
Standard Method of Test for

**Determining the Damage
Characteristic Curve and Failure
Criterion Using Small Specimens
in the Asphalt Mixture Performance
Tester (AMPT) Cyclic Fatigue Test**

AASHTO Designation: T 411-24¹

Technically Revised: 2024

**Technical Subcommittee: 2d, Proportioning
of Asphalt–Aggregate Mixtures**



**American Association of State Highway and Transportation Officials
555 12th Street NW, Suite 1000
Washington, DC 20004**

Determining the Damage Characteristic Curve and Failure Criterion Using Small Specimens in the Asphalt Mixture Performance Tester (AMPT) Cyclic Fatigue Test

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1. SCOPE

- 1.1. This test method covers procedures for preparing and testing both laboratory-compacted and field-cored asphalt mixture specimens to determine the damage characteristic curve and fatigue analysis parameters via the direct tension cyclic fatigue test using the asphalt mixture performance tester (AMPT).
- 1.2. This standard is intended for dense-graded mixtures with nominal maximum aggregate size less than or equal to 19.0 mm (0.75 in.). Mixtures with a nominal maximum aggregate size greater than 19.0 mm (0.75 in.) should be tested following T 400.
- 1.3. *This standard may involve hazardous material, operations, and equipment. This standard does not purport to address all safety problems 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.*
- 1.4. *The quality of the results produced by this standard is 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 STANDARDS

- 2.1. *AASHTO Standards:*
 - M 320, Performance-Graded Asphalt Binder
 - M 332, Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test
 - PP 99, Preparation of Small Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC) and Field Cores
 - R 18, Establishing and Implementing a Quality Management System for Construction Materials Testing Laboratories

- T 400, Determining the Damage Characteristic Curve and Failure Criterion Using the Asphalt Mixture Performance Tester (AMPT) Cyclic Fatigue Test
- TP 132, Determining the Dynamic Modulus for Asphalt Mixtures Using Small Specimens in the Asphalt Mixture Performance Tester (AMPT)

2.2. *Federal Highway Administration:*

- *Cyclic Fatigue Index Parameter (S_{app}) for Asphalt Performance Engineered Mixture Design*, FHWA-HIF-091, 2019
- *Development of Asphalt Mixture Performance Related Specifications*, Final Report, FHWA Project No. DTFH61-08-H-00005, 2020

2.3. *National Cooperative Highway Research Program:*

- *NCHRP. Equipment Specification for the Simple Performance Test System*, Version 3.0, Prepared for National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, DC, October 16, 2007.

2.4. *Other Documents:*

- Lee, K., S. Pape, C. Castorena, B. S. Underwood, and Y. R. Kim. Strain-Level Determination Procedure for Small-Specimen Cyclic Fatigue Testing in the Asphalt Mixture Performance Tester. In *Transportation Research Record 2673*. pp. 824–835, 2019.
- Li, X. and N. H. Gibson. Using Small Specimens for AMPT Dynamic Modulus and Fatigue Tests. *Asphalt Paving Technology*, Journal of the Association of Asphalt Paving Technologists, Vol. 82, pp. 579–615, 2013.

3. TERMINOLOGY

- 3.1. *alpha term (α)*—Value corresponding to the slope of the relaxation modulus master curve which is used in the accumulation of damage with time.
- 3.2. *command load*—The load level that a user inputs to the control software of the AMPT equipment.
- 3.3. *cyclic fatigue index parameter (S_{app})*—The apparent damage capacity of the material.
- 3.4. *cyclic pseudo secant modulus (C^*)*—The secant modulus in stress–pseudo strain space for a single cycle. This pseudo modulus differs from C because it is computed using a steady-state assumption and is used only with cycle-based data.
- 3.5. *damage (S)*—The internal state variable that quantifies microstructural changes in asphalt mixtures.
- 3.6. *damage characteristic curve (C versus S curve)*—The curve formed when plotting the damage on the x -axis and the pseudo secant modulus on the y -axis. It defines the unique relationship between the structural integrity and amount of damage in a given mixture.
- 3.7. *dynamic modulus ($|E^*|$)*—The peak-to-peak stress divided by the peak-to-peak axial strain resulting from sinusoidal loading measured during the steady-state period.
- 3.8. *dynamic modulus ratio (DMR)*—The ratio between the fingerprint dynamic modulus and the dynamic modulus value from a master curve construction, both evaluated at the same temperature and frequency condition. This value is also used to characterize specimen-to-specimen variability.
- 3.9. *end failure*—Specimen failure in which the macrocrack develops outside the range of one or more axial deformation sensors. Several example end failure locations are shown in Figure 1.

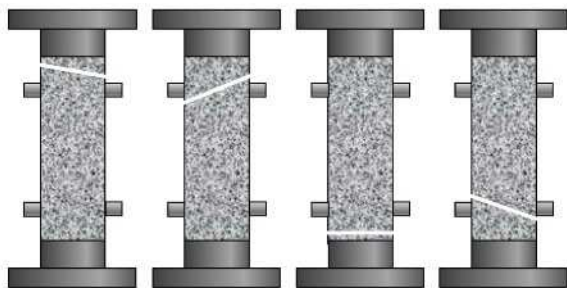


Figure 1—Example End Failure Locations

- 3.10. *fingerprint dynamic modulus* ($|E^*|_{\text{fingerprint}}$)—The dynamic modulus that is measured on the test specimen prior to performing the cyclic fatigue test.
- 3.11. *highly modified polymer binder*—Asphalt binder that has been specially modified beyond typical polymer modification levels (which are approximately 3 to 3.5 percent content) and meets the applicable performance thresholds as dictated by state or local practices for highly modified polymer binder.
- 3.12. *middle failure*—Specimen failure in which the macrocrack develops within the range of all axial deformation sensors. Several example middle failure locations are shown in Figure 2.

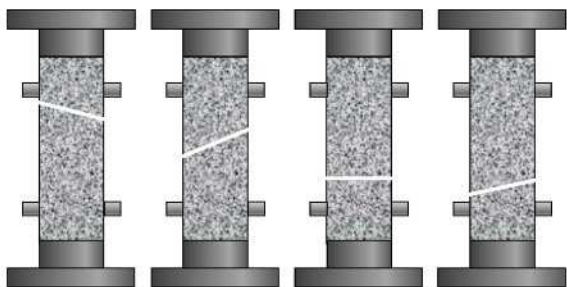


Figure 2—Example Middle Failure Locations

- 3.13. *number of cycles to failure* (N_f)—The cycle in which the product of peak-to-peak stress and cycle number reaches a maximum value after a stable increase during cyclic loading.
- 3.14. *phase angle* (θ)—The angle, expressed in degrees, between an applied sinusoidal stress and the resulting sinusoidal strain measured during the steady-state period.
- 3.15. *pseudo energy-based fatigue failure criterion* (D^R)—The average loss of integrity of the material during the fatigue loading.
- 3.16. *pseudo secant modulus* (C)—The secant modulus in stress–pseudo strain space.
- 3.17. *pseudo strain* (ϵ_R)—A quantity that is similar to strain but does not include time effects. Pseudo strain is calculated by solving the convolution integral of the strain and $E(t)$.
- 3.18. *relaxation modulus* ($E(t)$)—The quotient of the stress response of a material with time to a constant step amplitude of strain.
- 3.19. *resulting load*—The load level that the AMPT applies as a result of the command load.

- 3.20. *storage modulus (E')*—The elastic component of the dynamic modulus.
- 3.21. *test specimen*—A38-mm (1.50-in.) diameter by 110-mm (4.33-in.) tall cylindrical specimen cored and sawed from either an SGC specimen or field core.

4. SUMMARY OF METHOD

- 4.1. An actuator displacement-controlled repeated cyclic loading is applied to an asphalt mixture test specimen until failure. The applied stress and on-specimen axial strain response are measured and used to calculate the necessary quantities. The analysis of this test procedure requires dynamic modulus data conducted in accordance with TP 132. The test outcomes are two material functions, the C versus S curve and the D^R . It is important to recognize that this document pertains to direct tension testing in an AMPT. Test procedures will differ if using other machines and it is recommended that more specialized procedures be developed for these other machines.

5. SIGNIFICANCE AND USE

- 5.1. The C versus S curve and the D^R are independent of temperature, frequency, and mode of loading. The combination of linear viscoelastic properties, the C versus S curve, and the D^R can be used to calculate S_{app} . The procedure to calculate S_{app} is provided in Appendix X2. The combination of the C versus S curve and the D^R can also be used with pavement response models to predict the fatigue behavior of asphalt pavements.

6. APPARATUS

- 6.1. *Asphalt Mixture Performance Tester*—An AMPT or other machine meeting or exceeding the requirements of the equipment specification for the Simple Performance Test (SPT) System, version 3.0, with the additional capability to conduct direct tension testing. An example schematic of an AMPT with direct tension capability is shown in Figure 3.

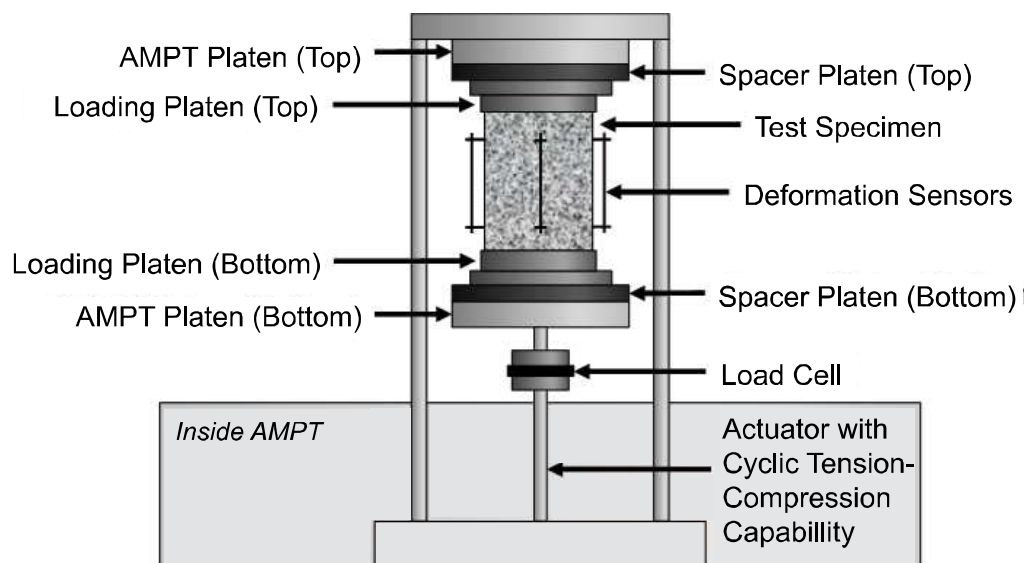


Figure 3—Example Schematic of an AMPT with Direct Tension Testing Capability

- 6.2. *Dummy Specimen (optional)*—A 38-mm (1.50 in.) diameter by 110-mm (4.33 in.) tall cylindrical specimen cored and sawed from an SGC specimen with a thermocouple or other calibrated temperature-measuring device mounted in the center to check the temperature. It is recommended to use a dummy specimen made with an identical mixture to a specimen to be tested. If not possible, it is recommended that a mixture with identical NMAS as the one to be tested be used as the dummy specimen.
- 6.3. *External Conditioning Chamber (optional)*—An environmental chamber for conditioning the test specimens to the desired testing temperature. The chamber shall be capable of controlling the temperature of the test specimen over a temperature range of 9 to 21°C (48 to 70°F) to within $\pm 0.5^\circ\text{C}$ ($\pm 1^\circ\text{F}$). The chamber shall be large enough to accommodate at least a single test specimen and the “dummy” specimen.
- 6.4. *Axial Deformation Measurement System*—Axial deformations shall be measured in the middle $70\text{ mm} \pm 1\text{ mm}$ (2.76 in. $\pm$ 0.04 in.) of the test specimen using sensors mounted between gauge points that are glued to the test specimen. The deformations shall be measured at three locations approximately 120 degrees apart.

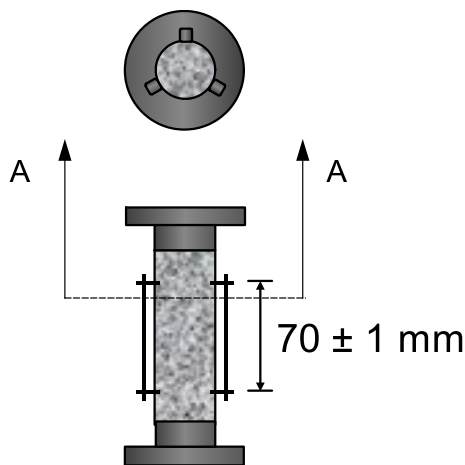


Figure 4—General Schematic of Gauge Points (Not to Scale)

- 6.5. *Loading Platens*—Are glued to the top and bottom of the test specimen to transfer the load from the testing machine to the test specimen. The diameter of the loading platens shall be 37.8 to 39.2 mm (1.49 to 1.54 in.). These platens should be made of hardened or plated steel or anodized high-strength aluminum. Materials that have linear elastic moduli and hardness lower than that of 6061-T6 aluminum shall not be used. The surface of each loading platen that will be in contact with the epoxy shall be grooved to provide better adhesion between the epoxy adhesive and platen. The top loading platen shall be designed so that it can be mated to the test machine without inducing any loading eccentricity.
- Note 1**—It is recommended the grooves in the loading platens be approximately 0.6 mm (0.02 in.) deep and spaced laterally by a distance of approximately 1.9 mm (0.07 in.). The grooving pattern can be concentric circle, spiral, or cross-hatched. A V-shaped or U-shaped groove is suggested. The 60-degree point threading bit has been used successfully for making the grooves.
- 6.6. *Shims*—Metal strips approximately 6.25 mm (0.25 in.) to 12.5 mm (0.5 in.) wide having a minimum length of 50 mm (2.0 in.) and ranging in thickness from at least 0.05 mm (0.002 in.) up to 0.762 mm (0.03 in.) in maximum increments of 0.05 mm (0.002 in.) shall be used to fill gaps

between the top of the test specimen loading platen and AMPT platen or spacer platen if one is used.

Note 2—Tapered leaf feeler gauges have been used successfully (Grainger Catalog Number 42DJ75 or equivalent).

6.7. *Diameter Carbon Steel Wire*—0.8-mm (0.031-in.) diameter carbon steel wire.

Note 3—McMaster Carr Catalog Number 9666K56 has been used successfully.

6.8. *Loading Platen Gluing Apparatus (optional)*—Used for gluing the loading platens to the test specimen with epoxy adhesive. The device should ensure that the loading platens and test specimen are all centered, that the two loading platens are held parallel, and that the test specimen is standing perpendicular to the loading platens. The weight resting on the test specimen during curing of the adhesive shall not exceed 0.03 kN (6.7 lb).



Figure 5—Example of a Loading Platen Gluing Apparatus

- 6.9. *Spacer Platens (optional)*—May be required to attach the loading platens to the AMPT platens due to the small test specimen size.
- 6.10. *Epoxy Adhesive*—Is required to affix the loading platens and gauge points to the test specimen. The epoxy adhesive must be capable of maintaining adhesion between metal and asphalt mixture under cyclic tension loading. The epoxy should have a working time greater than or equal to the time needed to glue loading platens and gauge points to the test specimen (typically five minutes).
Note 4—Devcon 10240 Plastic Steel 5 Minute Putty has been used successfully (McMaster Carr Catalog Number 74575A63).
- 6.11. *Gauge Point Gluing Apparatus (optional)*— A device used to position and place the gauge points on the test specimen and hold them there until the epoxy adhesive cures. The device shall be capable of holding the gauge points at a separation distance of 70 mm $\pm$ 1 mm, approximately in the middle of specimen, measured center to center of the gauge points. It should also be capable of attaching the gauge points approximately 120 degrees apart.

7. HAZARDS

- 7.1. Use standard laboratory safety precautions, equipment, and personal protection equipment when preparing and testing asphalt mixture specimens.

8. TESTING EQUIPMENT CALIBRATION

- 8.1. The guidelines provided in TP 132 shall be followed to ensure that the test equipment and on-specimen measurement devices are properly calibrated.
- 8.2. If any of the verifications yield data that does not comply with the accuracy specified, the problem shall be corrected prior to further testing.
- 8.3. The hydraulic machine shall be properly tuned in displacement control mode to enable the use of the strain selection guidance in this standard. Consult the equipment manufacturer for guidance on the specific equipment.

9. TEST SPECIMEN MOUNTING AND INSTRUMENTATION PROCEDURE

- 9.1. Prepare at least three test specimens at the target air void content ± 0.5 percent in accordance with PP 99.
- 9.2. Attach the gauge points to each test specimen with the epoxy adhesive in accordance with the manufacturer's instructions. Avoid placing gauge points directly in line with screw holes in the loading platens, which will be used to attach the test specimen to the testing machine.
Note 5—Users may attach gauge points before or after the loading platens. However, the gauge point gluing apparatus may require that the loading platens and gauge points be attached in a specific order.
- 9.3. Verify that the gauge length is 70 mm $\pm$ 1 mm (2.76 in. $\pm$ 0.04 in.), measured center to center of the gauge points.
- 9.4. Thoroughly clean all loading platens, including both new and used loading platens.
- 9.4.1. Heavily brush the surface of each loading platen that will be in contact with the epoxy using either a hand-operated wire brush, sandpaper, or a wire brush attached to a standard electric drill.

- 9.4.2. Wipe the surface clean of dust and residue by using a towel dipped in acetone or similar solvent.
- 9.5. Wipe both ends of the test specimen clean of any residual dust.
- 9.6. Weigh out an appropriate amount of each part of the epoxy adhesive to glue the loading platens and test specimen to one another.
Note 6—Approximately 6 g (0.21 oz.) of the epoxy adhesive has been found suitable for adhering 38-mm (1.50-in.) diameter test specimens.
- 9.7. Fill in any surface voids and pores in the top and bottom surfaces of the test specimen with the adhesive.
- 9.8. Divide the remaining adhesive in half and spread one half evenly on the top loading platen and the other half evenly on the bottom loading platen, ensuring that the grooves are filled.
- 9.9. If gluing test specimens with the gluing apparatus, continue to Section 9.10. If gluing test specimens with the AMPT, skip to Section 9.16.
- 9.10. Insert and secure the loading platens into the gluing apparatus and gently place the test specimen on top of the bottom loading platen, as close as possible to the center.
- 9.11. Engage the centering mechanism to center the test specimen on the loading platen.
- 9.12. Lower the top platen into position and secure if necessary. The final adhesive thickness should be approximately 1 mm (0.04 in.)
- 9.13. Allow the epoxy adhesive to reach its initial set before moving the test specimen from the gluing apparatus.
- 9.14. Remove the test specimen from the gluing apparatus after initial set. Take special care to support the entire test specimen from the bottom loading platen. Do not lift the test specimen by the top loading platen to ensure tension is not applied to the test specimen and epoxy adhesive.
- 9.15. Skip to Section 9.19.
- 9.16. Insert and secure the loading platens to the AMPT and gently place the test specimen on top of the bottom loading platen, as close as possible to the center.
- 9.17. Set the command load to 0.03 kN (6.7 lb) compressive force.
- 9.18. If removing the test specimen from the AMPT before testing, then allow the epoxy adhesive to reach its initial set before moving. Take special care to support the entire test specimen from the bottom loading platen. Do not lift the test specimen by the top loading platen, to ensure tension is not applied to the test specimen and epoxy adhesive.
- 9.19. Allow the epoxy adhesive to reach a functional cure before testing. Follow the manufacturer's recommendation to determine the time needed to reach functional cure.

10. TEST INFORMATION

- 10.1. This procedure is designed to first test a specimen at a low strain to obtain a linear viscoelastic fingerprint and then test the specimen at a higher strain until it fails. Both tests are performed at a frequency of 10 Hz in oscillation (cyclic) mode and at a constant temperature prescribed in Section 10.3.

- 10.2. A total of three acceptable tests are required, with test specimens experiencing middle failure between 2,000 and 80,000 cycles to failure, and with a DMR between 0.85 and 1.15.
- 10.3. For mixtures containing a highly modified polymer binder, the testing temperature shall be 18°C. For all other mixtures, the testing temperature shall be selected using Table 1 or Table 2, where the specified PG of the binder material is used to determine the test temperature. Table 1 is used for PG grades developed using M 320, or PG grades designated as “S” in M 332. Table 2 is used for PG grades designated as “H”, “V” or “E” in M 332. If the mixture contains recycled material and the PG of the virgin binder was adjusted to account for this recycled material, then select the temperature based on the PG of the virgin binder that would have been used for a mixture without any recycled materials.

Table 1—Recommended Test Temperatures for Different Standard PG Binder Grades

PG Low Temperature, °C	Test Temperature, °C							
	PG High Temperature, °C							
	46	52	58	64	67	70	76	82
−10	21	21	21	21	21	21	21	21
−16	18	21	21	21	21	21	21	21
−22	15	18	21	21	21	21	21	21
−28	12	15	18	21	21	21	21	21
−34	9	12	15	18	18	21	21	21
−40	9	9	12	15	15	18	21	21
−46	9	9	9	12	12	15	18	21

Table 2—Recommended Test Temperatures for Different PG Binder Grades with MSCR “H”, “V”, or “E” Designations

PG Low Temperature, °C	Test Temperature, °C							
	PG High Temperature, °C							
	46	52	58	64	67	70	76	82
−10	21	21	21	21	21	21	21	21
−16	21	21	21	21	21	21	21	21
−22	18	21	21	21	21	21	21	21
−28	15	18	21	21	21	21	21	21
−34	12	15	18	21	21	21	21	21
−40	9	12	15	18	18	21	21	21
−46	9	9	12	15	15	18	21	21

11. PROCEDURE

- 11.1. *Test Setup:*
- 11.1.1. Spacer platens may need to be placed between the loading platens and AMPT platens to compensate for the reduced height and diameter of the test specimens. If so, attach the spacer platens to the machine according to the manufacturer’s instructions.
- 11.1.2. If using an external conditioning chamber to temperature-condition the test specimens, continue to Section 11.1.3. If using the AMPT testing chamber to temperature-condition the test specimens, skip to Section 11.1.5.