
Standard Method of Test for

**Determining the Rheological
Properties of Asphalt Binder Using
a Dynamic Shear Rheometer (DSR)**

AASHTO Designation: T 315-22¹

Technically Revised: 2022

Technical Subcommittee: 2b, Liquid Asphalt



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Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

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1. SCOPE

- 1.1. This test method covers the determination of the dynamic shear modulus and phase angle of asphalt binder when tested in dynamic (oscillatory) shear using parallel plate test geometry. It is applicable to asphalt binders having dynamic shear modulus values in the range from 100 Pa to 10 MPa. This range in modulus is typically obtained between 6 and 88°C at an angular frequency of 10 rad/s. This test method is intended for determining the linear viscoelastic properties of asphalt binders as required for specification testing and is not intended as a comprehensive procedure for the full characterization of the viscoelastic properties of asphalt binder.
- 1.2. This standard is appropriate for unaged material or material aged in accordance with T 240 and R 28.
- 1.3. Particulate material in the asphalt binder is limited to particles with longest dimensions less than 250 µm.
- 1.4. *This standard 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 procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*
- 1.5. *The quality of the results produced by this standard are dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used. Agencies that meet the criteria of R 18 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with R 18 alone does not completely assure reliable results. Reliable results depend on many factors; following the suggestions of R 18 or some similar acceptable guideline provides a means of evaluating and controlling some of those factors.*

2. REFERENCED DOCUMENTS

- 2.1. AASHTO Standards:
 - M 320, Performance-Graded Asphalt Binder
 - M 339M/M 339, Thermometers Used in the Testing of Construction Materials
 - R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories

- R 28, Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
- R 29, Grading or Verifying the Performance Grade (PG) of an Asphalt Binder
- R 66, Sampling Asphalt Materials
- T 240, Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test)
- T 314, Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)

2.2. *ASTM Standards:*

- C670, Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials
- D2170/D2170M, Standard Test Method for Kinematic Viscosity of Asphalts
- D2171/D2171M, Standard Test Method for Viscosity of Asphalts by Vacuum Capillary Viscometer
- E1, Standard Specification for ASTM Liquid-in-Glass Thermometers
- E879, Standard Specification for Thermistor Sensors for General Purpose and Laboratory Temperature Measurements
- E1137/E1137M, Standard Specification for Industrial Platinum Resistance Thermometers

2.3. *International Electrotechnical Commission Standard:*

- IEC 60751: 2008 Industrial Platinum Resistance Thermometers and Platinum Temperature Sensors

2.4. *ISO/IEC Standard:*

- ISO/IEC 17025, General Requirements for the Competence of Testing and Calibration Laboratories

3. TERMINOLOGY

3.1. *Definitions:*

- 3.1.1. *asphalt binder*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of nonparticulate organic modifiers.

3.2. *Descriptions of Terms Specific to This Standard:*

- 3.2.1. *annealing*—heating the binder until it is sufficiently fluid to remove the effects of steric hardening.
- 3.2.2. *calibration*—process of checking the accuracy and precision of a device using NIST-traceable standards and making adjustments to the device where necessary to correct its operation or precision and accuracy.
- 3.2.3. *complex shear modulus (G^*)*—ratio calculated by dividing the absolute value of the peak-to-peak shear stress, τ , by the absolute value of the peak-to-peak shear strain, γ .
- 3.2.4. *dummy test specimen*—a specimen formed between the dynamic shear rheometer (DSR) test plates from asphalt binder or other polymer to measure the temperature of the asphalt binder held between the plates. The dummy test specimen is used solely to determine temperature corrections.
- 3.2.5. *linear viscoelastic*—within the context of this specification refers to a region of behavior in which the dynamic shear modulus is independent of shear stress or strain.

- 3.2.6. *loading cycle*—a unit cycle of time for which the test sample is loaded at a selected frequency and stress or strain level.
- 3.2.7. *loss shear modulus (G'')*—the complex shear modulus multiplied by the sine of the phase angle expressed in degrees. It represents the component of the complex modulus that is a measure of the energy lost (dissipated during a loading cycle).
- 3.2.8. *molecular association*—a process where associations occur between asphalt binder molecules during storage at ambient temperature. Often called steric hardening in the asphalt literature, molecular associations can increase the dynamic shear modulus of asphalt binders. The amount of molecular association is asphalt specific and may be significant even after a few hours of storage.
- 3.2.9. *oscillatory shear*—refers to a type of loading in which a shear stress or shear strain is applied to a test sample in an oscillatory manner such that the shear stress or strain varies in amplitude by about zero in a sinusoidal manner.
- 3.2.10. *parallel plate geometry*—refers to a testing geometry in which the test sample is sandwiched between two relatively rigid parallel plates and subjected to oscillatory shear.
- 3.2.11. *phase angle (δ)*—the angle in radians between a sinusoidally applied strain and the resultant sinusoidal stress in a controlled-strain testing mode, or between the applied stress and the resultant strain in a controlled-stress testing mode.
- 3.2.12. *portable thermometer*—an electronic device that consists of a temperature detector (probe containing a resistive element), required electronic circuitry, and readout system.
- 3.2.13. *reference thermometer*—a NIST-traceable liquid-in-glass or electronic thermometer that is used as a laboratory standard.
- 3.2.14. *steric hardening*—see molecular association.
- 3.2.15. *storage shear modulus (G')*—the complex shear modulus multiplied by the cosine of the phase angle expressed in degrees. It represents the in-phase component of the complex modulus that is a measure of the energy stored during a loading cycle.
- 3.2.16. *temperature correction*—difference in temperature between the temperature indicated by the DSR and the test specimen as measured by the portable thermometer inserted between the test plates.
- 3.2.17. *thermal equilibrium*—is reached when the temperature of the test specimen mounted between the test plates is constant with time.
- 3.2.18. *verification*—process of checking the accuracy of a device or its components against an internal laboratory standard. It is usually performed within the operating laboratory.

4. SUMMARY OF TEST METHOD

- 4.1. This standard contains the procedure used to measure the complex shear modulus (G^*) and phase angle (δ) of asphalt binders using a dynamic shear rheometer and parallel plate test geometry.
- 4.2. The standard is suitable for use when the dynamic shear modulus varies between 100 Pa and 10 MPa. This range in modulus is typically obtained between 6 and 88°C at an angular frequency of 10 rad/s, dependent on the grade, test temperature, and conditioning (aging) of the asphalt binder.

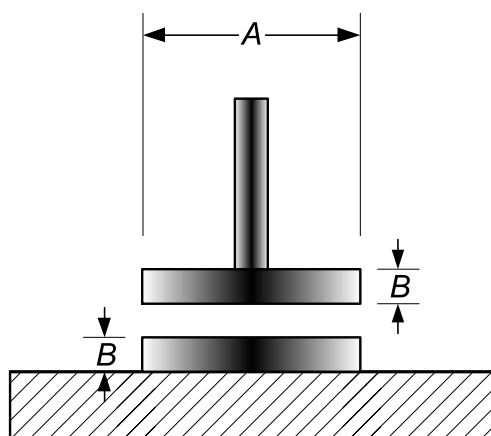
- 4.3. Test specimens 1 mm thick by 25 mm in diameter or 2 mm thick by 8 mm in diameter are formed between parallel metal plates. During testing, one of the parallel plates is oscillated with respect to the other at preselected frequencies and rotational deformation amplitudes (strain control) (or torque amplitudes [stress control]). The required stress or strain amplitude depends on the value of the complex shear modulus of the asphalt binder being tested. The required amplitudes have been selected to ensure that the measurements are within the region of linear behavior.
- 4.4. The test specimen is maintained at the test temperature to within $\pm 0.1^\circ\text{C}$ by positive heating and cooling of the upper and lower plates or by enclosing the upper and lower plates in a thermally controlled environment or test chamber.
- 4.5. Oscillatory loading frequencies using this standard can range from 1 to 100 rad/s using a sinusoidal waveform. Specification testing is performed at a test frequency of 10 rad/s. The complex modulus (G^*) and phase angle (δ) are calculated automatically as part of the operation of the rheometer using proprietary computer software supplied by the equipment manufacturer.

5. SIGNIFICANCE AND USE

- 5.1. The test temperature for this test is related to the temperature experienced by the pavement in the geographical area for which the asphalt binder is intended to be used.
- 5.2. The complex shear modulus is an indicator of the stiffness or resistance of asphalt binder to deformation under load. The complex shear modulus and the phase angle define the resistance to shear deformation of the asphalt binder in the linear viscoelastic region.
- 5.3. The complex modulus and the phase angle are used to calculate performance-related criteria in accordance with M 320.

6. APPARATUS

- 6.1. *Dynamic Shear Rheometer (DSR) Test System*—Consisting of parallel metal plates, an environmental chamber, a loading device, and a control and data acquisition system.
- 6.1.1. *Test Plates*—Stainless steel or aluminum plates with smooth ground surfaces. One 8.00 ± 0.02 mm in diameter and one 25.00 ± 0.05 mm in diameter (Figure 1). The base plate in some rheometers is a flat plate. A raised portion, a minimum of 1.50 mm high, with the same radius as the upper plate is required. The raised portion makes it easier to trim the specimen and may improve test repeatability.
- Note 1**—To obtain correct data, the upper and lower plates should be concentric with each other. At present there is no suitable procedure for the user to check the concentricity except to visually observe whether or not the upper and lower plates are centered with respect to each other. The moveable plate should rotate without any observable horizontal or vertical wobble. This operation may be checked visually or with a dial gauge held in contact with the edge of the moveable plate while it is being rotated. There are two values that determine the operating behavior of a measuring system: centricity (horizontal wobble) and runout (vertical wobble). Typically, wobble can be detected if it is greater than ± 0.02 mm. For a new system, a wobble of ± 0.01 mm is typical. If the wobble grows to more than ± 0.02 mm with use, it is recommended that the instrument be serviced by the manufacturer.



Dimension	8-mm Nominal	25-mm Nominal
A	8 ± 0.02 mm	25 ± 0.05 mm
B	≥ 1.50 mm	≥ 1.50 mm

Figure 1—Plate Dimensions

6.1.2. *Environmental Chamber*—For controlling the test temperature, by heating or cooling (in steps or ramps), to maintain a constant specimen environment. The medium for heating and cooling the specimen in the environmental chamber shall not affect asphalt binder properties. The temperature in the chamber may be controlled by the circulation of fluid such as water, conditioned gas such as nitrogen, or by a suitable arrangement of solid-state Peltier elements surrounding the sample. When forced air is used, a suitable drier must be included to prevent condensation of moisture on the plates and fixtures and, if operating below freezing temperatures, the formation of ice. The environmental chamber and the temperature controller shall control the temperature of the specimen, including thermal gradients within the sample, to an accuracy of $\pm 0.1^\circ\text{C}$. The chamber shall completely enclose the top and the bottom plates to minimize thermal gradients.

Note 2—A circulating bath unit, separate from the DSR, that pumps the bath fluid through the test chamber may be required if a fluid medium is used. The flow rate of the bath media should not be modified once the temperature settings have been adjusted to the desired value. Media lines should be periodically inspected and cleaned or replaced if necessary to remove obstructions

6.1.3. *Temperature Controller*—Capable of maintaining and displaying specimen temperatures at any given test temperature from 3 to 88°C with an accuracy of $\pm 0.1^\circ\text{C}$.

6.1.4. *Loading Device*—Capable of applying a sinusoidal oscillatory load to the specimen at a frequency of 10.0 ± 0.1 rad/s. If frequencies other than 10 rad/s are used, the frequency shall be accurate to 1 percent. The loading device shall be capable of providing either a stress-controlled or strain-controlled load. If the load is strain controlled, the loading device shall apply a cyclic torque sufficient to cause an angular rotational strain accurate to within $100 \mu\text{rad}$ of the strain specified. If the load is stress controlled, the loading device shall apply a cyclic torque accurate to within 10 mN·m of the torque specified. Total system compliance at 100 N·m of torque shall be less than 2 mrad/N·m. The manufacturer of the device shall certify that the frequency, stress, and strain are controlled and measured with an accuracy of one percent or less in the range of this measurement.

6.1.5. *Control and Data Acquisition System*—Capable of providing a record of temperature, frequency, deflection angle, and torque. Devices used to measure these quantities shall meet the accuracy requirements specified in Table 1. In addition, the system shall calculate and record the shear stress, shear strain, complex shear modulus (G^*), and phase angle (δ). The system shall measure

and record G^* , in the range of 100 Pa to 10 MPa, to an accuracy of 1.0 percent or less, and the phase angle, in the range of 0 to 90 degrees, to an accuracy of 0.1 degree.

Table 1—Control and Data Acquisition System Requirements

Property	Accuracy
Temperature	0.1°C
Frequency	1%
Torque	10 mN·m
Deflection angle	100 μ rad

- 6.2. *Specimen Mold (Optional)*—The overall dimensions of the silicone rubber mold for forming asphalt binder test specimens may vary but the thickness shall be greater than 5 mm. If the mold is a single sample mold, the following dimensions have been found suitable: For a 25-mm test plate with a 1-mm gap, a mold cavity approximately 18 mm in diameter and 2.0 mm deep. For an 8-mm test plate with a 2-mm gap, a mold cavity approximately 8 mm in diameter and 2.5 mm deep.
- 6.3. *Specimen Trimmer*—With a straightedge at least 4 mm wide.
- 6.4. *Wiping Material*—Clean cloth, paper towels, cotton swabs, or other suitable material as required for wiping the plates.
- 6.5. *Cleaning Solvents*—Mineral oil, citrus-based solvents, mineral spirits, toluene, or similar solvent as required for cleaning the plates. Acetone for removing the solvent residue from the surfaces of the plates is also necessary.
- 6.6. *Reference Thermometer*—A reference thermometer for calibrating the portable digital thermometer shall meet the requirements of M 339M/M 339 with a temperature of at least 0 to 90°C and an accuracy of $\pm 0.03^\circ\text{C}$ that is traceable to the International System of Units (SI) by an entity accredited to ISO/IEC 17025 such as NIST (see Note 3). This temperature standard shall be used to standardize the portable thermometer (Section 9.3).
Note 3—Thermometer types suitable for use include ASTM E1 mercury thermometers; ASTM E879 thermistor thermometer, special order; ASTM E1137/E1137M Pt-100 RTD platinum resistance thermometer, special order; or IEC 60751: 2008 Pt-100 RTD platinum resistance thermometer, special order.
- 6.7. *Portable Thermometer*—A portable thermometer for use in a dummy specimen, as required by Section 9.4.1 or 9.4.2, to verify DSR chamber temperature shall meet the requirements of M 339M/M 339 with a temperature range of at least 0 to 90°C and an accuracy of $\pm 0.05^\circ\text{C}$ (see Note 4).
Note 4—Thermometer types suitable for use include ASTM E879 thermistor thermometer, special order sealed ultra-small, paired with a compatible meter; ASTM E1137/E1137M Pt-100 RTD platinum resistance thermometer, special order sealed ultra-small, paired with a compatible meter; or IEC 60751: 2008 Pt-100 RTD platinum resistance thermometer, special order sealed ultra-small, paired with a compatible meter.

7. HAZARDS

- 7.1. Standard laboratory caution should be used in handling the hot asphalt binder when preparing test specimens.

8. PREPARATION OF APPARATUS

- 8.1. Prepare the apparatus for testing in accordance with the manufacturer's recommendations. Specific requirements will vary for different DSR models and manufacturers.
- 8.2. Inspect the surfaces of the test plates and discard any plates with jagged or rounded edges or deep scratches. Clean any asphalt binder residue from the plates with an organic solvent such as mineral oil, mineral spirits, a citrus-based solvent, or toluene. Remove any remaining solvent residue by wiping the surface of the plates with a cotton swab or a soft cloth dampened with acetone. If necessary, use a dry cotton swab or soft cloth to ensure that no moisture condenses on the plates.
- 8.3. Mount the cleaned and inspected test plates on the test fixtures and tighten firmly.
- 8.4. Select the testing temperature according to the grade of the asphalt binder or according to the preselected testing schedule (see Note 5). Allow the DSR to reach a stabilized temperature within $\pm 0.1^\circ\text{C}$ of the test temperature.

Note 5—M 320 and R 29 provide guidance on the selection of test temperatures.

- 8.5. With the test plates at the test temperature or the middle of the expected testing range, establish the zero gap level (1) by manually spinning the moveable plate, and while the moveable plate is spinning, close the gap until the removable plate touches the fixed plate (the zero gap is reached when the plate stops spinning completely), or (2) for rheometers with normal force transducers, by closing the gap and observing the normal force and after establishing contact between the plates, setting the zero gap at approximately zero normal force.

Note 6—The frame, detectors, and fixtures in the DSR change dimension with temperature causing the zero gap to change with changes in temperature. Adjustments in the gap are not necessary when measurements are made over a limited range of temperatures. The gap should be set at the test temperature or, when tests are to be conducted over a range of temperatures, the gap should be set at the middle of the expected range of test temperatures. For most instruments, no gap adjustment is needed as long as the test temperature is within $\pm 12^\circ\text{C}$ of the temperature at which the gap is set. If the instrument has thermal gap compensation, the gap may be set at the first test temperature instead of the middle of the range of test temperatures.

- 8.6. Once the zero gap is established as per Section 8.5, move the plates apart to approximately the test gap and preheat the plates. Preheating the plates promotes adhesion between the asphalt binder and the plates, especially at the intermediate grading temperatures.
- 8.7. To preheat 25-mm plates, bring the test plates to the test temperature or the lowest test temperature if testing is to be conducted at more than one temperature. To preheat 8-mm plates, bring the plates to between 34 and 46°C. Move the plates apart and establish a gap setting of 1.05 mm (for 25-mm diameter test specimens) or 2.10 mm (for 8-mm diameter test specimens).

Note 7—In order to obtain adequate adhesion between the asphalt binder and the test plates, the plates must be preheated. Preheating is especially critical when the silicone mold is used to prepare the asphalt binder for transfer to the test plates and when the testing is conducted with the 8-mm plates. When the direct placement method is used, as long as the test plates are immediately brought in contact with the asphalt binder, the heat carried with the asphalt binder improves adhesion. The preheating temperature needed for proper adhesion will depend on the grade and nature of the asphalt binder and the test temperature (8-mm or 25-mm plates). For some of the stiffer binder grades, especially those with high levels of modification, heating the plates to 46°C may not be sufficient to ensure proper adhesion of the asphalt binder to the test plates, especially if the silicone mold is used and the testing is conducted with 8-mm plates. For highly modified asphalt binders only, higher preheat temperatures may be used.

9. VERIFICATION AND CALIBRATION

9.1. Verify the DSR and its components at least every 6 months and when the DSR or plates are newly installed, when the DSR is moved to a new location, or when the accuracy of the DSR or any of its components is suspect. Four items require verification—the test plate diameter, DSR torque transducer, portable thermometer, and DSR test specimen temperature. Verify the DSR temperature transducer before verifying the torque transducer.

9.2. *Verification of Plate Diameter*—Measure the diameters to the nearest 0.01 mm. Maintain a log of the measured diameters as part of the laboratory quality control program so that the measurements are clearly identified with the specific plates. Enter the actual measured dimensions into the DSR software for use in calculations. If the top and bottom plates differ in diameter, enter the smaller of the two measured diameters.

Note 8—An error of ± 0.05 mm in the diameter of the plate results in a 0.8 percent error in the complex modulus for the 25-mm plate. For the 8-mm plate, errors in diameter of ± 0.01 , ± 0.02 , and ± 0.05 mm give respective errors in complex modulus of 0.5, 1.0, and 2.5 percent (see Figure 2).

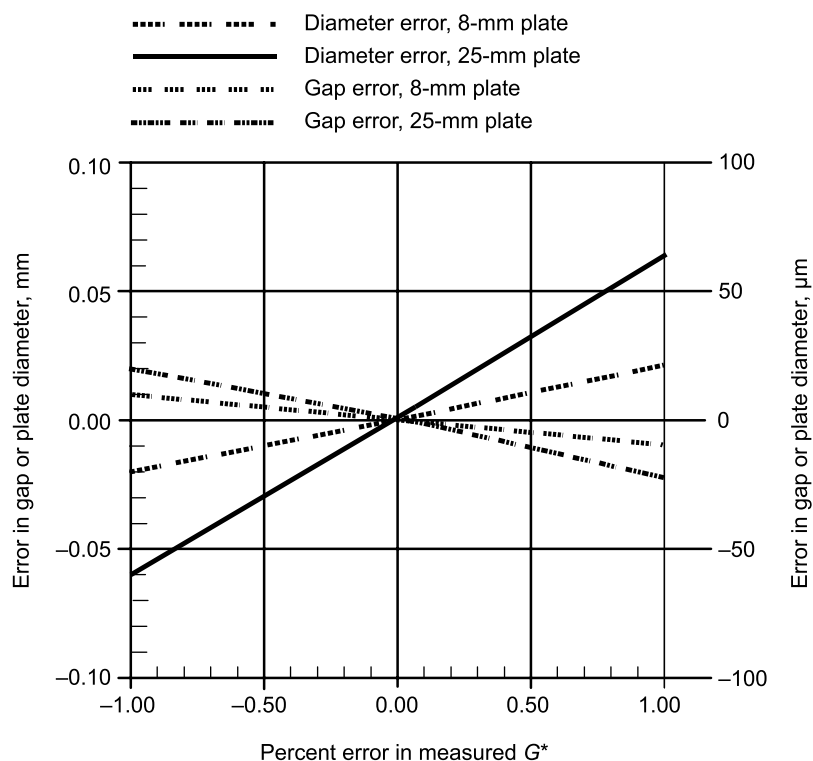


Figure 2—Effect of Error in Gap or Plate Diameter

9.3. *Verification of Portable Thermometer*—Verify the portable thermometer (used to measure the temperature between the test plates), using the laboratory reference thermometer. A portable thermometer shall be considered the combination of the meter (readout device) and the thermistor (temperature probe) as a single unit, and must be verified as such. If the reference thermometer (Section 6.6) is also used as a portable thermometer to measure the temperature between the test plates, it shall meet the requirements of Section 6.7.

9.3.1. *Recommended Verification Procedure*—Bring the reference thermometer into intimate contact with the detector from the portable thermometer and place them in a thermostatically controlled

and stirred water bath (Note 9). Ensure that deionized water is used to prevent electrical conduction from occurring between the electrodes of the resistive temperature sensitive element. If deionized water is not available, encase the reference thermometer and detector of the portable thermometer in a waterproof plastic bag prior to placement in the bath. Obtain measurements at intervals of approximately 6°C over the range of test temperatures allowing the bath to reach thermal equilibrium at each temperature. If the readings of the portable thermometer and the reference thermometer differ by 0.1°C or more, record the difference at each temperature as a temperature correction, and maintain the corrections in a log as part of the laboratory quality control program.

Note 9—A recommended procedure for the high-temperature range is to use a stirred water bath that is controlled within $\pm 0.1^\circ\text{C}$ such as the viscosity bath used for ASTM D2170/D2170M or D2171/D2171M. For a low-temperature bath, an ice bath or controlled-temperature bath may be used. Bring the probe from the portable thermometer into contact with the reference thermometer, and hold the assembly in intimate contact. A rubber band works well for this purpose. Immerse the assembly in the water bath, and bring the water bath to thermal equilibrium. Record the temperature on each device when thermal equilibrium is reached.

Note 10—If the readings from the two devices differ by 0.5°C or more, the calibration or operation of the portable thermometer may be suspect, and it may need to be recalibrated or replaced. A continuing change in the temperature corrections with time may also make the portable thermometer suspect.

9.4. *Test Specimen Temperature Correction*—Thermal gradients within the rheometer can cause differences between the temperature of the test specimen and the temperature indicated by the DSR thermometer (also used to control the temperature of the DSR). The DSR thermometer shall be checked at an interval no greater than six months. When these differences are 0.1°C or greater, determine a temperature correction by using a thermal detector mounted in a silicone rubber wafer (Section 9.4.1) or by placing asphalt binder (dummy sample) between the plates and inserting the detector of the portable thermometer into the asphalt binder (Section 9.4.2).

9.4.1. *Method Using Silicone Rubber Wafer*—For the entire range of test temperatures, place the wafer between the 25-mm test plates, and close the gap to bring the wafer into contact with the upper and lower plate so that the silicone rubber makes complete contact with the surfaces of the upper and lower plates. If needed, apply a thin layer of petroleum grease or anti-seize compound (see Note 11) to completely fill any void space between the silicone rubber and the plates. Complete contact is needed to ensure proper heat transfer across the plates and silicone rubber wafer. Determine any needed temperature correction as per Section 9.4.3.

Note 11—Anti-seize compound available by that name at hardware and auto supply stores is much less apt to contaminate the circulating water than petroleum grease.

Note 12—The thickness of the silicone wafer should be measured with calipers to identify the actual thickness. The thickness can be used to set the gap for temperature.

9.4.2. *Method Using Dummy Test Specimen*—The dummy test specimen shall be formed from asphalt binder or other polymer that can be readily formed between the plates. Mount the dummy test specimen between the test plates, and insert the detector (probe) of the portable thermometer into the dummy test specimen. Close the gap to the test gap (1 mm for 25-mm plates and 2 mm for 8-mm plates) keeping the detector centered vertically and radially in the dummy test specimen. Heat the plates as needed to allow the dummy test specimen to completely fill the gap between the test plates. It is not necessary to trim the dummy test specimen but avoid excessive material around the edges of the plates. Determine any needed temperature correction as per Section 9.4.3.

Note 13—Silly putty can leave a residue of silicone oil on the surfaces of the plates, and for this reason, its use as a dummy specimen is not recommended.

9.4.3. *Determination of Temperature Correction*—Obtain simultaneous temperature measurements with the DSR thermometer and the portable thermometer at 6°C increments to cover the range of test