Standard Method of Test for

Determining the Fracture Potential of Asphalt Mixtures Using Semicircular Bend Geometry (SCB) at Intermediate Temperature

AASHTO Designation: TP 124-16
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AASHTO

1. SCOPE

1.1. This test method covers the determination of the fracture energy (G_f) of asphalt mixtures using the semicircular bend (SCB) geometry at an intermediate test temperature. The method also includes procedures for calculating other relevant parameters derived from the load-displacement curve. These parameters, in conjunction with field performance, can be used to develop a Flexibility Index (FI) to predict an asphalt mixtures' damage resistance. The index can be used as part of the asphalt mixture approval process.

1.2. These procedures apply to test specimens having a nominal maximum aggregate size (NMAS) of 19 mm or less. Lab compacted and field core specimens can be used. Lab compacted specimens shall be 150 ± 1 mm in diameter and 50 ± 1 mm thick. When field cores are used, specimens shall be 150 ± 8 mm in diameter and 25 to 50 mm thick. A thickness correction factor may be applied for field cores tested at thickness less than 45 mm.

1.3. A vertical notch parallel to the loading axis shall be cut on the SCB specimen. The SCB specimen is a half disc with a notch parallel to the loading and the vertical axis of the semicircular disc.

1.4. *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 and follow appropriate health and safety practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 166, Bulk Specific Gravity (G_{mb}) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
- T 209, Theoretical Maximum Specific Gravity (G_{mm}) and Density of Hot Mix Asphalt (HMA)
- T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
- T 283, Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage
- T 312, Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor
- TP 105, Determining the Fracture Energy of Asphalt Mixtures using Semicircular Bend Geometry (SCB)

2.2. *ASTM Standards*:

- D8, Standard Terminology Relating to Materials for Roads and Pavements

- D3549/D3549M, Standard Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
- D5361/D5361M, Standard Practice for Sampling Compacted Bituminous Mixtures for Laboratory Testing

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *critical displacement*, u_1—intersection of the post-peak slope with the displacement-axis yields.

3.1.2. *displacement at peak load*, u_0—recorded displacement at peak load.

3.1.3. final displacement, u_{final}—recorded displacement at the 0.1-kN cut-off load.

3.1.4. *flexibility index,* FI—index intended to characterize the damage resistance of asphalt mixtures.

3.1.5. *fracture energy, G_f*—energy required to create a unit surface area of a crack.

3.1.6. *linear variable displacement transducer*, LVDT—sensor device for measuring linear displacement.

3.1.7. *ligament area,* $Area_{lig}$—cross-sectional area of specimen through which the crack propagates, calculated by multiplying ligament width (test specimen thickness) and ligament length.

3.1.8. *load line displacement*, LLD—displacement measured in the direction of the load application.

3.1.9. *post-peak slope, m*—slope at the first inflection point of the load-displacement curve after the peak.

3.1.10. *semicircular bend (SCB) geometry*—geometry that utilizes a semicircular specimen.

3.1.11. *secant stiffness, S*—secant slope is defined between the starting point of load vs. load line displacement curve and point peak load is reached.

3.1.12. *work of fracture (W_f)*—calculated as the area under the load versus load line displacement curve.

4. SUMMARY OF METHOD

4.1. An asphalt pavement core or Superpave Gyratory Compactor (SGC) compacted asphalt mixture specimen is cut in half to create a semicircular test specimen. A notch is sawn in the flat side of the semicircular specimen opposite the curved edge. The semicircular specimen is positioned in the fixture with the notched side down centered on two rollers. A load is applied along the vertical radius of the specimen and the load and load line displacement (LLD) are measured during the entire duration of the test. The load is applied such that a constant LLD rate of 50 mm/min is obtained and maintained for the duration of the test. The SCB test fixture and SCB specimen geometry are shown in Figure 1.

4.2. Fracture energy (G_f), secant stiffness (S), post-peak slope (m), displacement at peak load (w_0), and critical displacement (w_1), and a flexibility index are calculated from the load and LLD results.

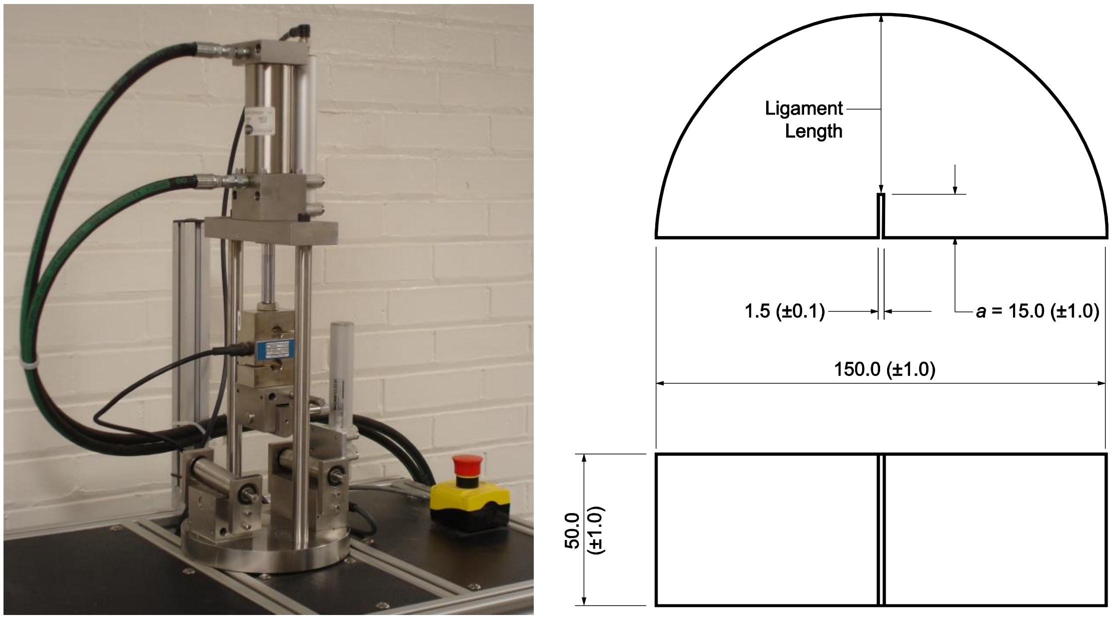


Figure 1—SCB Test Specimen and Configuration (dimensions in millimeters)

5. SIGNIFICANCE AND USE

5.1. The SCB test is used to determine fracture resistance parameters of an asphalt mixture at an intermediate temperature. Low temperature fracture parameters can be determined in accordance with TP 105. These parameters describe the fracture and fatigue resistance of asphalt mixtures. The calculated fracture energy indicates an asphalt mixture's overall capacity to resist cracking related damage. Generally, a mixture with higher fracture energy can resist greater stresses with higher damage resistance. It should not be directly used in structural design and analysis of pavements. It also represents the main parameter used in more complex analyses based on a theoretical crack (cohesive zone) models. In order to be used as part of a cohesive zone model, fracture energy as calculated from the experiment shall be corrected to determine energy associated with crack propagation only. A correction factor may be used to eliminate other sources of inelastic energy contributing to the total fracture energy calculated directly from the experiment.

5.2. From the fracture parameters obtained at intermediate temperature, the Flexibility Index (FI) of an asphalt mixture is calculated. The Flexibility Index is calculated considering the fracture energy and slope of the load-displacement curve after the post-peak representing average crack growth rate. The FI provides a means to identify brittle mixes that are prone to premature cracking. Flexibility Index values obtained using this procedure are used in ranking cracking resistance of alternative mixes for a given layer in a structural design. The range for an acceptable FI will vary according to local environmental conditions, application of mixture and expectation of service life.

5.3. This test method and flexibility index can be used to rank the cracking resistance of asphalt mixtures containing various asphalt binders, modifiers of asphalt binders, aggregate blends, fibers, and recycled materials.

5.4. The specimens can be readily obtained from SGC compacted cylinders or from field cores with a diameter of 150 mm.

6. APPARATUS

6.1. *Testing Machine*—A semicircular bend (SCB) test system consisting of a closed-loop axial loading device, a load measuring device, a bend test fixture, specimen deformation measurement devices, and a control and data acquisition system. A constant displacement-rate device shall be used such as an electromechanical, screw-driven machine, or a closed loop, feedback-controlled servo-hydraulic load frame.

6.1.1. *Axial Loading Device*—The loading device shall be capable of delivering loads in compression with a resolution of 10 N and a minimum capacity of 10 kN.

6.1.2. *Bend Test Fixture*—The fixture is composed of a steel base plate, two U-shaped roller support steel blocks, two steel rollers with a diameter (*D*) of 25 mm and a U-shaped LVDT positioning frame (see Figure 2). The initial roller position is fixed by springs and backstops that establish the initial test spans dimension. The support rollers are allowed to rotate away from the backstops during the test; but remain in contact with the sample. The tip of the loading head has a contact curvature of 12.5 mm radius. Illustrations of the loading and supports are shown in Figure 2.

Note 1—The length of the two roller supports in Figure 2 shall be a minimum of 65 mm.

6.1.3. *Internal Displacement Measuring Device*—The displacement measurement can be performed using the machine's stroke (position) transducer if the resolution of the stroke is sufficient (0.01 mm or lower). The fracture test displacement data may be corrected for system compliance, loading-pin penetration and specimen compression by performing a calibration of the testing system.

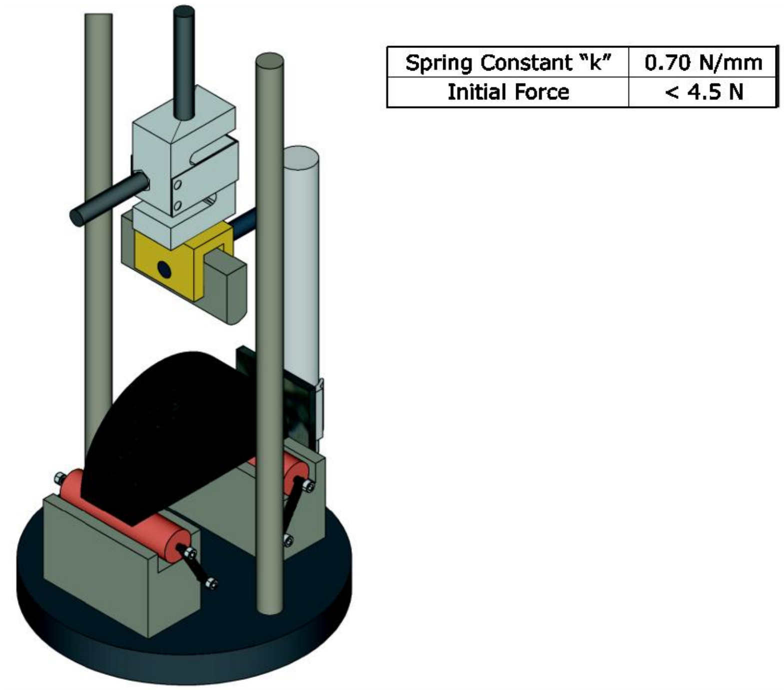
6.1.4. *External Displacement Measuring Device*— If an internal displacement measuring device does not exist or has insufficient precision, an externally applied displacement measurement device such as a linear variable differential transducer (LVDT) accurate to 0.01mm can be used (Figure 2).

6.1.5. *Control and Data Acquisition System*—Time and load, and load-line displacement (using external or internal displacement measurement device) is recorded. The control data acquisition system is required to apply a constant load-line displacement rate at a precision of 50 ± 1 mm/min and collect data at a minimum sampling frequency of 20 Hz in order to obtain a smooth load-load line displacement curve.

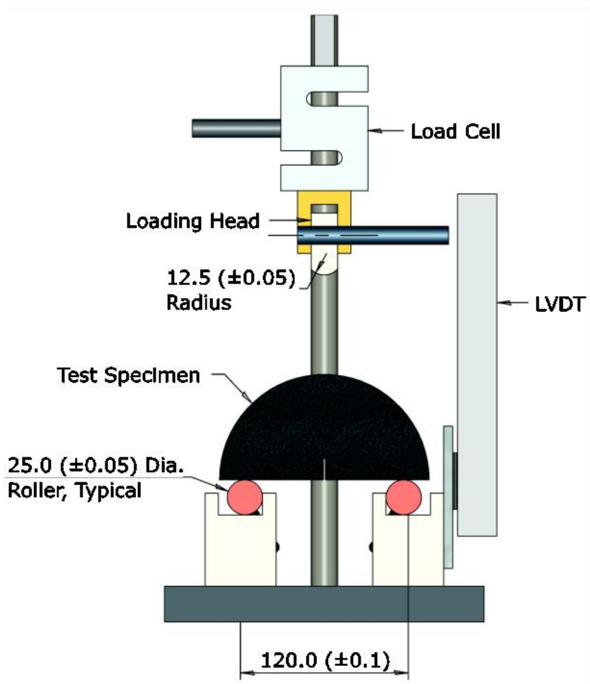
6.1.6. *Saw*—Laboratory saw capable of cutting asphalt specimens; must be capable of cutting the notch described in Figure 1.

6.1.7. *Conditioning Chamber*—Environmental chamber or water bath capable of maintaining specimen temperature as described in Section 10.1.

6.1.8. *Measuring Device*—Caliper or ruler accurate to ±1mm for specimen thickness and area measurement.



a. Isometric View



b. Section A-A

Figure 2—Isometric, Cross-Section, and Elevation of the SCB Test Fixture (dimension in millimeters)
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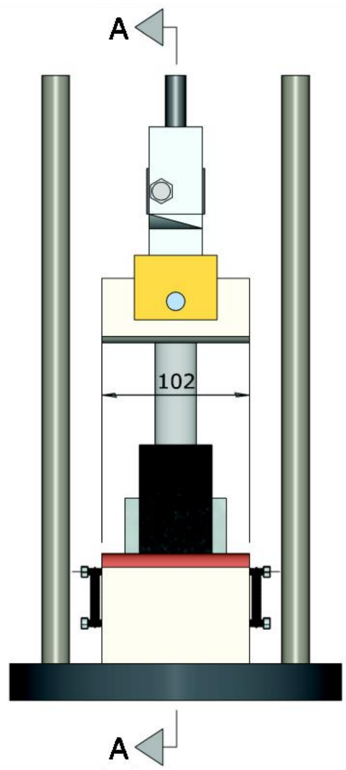

c. Elevation

Figure 2—*(continued)*

7. HAZARDS

7.1. Standard laboratory caution should be used in handling, compacting, and fabricating asphalt mixtures test specimens in accordance with AASHTO T 312.

8. CALIBRATION AND STANDARDIZATION

8.1. Verify the capability of the environmental chamber to maintain a constant and uniform temperature. A water bath as used in AASHTO T 283 may be used in lieu of an environmental chamber.

Note 2—Caution should be used if an oven is selected for sample conditioning as this will likely result in variable sample conditioning.

8.2. Verify the calibration of all measurement components (such as load cells and LVDTs) of the testing system.

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

9. PREPARATION OF TEST SPECIMENS AND PRELIMINARY DETERMINATIONS

9.1. *Test Specimen Size*—For mixtures with nominal maximum aggregate size of 19 mm or less, prepare the test specimens from a lab compacted SGC cylinder or from pavement cores. The final SGC test cylinders shall have smooth parallel faces with a thickness of 50 ± 1 mm and a diameter of 150 ± 1 mm (see Figure 4). If field specimens are used, the final test specimen dimensions shall be 150 ± 8 mm in diameter with smooth parallel faces 25 to 50 mm thick depending on available layer thickness.

Note 3—A typical laboratory saw for mixture specimen preparation can be used to obtain cylindrical slices with smooth parallel surfaces. Diamond-impregnated cutting faces and water cooling are recommended to minimize damage to the specimen. When cutting the SCB specimens, it is recommended not to push the two halves against each other because it may create an uneven base surface of the test specimen that will affect the results.

9.1.1. *SGC Specimens*—Prepare one laboratory SGC specimen according to T 312 in the SGC with a minimum compaction height of 160 mm. From the center of the SGC specimen, obtain two cylindrical 50 ± 1 mm thick slices (see Figure 4). Cut each slice into two identical "halves". This results in four SCB test specimens with target 7.0 ± 0.5% air voids in the top and bottom slices.

Note 4—For laboratory compacted specimens, if target air voids cannot be achieved for each slice, specimen height can be increased. If specimen height cannot be increased to get target air voids in the slices, obtain a single slice from the middle of two SGC specimens.

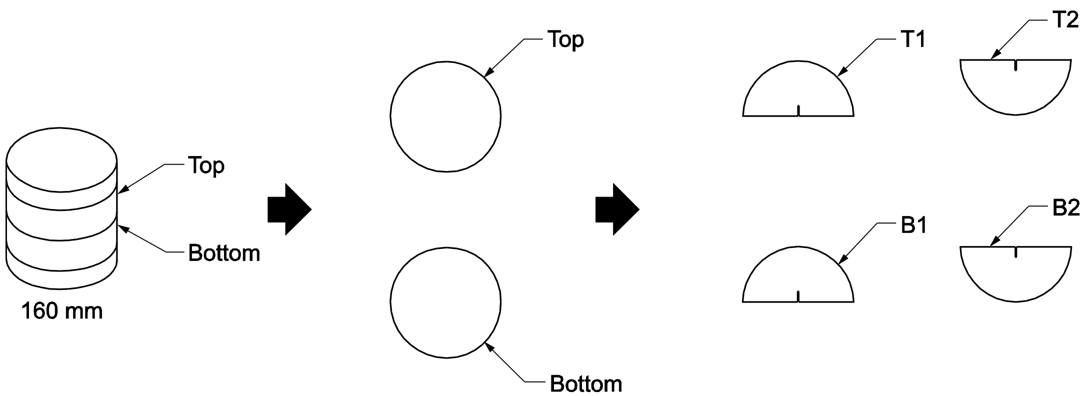

Figure 3—Specimen preparation from SGC specimens

9.1.2. *Field Cores*—Obtain field cores from the pavement in accordance with ASTM D5361. Obtain one 150 mm diameter pavement cores if the lift thickness is greater than or equal to 100 mm or two 150-mm diameter cores if the lift thickness is less than 100 mm.

9.1.2.1. *Field Specimens*—Prepare four replicate SCB test specimens using pavement cores obtained from a pavement lift, with smooth, parallel surfaces that conform to the height and diameter requirements specified herein. The thickness of test specimens in most cases for field cores may vary from 25 to 50 mm. If the lift thickness is less than 50 mm, test specimens should be prepared as thick as possible but in no case be less than two times the nominal maximum aggregate size of the mixture or 25 mm, whichever is greater. If lift thickness is greater than 50 mm, a 50-mm slice shall be prepared. Cores from pavements with lifts greater than 75 mm may be sliced to provide two cylindrical specimens of equal thickness. Cut each cylindrical specimen exactly in half to produce two identical, semicircular SCB specimens. Each slice of the field core shall have parallel smooth cut faces on the top and bottom.

9.2. *Notch Cutting*—Cut a notch along the axis of symmetry of each semicircular specimen to a depth of 15 ± 1 mm and 1.5 ± 0.1 mm in width (see Figure 1).

Note 5—If the notch terminates in an aggregate particle 9.5 mm or larger on both faces of the specimen, the specimen shall be discarded.

9.3. *Determining Specimen Dimensions*—Measure and record the ligament length (see Figure 1) and thickness of each specimen in accordance with ASTM D3549/D3549M, to the nearest 1 mm. Measure the notch depth on both faces of the specimen and record the average value to the nearest 0.5 mm.

9.4. *Determining the Bulk Specific Gravity*—Determine the bulk specific gravity directly on the test specimens obtained from SGC cylinders or field cores according to AASHTO T 166.

10. TEST PROCEDURE

10.1. *Conditioning*—Test specimens shall be conditioned in an environmental chamber or water bath at 25 ± 0.5 °C for 2 ± 10 minutes.

10.1.1. *Temperature Control*—The temperature of the specimen shall be maintained within 0.5°C of the desired test temperature (25°C) throughout the conditioning and testing periods. Testing shall be completed within 5 ± 1 minutes after removal from the environmental chamber or water bath.

10.2. *Specimen Placement in Loading Jig*—The test specimen shall be positioned so that it is symmetrical in every direction with respect to the roller supports. The specimen shall be perpendicular to the roller supports in both the horizontal plane and the vertical plane. The line of the force applied by the loading head shall pass vertically through the center of the specimen and through the sawed notch.

10.3. *Contact Load*—First, impose a small contact load of 0.1 ± 0.01 kN in line load displacement (LLD) control with a loading rate of 0.05 kN/s. Subtract the weight of the loading head from the contact load so that the actual contact load on the specimen is the same for all of the various machines that may be used to conduct the test.

10.3.1. *Record Contact Load*— Record the contact load to ensure it is achieved.

10.3.2. *Loading*—After the contact load of 0.1 kN is reached, the test is conducted using LLD control at a rate of 50 mm/min. The test stops when the load drops below 0.1 kN.

11. PARAMETERS

11.1. *Determining Work of Fracture* (W_f)—The work of fracture is calculated as the area under the load vs. LLD curve. If test is stopped prior to reaching 0.1 kN, the remainder of the load vs. LLD curve should be produced by extrapolation techniques.

The area under the load-displacement curve is calculated using a numerical integration technique. In order to apply the numerical integration, raw load-displacement data shall be divided into two curves described by an appropriate fitting equation. A polynomial equation with a degree of three is sufficient for the curve prior to peak load (Equation 1). An exponential-based function (Equation 2) is used for the post-peak load portion of the curve. Then, analytical integration shall be applied to calculate the area under each curve (Equation 3).

For displacements (u) prior to the peak load (P_{max}):

$$P_1(u) = c_1 \times u^3 + c_2 \times u^2 + c_3 \times u + c_4 \quad (1)$$

where:

c = polynomial coefficients.

For displacements (u) after the peak load (P_{max}) to the cut-off displacement (u_{final}):

$$P_2(u) = \sum_{i-1}^{n} d_i \exp\left[-\left(\frac{u-e_i}{f_i}\right)^2\right] \quad (2)$$

where:

d, e, f = polynomial coefficients, n is the number of exponential terms.

Work of fracture can be analytically or numerically calculated using the integral equation below and boundaries of displacement:

$$W_f = \int_0^{u_0} P_1(u)\,du + \int_{u_0}^{u_{final}} P_2(u)\,du \quad (3)$$

where:

u_{final} = displacement at the 0.1 kN cut-off load.

Note 6—Due to the relative difference between the compliance of testing frame and specimen, displacement recorded may vary. A correction factor may be considered to correct recorded displacements when applicable.

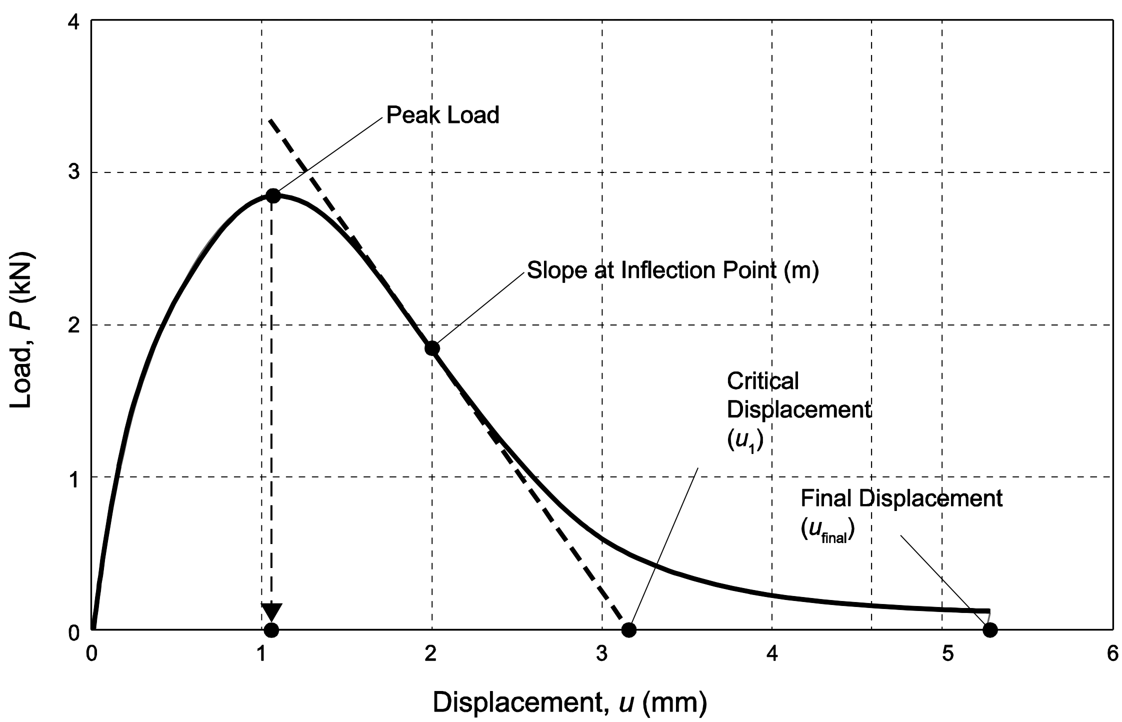

Figure 4—Recorded load (P) versus LLD (u) curve

11.2. *Fracture Energy (G_f)*—The fracture energy GF (RILEM TC 50-FMC) is calculated by dividing the work of fracture (the area under the load versus the average load line displacement curve; see Figure 5) by the ligament area (the product of the ligament length and the thickness of the specimen) of the SCB specimen prior to testing:

$$G_f = \frac{W_f}{\text{Area}_{\text{lig}}} \times 10^6 \qquad (4)$$

where:

G_f	=	fracture energy (Joules/m^2);
W_f	=	work of fracture (Joules);
P	=	load (kN);
u	=	load line displacement (mm); and
Area_{lig}	=	ligament area (mm^2), where
Area_{lig}	=	ligament length × t and
t	=	specimen thickness (mm)

Note 7—Fracture energy is a size dependent property. This specification does not aim at calculating size independent fracture energy. Therefore, cracking resistance of asphalt mixes quantified with fracture energy may vary when the notch length to radius ratio changes.

11.3. *Determining Secant Stiffness (S)*—Secant stiffness is calculated by dividing the peak load by the displacement achieved at the same load.

11.4. *Determining Post-Peak Slope (m)*—The inflection point is determined on the load-displacement curve (Figure 5) after the peak point. The slope of the tangential curve drawn at the inflection point represents post-peak slope.

11.5. *Determining Displacement at Peak Load (u_0)*— The displacement when peak load is reached.

11.6. *Determining Critical Displacement (u_1)*—Intersection of the tangential post-peak slope with the displacement axis yields the critical displacement value. A straight line is drawn connecting the inflection point and displacement axis with a slope *m*.

11.7. *Flexibility Index (FI)*—Flexibility index can be calculated from the parameters obtained using the load displacement curve. The factor *A* is used for unit conversion and scaling. *A* is equal to 0.01.

$$FI = \frac{G_f}{|m|} \times A \qquad (5)$$

where:

$|m|$ = absolute value of post-peak load slope *m* (kN/mm).

12. CORRECTION FACTORS

12.1. *Specimen Thickness Correction for Energy Parameters*—Thickness correction for energy and other load-displacement curve parameters may be needed. This correction factor will be applied to the flexibility index obtained from field specimens. A thickness correction factor may be applied for field cores tested at thickness less than 45 mm.

12.2. *Shift Factor from Lab to Field Specimens*—Apply a shift factor between SGC and pavement cores specimens based on the age of field specimens.

13. REPORT

13.1. *Report the following information*:

13.1.1. Bulk specific gravity of each specimen tested, to the nearest 0.001;

13.1.2. Air void content of each slice, to the nearest 0.1;

13.1.3. Thickness *t* and ligament length of each specimen tested, to the nearest 0.1 mm;

13.1.4. Initial notch length *a*, to the nearest 0.5 mm;

13.1.5. Average and coefficient of variation of peak load, to the nearest 0.1 kN

13.1.6. Average and coefficient of variation of recorded time at peak load, to the nearest 0.1 s;

13.1.7. Average and coefficient of variation of load-line displacement at the peak load (u_0), to the nearest 0.1 mm

13.1.8. Average and coefficient of variation of critical displacement (u_1), to the nearest 0.1 mm;

13.1.9. Average and coefficient of variation of secant stiffness *S*, to the nearest 0.1 kN/mm

13.1.10. Average and coefficient of variation of post-peak slope (*m*), to the nearest 0.1 kN/mm

13.1.11. Average and coefficient of variation of fracture energy G_f, to the nearest 1 J/m^2.

13.1.12. Average and coefficient of variation of flexibility index to the nearest 0.1.

14. PRECISION AND BIAS

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

14.2. *Bias*—The research required to establish the bias of this method has not been conducted.

15. KEYWORDS

15.1. Asphalt mixture; flexibility index; fracture energy; semicircular bend (SCB); stiffness; work of fracture.

16. REFERENCES

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