299 through 4301
69 through 71	4699 through 4701
79 through 81	4999 through 5001
89 through 91	5299 through 5301
99 through 101	5699 through 5701
199 through 201	5999 through 6001
299 through 301	6299 through 6301
399 through 401	6699 through 6701
499 through 501	6999 through 7001
599 through 601	7299 through 7301
699 through 701	7699 through 7701
799 through 801	7999 through 8001
899 through 901	8299 through 8301
999 through 1001	8699 through 8701
1299 through 1301	8999 through 9001
1699 through 1701	9299 through 9301
1999 through 2001	9699 through 9701
2299 through 2301	9999 through 10000

APPENDIX

(Nonmandatory Information)

X1. CALCULATING AGGREGATE BATCH WEIGHTS

X1.1 Calculating Aggregate Batch Weight for LMLC Specimens

X1.1.1 To calculate the aggregate batch weight required for laboratory-mixed, laboratory-compacted (LMLC) specimens, use the following equation (valid for 150 mm diameter specimens):

$$\text{Mass} = \frac{17.671 \cdot \text{Height} \cdot G_{mm} \cdot (1 - AV)}{(1 - AC)} \tag{X1.1}$$

where:

Mass = aggregate batch weight, g,
Height = target compacted height of the specimen, mm,
G_{mm} = maximum theoretical specific gravity (Test Method D2041 or D6857) of the mixture,
AV = percentage of air voids desired, expressed as a decimal (that is, 0.04 rather than 4.0 %), and
AC = asphalt binder content of the mix, expressed as a decimal (that is, 0.045 rather than 4.5 %).

X1.1.2 *Example*—A mixture with a 5.2 % asphalt binder content and a G_{mm} of 2.533 is intended to be evaluated in the repeated shear test to estimate rutting susceptibility. The technician desires the test specimen to have 4.0 ± 0.5 % air voids. Therefore he anticipates compacting a specimen to a height of 75 mm and allowing a 1 % offset in air voids between the compacted specimen and the cut test specimen (see Note 10). Using the equation above, the aggregate batch weight is determined:

$$\text{Mass} = \frac{17.671 \cdot 75 \cdot 2.533 \cdot (1 - 0.05)}{(1 - 0.052)} = 3364 \text{ g} \tag{X1.2}$$

X1.2 Calculating Mixture Sample Weight for FMLC Specimens

X1.2.1 To calculate the mixture sample weight required for field-mixed, laboratory-compacted (FMLC) specimens, use the following equation (valid for 150-mm diameter specimens):

$$\text{Mass} = 17.671 \cdot \text{Height} \cdot G_{mm} \cdot (1 - AV) \tag{X1.3}$$

where:

Mass = aggregate batch weight, g,
Height = target compacted height of the specimen, mm,
G_{mm} = maximum theoretical specific gravity (Test Method D2041 or D6857) of the mixture, and
AV = percentage of air voids desired, expressed as a decimal (that is, 0.04 rather than 4.0 %).

X1.2.2 Alternatively, if the sample mass is known, then the compacted specimen height can be determined as follows:

$$\text{Height} = \frac{\text{Mass}}{17.671 \cdot G_{mm} \cdot (1 - AV)} \tag{X1.4}$$

X1.2.3 *Example*—A mixture sample of 4220 g is obtained. The G_{mm} of the mixture is determined to be 2.471. To produce a test specimen having approximately 4.0 ± 0.5 % air voids, the target compacted height should be calculated as follows:

$$\text{Height} = \frac{4220}{17.671 \cdot 2.471 \cdot (1 - 0.05)} = 101.7 \text{ mm} \tag{X1.5}$$