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The SUPERPAVE Mix Design System Manual of Specifications, Test Methods, and Practices

Edited by E.T. Harrigan, R.B. Leahy and J.S. Youtcheff
Strategic Highway Research Program

With contributions by the staffs of:

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Program Manager: *Edward T. Harrigan*
Project Managers: *Rita B. Leahy*
Jack S. Youtcheff
Program Area Secretary: *Juliet Narsiah*
Copyeditor: *Katharyn L. Bine*
Production Editor: *Lynn E. Stanton*

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SUPERPAVE®

Strategic Highway Research Program
National Academy of Sciences
2101 Constitution Avenue N.W.
Washington, DC 20418

(202) 334-3774

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Contents

Acknowledgments	iii
Abstract	vii
Introduction	ix

Test Methods for Asphalt Binders

MP1	Performance-Graded Asphalt Binder	1
TP1	Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer	7
TP5	Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer	29
TP3	Determining the Fracture Properties of Asphalt Binder in Direct Tension	43
PP1	Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel	61
B-006	Extraction and Recovery of Asphalt Cement for Rheological Testing	71

Test Methods for Hot Mix Asphalt

M-001	The Measurement of Initial Asphalt Adsorption and Desorption in the Presence of Moisture	87
M-002	Preparation of Compacted Specimens of Modified and Unmodified Hot Mix Asphalt by Means of the SHRP Gyrotory Compactor	95

M-003	Determining the Shear and Stiffness Behavior of Modified and Unmodified Hot Mix Asphalt with the SUPERPAVE® Shear Test Drive	103
M-005	Determining the Creep Compliance and Strength of Modified and Unmodified Hot Mix Asphalt Using Indirect Tensile Loading Techniques	121
M-006	Determining Moisture Sensitivity Characteristics of Compacted Bituminous Mixtures Subjected to Hot and Cold Climate Conditions	137
M-007	Short- and Long-Term Aging of Bituminous Mixes	159
M-008	Preparation of Test Specimens of Bituminous Mixtures by Means of Rolling Wheel Compaction	165
M-009	Determining the Fatigue Life of Compacted Bituminous Mixtures Subjected to Repeated Flexural Bending	177
M-010	Determining the Fracture Strength and Temperature of Modified and Unmodified Hot Mix Asphalt Subjected to Cold Temperatures	191

Practices and Protocols

PP5	The Laboratory Evaluation of Modified Asphalt Systems	203
PP6	Grading or Verifying the Performance Grade of an Asphalt Binder	225
P-004	Volumetric Analysis of Compacted Hot Mix Asphalt	233
P-005	Measurement of the Permanent Deformation and Fatigue Cracking Characteristics of Modified and Unmodified Hot Mix Asphalt	239

Abstract

The final product of the SHRP Asphalt Research Program is the SUPERPAVE® mix design system for new construction and overlays. This system employs a series of new *performance-based* specifications, test methods and practices for material selection, accelerated performance testing, and mix design. This report documents these new specifications and procedures in a format suitable for eventual AASHTO standardization.

Introduction

This volume of the *Final Report of the SHRP Asphalt Research Program* presents the specifications, test methods and practices that form the SUPERPAVE® mix design system. These specifications, test methods and practices were developed in SHRP contracts A-001, A-002A, A-003A and A-003B.

The SHRP-developed specifications, test methods and practices contained in this volume are listed in table 1. Table 2 provides a supplementary list of AASHTO, ASTM, and other test methods used in the SUPERPAVE® system; the text of these methods and practices are not included in this volume.

At the end of the SHRP asphalt research program, the methods and practices in table 1 were provided to the AASHTO Subcommittee on Materials for review and action towards their ultimate adoption as AASHTO standard methods of test. These methods and practices, while judged to be substantially accurate, will undergo further changes and revisions as AASHTO evaluation and adoption proceeds.

Table 1. SHRP Test Methods and Practices¹

SHRP Test Number	AASHTO Provisional Number	Test Method
none	MP1	Performance-Graded Asphalt Binder
B-002	TP1	Test Method for Determining the Flexural Creep Stiffness of an Asphalt Binder Using the Bending Beam Rheometer
B-003	TP5	Test Method for Determining the Rheological Properties of an Asphalt Binder Using a Dynamic Shear Rheometer
B-004	TP3	Test Method for Determining the Fracture Properties of an Asphalt Binder in Direct Tension
B-005	PP1	Practice for Accelerated Aging of an Asphalt Binder Using a Pressurized Aging Vessel
B-006	none	Extraction and Recovery of Asphalt Cement for Rheological Testing
M-001	none	The Measurement of Initial Asphalt Adsorption and Desorption in the Presence of Moisture (Net Adsorption Test)
M-002	none	Preparation of Compacted Specimens of Modified and Unmodified Hot Mix Asphalt by Means of the SHRP Gyratory Compactor
M-003	none	Determining the Shear and Stiffness Behavior of Modified and Unmodified Hot Mix Asphalt with the SUPERPAVE [®] Shear Test Device
M-005	none	Determining the Creep Compliance and Strength of Modified and Unmodified Hot Mix Asphalt Using Indirect Tensile Loading Techniques
M-006	none	Determining Moisture Sensitivity Characteristics of Compacted Bituminous Mixtures Subjected to Hot and Cold Climate Conditions
M-007	none	Short- and Long-Term Aging of Bituminous Mixes
M-008	none	Preparation of Test Specimens of Bituminous Mixtures by Means of Rolling Wheel Compaction
M-009	none	Determining the Fatigue Life of Compacted Bituminous Mixtures Subjected to Repeated Flexural Bending
M-010	none	Determining the Fracture Strength and Temperature of Modified and Unmodified Hot Mix Asphalt Subjected to Cold Temperatures
P-001	PP5	Guide for the Laboratory Evaluation of Modified Asphalt Systems
P-002	PP6	Guide for Grading or Verifying the Performance Grade of an Asphalt Binder
P-004	none	Volumetric Analysis of Compacted Hot Mix Asphalt
P-005	none	Measurement of the Permanent Deformation and Fatigue Cracking Characteristics of Modified and Unmodified Hot Mix Asphalt

¹B = Test Method for Asphalt Binders; M = Test Method for Hot Mix Asphalt; and PP = Practice or Protocol.

Table 2. AASHTO and Other Test Methods

Test Number	Test Method
AASHTO T27	Sieve Analysis of Fine and Coarse Aggregates
AASHTO T37	Sieve Analysis of Mineral Filler
AASHTO T44	Solubility of Bituminous Materials in Organic Solvents
AASHTO T48	Flash and Fire Points by Cleveland Open Cup
AASHTO T84	Specific Gravity and Absorption of Fine Aggregate
AASHTO T85	Specific Gravity and Absorption of Coarse Aggregate
AASHTO T96	Resistance to Abrasion of Small Size Coarse Aggregate by Use of the Los Angeles Machine
AASHTO T100	Specific Gravity of Soils ¹
AASHTO T104	Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
AASHTO T112	Clay Lumps and Friable Particles in Aggregate
AASHTO T164	Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
AASHTO T166	Bulk Specific Gravity of Compacted Bituminous Mixtures
AASHTO T170	Recovery of Asphalt from Solution by Abson Method
AASHTO T176	Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
AASHTO T201	Kinematic Viscosity of Asphalts
AASHTO T209	Maximum Specific Gravity of Bituminous Paving Mixtures
AASHTO T228	Specific Gravity of Semi-Solid Bituminous Materials
AASHTO T240	Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin Film Oven Test)
AASHTO T283	Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage
ASTM D4402	Measurement of Asphalt Viscosity Using a Rotational Viscometer
ASTM D4791	Flat or Elongated Particles in Coarse Aggregate
National Aggregates Association Test Method A	Fine Aggregate Angularity
Pennsylvania Test Method No. 621 (April 1987)	Determining the Percentage of Crushed Fragments in Gravel

¹Used to measure the specific gravity of mineral fillers.

Standard Method of Test for
Performance-Graded Asphalt Binder

AASHTO Designation: MP1¹

1. SCOPE

1.1 This specification covers asphalt binders graded by performance. Grading designations are related to average 7-day maximum pavement design temperatures and minimum pavement design temperatures.

NOTE 1.—For asphalt cements graded by penetration at 25°C, see M20. For asphalt cements graded by viscosity at 60°C, see M226.

NOTE 2.—Guide PP5 provides information on the evaluation of modified asphalt binders.

NOTE 3.—Guide PP6 provides information for determining the performance grade of an asphalt binder.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems 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 AASHTO Standards:

PP5	Guide for the Laboratory Evaluation of Modified Asphalt Systems
PP6	Guide for Grading or Verifying the Performance Grade of an Asphalt Binder
PPX	Selection of Asphalt Binders (being developed)
M20	Specification for Penetration-Graded Asphalt Cement
M226	Specification for Viscosity-Graded Asphalt Cement
PP1	Practice for Accelerated Aging of an Asphalt Binder Using a Pressurized Aging Vessel
T40	Practice for Sampling Bituminous Materials
T44	Solubility of Bituminous Materials in Organic Solvents

¹ This standard is based on SHRP Product 1001.

- T48 Method of Test for Flash and Fire Points by Cleveland Open Cup
- T55 Method of Test for Water in Petroleum Products and Bituminous Materials by Distillation
- T179 Test Method for Effect of Heat and Air on Asphalt Materials (Thin Film Oven Test)
- T201 Kinematic Viscosity of Asphalts
- T202 Viscosity of Asphalts by Vacuum Capillary Viscometer
- T240 Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin Film Oven Test)
- TP1 Test Method for Determining the Flexural Creep Stiffness of an Asphalt Binder Using the Bending Beam Rheometer
- TP3 Test Method for Determining the Fracture Properties of an Asphalt Binder in Direct Tension
- TP5 Test Method for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer

2.2 *ASTM Standards:*

- D8 Definitions of Terms Relating to Materials for Roads and Pavements
- D4402 Method for Viscosity Determinations of Unfilled Asphalt Using the Brookfield Thermosel Apparatus

2.3 *SHRP Documents:*

- P00X SUPERPAVE Software (being developed)

3. TERMINOLOGY

3.1 *Definitions:*

3.1.1 Definitions for many terms common to asphalt cement are found in ASTM D8.

3.1.2 asphalt binder, *n*—an asphalt-based cement that is produced from petroleum residue either with or without the addition of non-particulate organic modifiers.

4. ORDERING INFORMATION—When ordering under this specification, include in the purchase order the performance grade of asphalt binder required from table 1 (e.g., PG 52-16 or PG 64-34).

4.1 Asphalt binder grades may be selected by following the procedures described in provisional practice PPX, Selection of Asphalt Binders.

5. MATERIALS AND MANUFACTURE

5.1 Asphalt cement shall be prepared by the refining of crude petroleum by suitable methods, with or without the addition of modifiers.

5.2 Modifiers may be any organic material of suitable manufacture, used in virgin or recycled condition, and that is dissolved, dispersed or reacted in asphalt cement to enhance its performance.

5.3 The base asphalt binder shall be homogeneous, free from water and deleterious materials, and shall not foam when heated to 175°C.

5.4 The base asphalt binder shall be at least 99.0% soluble in trichloroethylene as determined by AASHTO T44.

5.5 The bending beam rheometer test, TP1, the direct tension test, TP3, and the dynamic shear rheometer test, TP5, are not suitable for asphalt binders in which fibers or other discrete particles are larger than 250 μm in size.

5.6 The grades of asphalt binder shall conform to the requirements given in table 1.

6. SAMPLING

The material shall be sampled in accordance with T40.

7. TEST METHODS

The properties outlined in 5.3, 5.4 and 5.6 shall be determined in accordance with T44, T48, T55, T179, T240, PP1, TP1, TP3, TP5, and ASTM D4402.

8. INSPECTION AND CERTIFICATION

Inspection and certification of the material shall be agreed upon between the purchaser and the seller. Specific requirements shall be made part of the purchase contract.

9. REJECTION AND REHEARING

If the results of any test do not conform to the requirements of this specification, retesting to determine conformity is performed as indicated in the purchase order or as otherwise agreed upon between the purchaser and the seller.

10. KEY WORDS

Asphalt binder, asphalt cement, direct tension, flash point, modifier, performance specifications, pressure aging, rheology.

Table 1. Performance-Graded Asphalt Binder Specification

PERFORMANCE GRADE	PG 46-			PG 52-						PG 58-					PG 64-						
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40
Average 7-day Maximum Pavement Design Temperature, °C ^a	<46			<52						<58					<64						
Minimum Pavement Design Temperature, °C ^a	>-34	>-40	>-46	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-40
ORIGINAL BINDER																					
Flash Point Temp, T48: Minimum °C	230																				
Viscosity, ASTM D4402 ^b : Maximum, 3 Pa·s, Test Temp, °C	135																				
Dynamic Shear, TP5 ^c : G*/sinδ, Minimum, 1.00 kPa Test Temp @ 10 rad/s, °C	46			52						58					64						
ROLLING THIN FILM OVEN (T240) OR THIN FILM OVEN RESIDUE (T179)																					
Mass Loss, Maximum, percent	1.00																				
Dynamic Shear, TP5: G*/sinδ, Minimum, 2.20 kPa Test Temp @ 10 rad/s, °C	46			52						58					64						
PRESSURE AGING VESSEL (PAV) RESIDUE (PP1)																					
PAV Aging Temperature, °C ^d	90			90						100					100						
Dynamic Shear, TP5: G*/sinδ, Maximum, 5000 kPa Test Temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16
Physical Hardening ^e	Report																				
Creep Stiffness, TP1: ^f S, Maximum, 300 MPa, m - value, Minimum, 0.300 Test Temp @ 60s, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30
Direct Tension, TP3: ^f Failure Strain, Minimum, 1.0% Test Temp @ 1.0 mm/min, °C	-24	-30	-36	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	-30

- ^a Pavement temperatures may be estimated from air temperatures using an algorithm contained in the SUPERPAVE software program; provided by the specifying agency; or found by following the procedures as outlined in PPX.
- ^b This requirement may be waived at the discretion of the specifying agency if the supplier warrants that the asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.
- ^c For quality control of unmodified asphalt cement production, measurement of the viscosity of the original asphalt cement may be substituted for dynamic shear measurements of G*/sinδ at test temperatures where the asphalt is a Newtonian fluid. Any suitable standard means of viscosity measurement may be used, including capillary or rotational viscometry (AASHTO T201 or T202).
- ^d The PAV aging temperature is based on simulated climatic conditions and is one of three temperatures: 90°C, 100°C or 110°C. The PAV aging temperature is 100°C for PG 58- and above, except for paving materials to be used in desert climates, where it is 110°C.
- ^e Physical Hardening—TP1 is performed on a set of asphalt beams according to section 13.1, except the conditioning time is extended to 24 hrs ± 10 minutes at 10°C above the minimum performance temperature. The 24-hour stiffness and m-value are reported for information purposes only.
- ^f If the creep stiffness is below 300 MPa, the direct tension test is not required. If the creep stiffness is between 300 and 600 MPa, the direct tension failure strain requirement can be used in lieu of the creep stiffness requirement. The m-value requirement must be satisfied in both cases.

Table 1. Performance-Graded Asphalt Binder Specification (Continued)

PERFORMANCE GRADE	PG 70-						PG 76-					PG 82-				
	10	16	22	28	34	40	10	16	22	28	34	10	16	22	28	34
Average 7-day Maximum Pavement Design Temperature, °C ^b	<70						<76					<82				
Minimum Pavement Design Temperature, °C ^b	> -10	> -16	> -22	> -28	> -34	> -40	> -10	> -16	> -22	> -28	> -34	> -10	> -16	> -22	> -28	> -34
ORIGINAL BINDER																
Flash Point Temp, T48: Minimum °C	230															
Viscosity, ASTM D4402: ^b Maximum, 3 Pa·s, Test Temp, °C	135															
Dynamic Shear, TP5: ^c G*/sinδ, Minimum, 1.00 kPa Test Temp @ 10 rad/s, °C	70						76					82				
ROLLING THIN FILM OVEN (T240) OR THIN FILM OVEN (T179) RESIDUE																
Mass Loss, Maximum, percent	1.00															
Dynamic Shear, TP5: G*/sinδ, Minimum, 2.20 kPa Test Temp @ 10 rad/s, °C	70						76					82				
PRESSURE AGING VESSEL (PAV) RESIDUE (PP1)																
PAV Aging Temperature, °C ^d	100(110)						100(110)					100(110)				
Dynamic Shear, TP5: G*/sinδ, Maximum, 5000 kPa Test Temp @ 10 rad/s, °C	34	31	28	25	22	19	37	34	31	28	25	40	37	34	31	28
Physical Hardening ^e	Report															
Creep Stiffness, TP1: ^f S, Maximum, 300.0 MPa, m - value, Minimum, 0.300 Test Temp @ 60s, °C	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24
Direct Tension, TP3: ^f Failure Strain, Minimum, 1.0% Test Temp @ 1.0 mm/min, °C	0	-6	-12	-18	-24	-30	0	-6	-12	-18	-24	0	-6	-12	-18	-24

Standard Method of Test for

**Determining the Flexural Creep Stiffness
of Asphalt Binder Using the Bending Beam
Rheometer**

AASHTO Designation: TP1¹

1. SCOPE

1.1 This test method covers the determination of the flexural creep stiffness or compliance of asphalt binders by means of a bending beam rheometer. It is applicable to material having flexural creep stiffness values from 30 MPa to 1 GPa (creep compliance values in the range of 300 mPa⁻¹ to 1 nPa⁻¹). It can be used with unaged material or with material aged using T240, T179, or PP1. The test apparatus is designed for testing within the temperature range of -40 to 25°C.

1.2 Test results are not valid for beams of asphalt binder that deflect more than 4 mm when tested in accordance with this method.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the 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.*

2. REFERENCE DOCUMENTS

2.1 AASHTO Standards:

MP1	Standard Method of Test for Performance-Graded Asphalt Binder
PP1	Practice for Accelerated Aging of an Asphalt Binder Using a Pressurized Aging Vessel
T40	Practice for Sampling Bituminous Materials
T179	Test Method for Effect of Heat and Air on Asphalt Materials (Thin Film Oven Test)
T240	Test Method for Effect of Heat and Air on Rolling Film of Asphalt (Rolling Thin Film Oven Test)

¹ This standard is based on SHRP Product 1002.

2.2 ASTM Standards:

- C802 Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials
- E1 Specification for ASTM Thermometers
- E77 Standard Test Method for Inspection and Verification of Liquid-in-Glass Thermometers

2.3 DIN Standards:

43760

3. TERMINOLOGY

3.1 Definitions:

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

3.1.2 physical hardening, n —a time-dependent stiffening of asphalt binder that results from time-delayed increase in stiffness when the asphalt binder is stored at low temperatures.

3.2 Descriptions of Terms Specific to this Standard:

3.2.1 flexural creep, n —a material characteristic determined by a test in which a simply-supported beam is loaded with a constant load at its midpoint and the deflection of the beam is measured with respect to loading time.

3.2.2 flexural creep stiffness, $S(t)$ —ratio obtained by dividing the maximum bending stress in the beam by the maximum bending strain.

3.2.3 flexural creep compliance, $D(t)$ —ratio obtained by dividing the maximum bending strain in the beam by the maximum bending stress. $D(t)$ is the inverse of $S(t)$. $S(t)$ has been used historically in asphalt technology while $D(t)$ is commonly used in studies of viscoelasticity.

3.2.4 m —absolute value of the slope of the logarithm of the stiffness curve versus the logarithm of time.

3.2.5 preload, n —load required to maintain positive contact between the beam and the loading shaft; 30 ± 5 mN.

3.2.6 initial seating load, n —load of 1-s duration required to seat the beam; 980 ± 50 mN.

3.2.7 test load, n —load of 240-s duration required to determine the stiffness of the material being tested; 980 ± 50 mN.

4. SUMMARY OF TEST METHOD

4.1 The bending beam rheometer measures the midpoint deflection of a simply-supported prismatic beam of asphalt binder that is subjected to a constant load applied to the midpoint of the beam. The device operates only in the loading mode. Recovery measurements are not obtained.

4.2 A test beam is placed in the controlled temperature fluid bath and loaded with a constant load for 240 seconds. The test load (980 ± 50 mN) and the midpoint deflection of the beam are monitored versus time using a computerized data acquisition system.

4.3 The maximum bending stress at the midpoint of the beam is calculated from the dimensions of the beam, the span length, and the load applied to the beam for loading times of 8, 15, 30, 60, 120, and 240 seconds. The maximum bending strain in the beam is calculated for the same loading times from the dimensions of the beam and the deflection of the beam. The stiffness of the beam for the loading times specified above is calculated by dividing the maximum stress by the maximum strain.

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.

5.2 The flexural creep stiffness or flexural creep compliance determined from this test describes the low-temperature stress-strain-time response of asphalt binder at the test temperature within the linear viscoelastic response range.

5.3 The low-temperature thermal cracking performance of paving mixtures is related to the creep stiffness and the slope of the logarithm of the creep stiffness versus the logarithm of the time curve of the asphalt binder contained in the mix.

5.4 The creep stiffness and the slope of the logarithm of the stiffness versus the logarithm of the time curve are used as performance-based specification criteria for asphalt binders in accordance with MP1.

6. INTERFERENCES

6.1 Measurements wherein the beam deflection is greater than 4.0 mm are suspect. Strains in excess of this value may exceed the linear response of asphalt binders.

6.2 Measurements wherein the beam deflection is less than 0.08 mm are suspect. When the beam deflection is less than 0.08 mm, the test system resolution may not be sufficient to produce reliable test results.

7. APPARATUS

7.1 Bending Beam Rheometer (BBR) Test System—A bending beam rheometer (BBR) test system consisting of (1) a loading frame which permits the test beam, supports, and the lower part of the test frame to be submerged in a constant temperature fluid bath, (2) a controlled temperature liquid bath which maintains the test beam at the test temperature and provides a buoyant force to counterbalance the force resulting from the mass of the beam, and (3) a computer-controlled automated data acquisition component.

7.1.1 Loading Frame—A frame consisting of a set of sample supports, a blunt-nosed shaft that applies the load to the midpoint of the test specimen, a load cell mounted on the loading shaft, a means for zeroing the load on the test specimen, a means for applying a constant load to the loading shaft, and a deflection-measuring transducer attached to the loading shaft. A schematic of the device is shown in figure 1.

7.1.1.1 Sample Supports—Sample supports consisting of two stainless steel half-rounds 25 mm in diameter that are spaced 102 ± 0.5 mm apart.

7.1.1.2 Loading Shaft—A blunt-nosed loading shaft continuous with the load cell and deflection-measuring transducer that is capable of applying a preload of 30 ± 5 mN and maintaining a test load of 980 ± 50 mN within ± 5 mN using differential air pressure or other means, such as electro-hydraulic, for adjustment. The rise time for the test load shall be less than 0.1 s, where the rise time is the time required for the load to rise from the 30 ± 5 mN preload to the 980 ± 50 mN test load. During the rise time the system shall dampen the test load to a constant ± 5 mN value.

7.1.1.3 Load Cell—A load cell with a minimum capacity of 2000 mN having a sensitivity of 1 mN, mounted in line with the loading shaft and above the fluid to measure the preload and the test load.

7.1.1.4 Linear Variable Differential Transducer—A linear variable differential transducer (LVDT) or other suitable device mounted axially above the loading shaft, capable of resolving a linear movement $\leq 2.5 \mu\text{m}$ with a range of at least 10 mm, to measure the deflection of the test beam. Digital or analog smoothing of the load and deflection data may be required to eliminate electronic noise that could otherwise affect the ability of the second order polynomial to fit the data with sufficient accuracy to provide a reliable estimate of the m-value. Averaging five or more load or deflection signals equally spaced over a range ± 0.2 s from the reported time is acceptable to smooth the load or deflection signal.

7.1.2 Controlled-Temperature Fluid Bath—A controlled-temperature liquid bath capable of maintaining the temperature at all points within the bath between -40 and 25°C within $\pm 0.1^\circ\text{C}$. Placing a cold specimen in the bath may cause the bath temperature to fluctuate $\pm 0.2^\circ\text{C}$ from the target test temperature. Consequently bath fluctuations of $\pm 0.2^\circ\text{C}$ during testing and isothermal conditioning shall be allowed.

7.1.2.1 Bath Fluid—A bath fluid that is not absorbed by or does not affect the properties of the asphalt binder tested.

7.1.2.2 Bath Agitator—A bath agitator for maintaining the required temperature homogeneity with agitation intensity such that the fluid currents do not disturb the testing process and mechanical noise caused by vibrations is less than the resolution specified in 7.1.1.4.

7.1.2.3 Circulating Bath (Optional)—A circulating bath unit separate from the test frame that pumps the bath fluid through the test bath. If used, vibrations from the circulating system shall be isolated from the bath test chamber so that mechanical noise is less than the resolution specified in section 7.1.1.4.

7.1.3 Data Acquisition System—A data acquisition system that resolves loads to the nearest 0.1 mN, beam deflection to the nearest 2.5 μm , and bath fluid temperature to the nearest 0.1°C. The system shall sense the point in time when the load is first applied (zero time) and, using this time as a reference, shall provide a record of subsequent load and deflection measurements relative to this time within ± 0.20 s. The system shall record the load and deflection at loading times of 8, 15, 30, 60, 120 and 240 s, with less than 0.1 s between load and deflection measurement times. All readings shall be an average of five or more points within ± 0.2 s from the loading time, e.g., for a loading time of 8 s, average 7.8, 7.9, 8.0, 8.1 and 8.2 s.

7.2 Temperature Measuring Equipment—A calibrated temperature transducer capable of measuring the temperature to 0.1°C over the range -40 to 25°C mounted in the immediate vicinity of the midpoint of the test specimen.

NOTE 1.—Required temperature measurement can be accomplished with an appropriately calibrated platinum resistance thermometer (RTD) or a thermistor. Calibration of the RTD or thermistor can be verified as per section 7.6. The RTDs meeting DIN Standard 43760 (Class A) are recommended for this purpose. The required precision and accuracy cannot be obtained unless each RTD is calibrated as a system with its respective meter or electronic circuitry.

7.3 Test Beam Molds—Test beam molds of suitable dimensions to yield demolded test beams 6.35 ± 0.05 mm thick by 12.70 ± 0.05 mm wide by 127 ± 0.5 mm long fabricated from aluminum flat stock as shown in figure 2, or from silicone rubber as shown in figure 3.

7.4 Stainless Steel Beams—One stainless steel beam 6.4 ± 0.1 mm thick by 12.7 ± 0.1 mm wide by 127 ± 0.5 mm long for measuring system compliance and one stainless steel beam 1.0 to 1.6 mm thick by 6.35 mm wide measured to ± 0.02 mm by 127 mm long measured to ± 0.5 mm with a known stiffness modulus, for performing periodic checks on the performance of the BBR.

7.5 Standard Masses—Four standard masses 50.0 or 100.0 ± 0.2 g masses for periodic BBR calibration verification.

7.6 Calibrated Thermometers—Calibrated liquid-in-glass thermometers for verification of the temperature transducer of suitable range with subdivisions of 0.1°C. These thermometers shall be calibrated in accordance with ASTM E77. ASTM thermometers 89C and 119C are suitable thermometers.

7.7 Thickness Gauge—A stepped-thickness gauge for verifying the calibration of the displacement transducer as described in figure 4.

8. MATERIALS

8.1 Plastic Sheeting—Clear plastic sheeting 0.12 to 0.15 mm thick, for lining the interior faces of the three long aluminum mold sections. Sheeting should not be distorted by hot asphalt binder. Transparency film sold for use with laser printers has been found suitable.

8.2 Petroleum-Based Grease—A petroleum-based grease used to hold the plastic sheeting to the interior faces of the three long aluminum mold sections. (**Warning: do not use any silicone-based products.**)

8.3 Glycerol-Talc Mixture—Used to coat the end pieces of aluminum molds.

8.4 Suitable bath fluids include ethanol and glycol-methanol mixtures (e.g., 60% glycol, 15% methanol, 25% water).

9. HAZARDS

9.1 Observe standard laboratory safety procedures when handling hot asphalt binder and preparing test specimens.

10. PREPARATION OF APPARATUS

10.1 Clean the supports, loading head and bath fluid of any particulates and coatings as necessary.

NOTE 2.—Because of the brittleness of asphalt binder at the specified test temperatures, small fragments of asphalt binder can be introduced into the bath fluid. If these fragments are present on the supports or the loading head, they will affect the measured deflection. Because of their small size, the fragments will deform under load and add an apparent deflection to the true deflection of the beam. Filtration of the bath fluid will aid in preserving the required cleanliness.

10.2 Select the test temperature and adjust the bath fluid to the selected temperature. Wait until the temperature stabilizes and then allow the bath to equilibrate to the test temperature $\pm 0.2^\circ\text{C}$.

10.3 Activate the data acquisition system and load the software as explained in the manufacturer's manual for the test system.

11. STANDARDIZATION

11.1 Verify calibration of the displacement transducer, load cell, and temperature transducer. Conduct each of the steps in this section each day before conducting any tests.

NOTE 3.—Calibration is usually performed by a calibration service agency. Calibration verification and quality checks may be performed by the manufacturer, other agencies providing such services, or in-house personnel using the procedures described below.

11.1.1 Verify calibration of the displacement transducer using a stepped thickness gauge of known dimensions similar to the one shown in figure 4. Remove the loading frame from the bath. Place the gauge on a reference platform underneath the loading shaft. Measure the rise of the steps relative to the top surface of the gauge with the displacement transducer. Compare the measured values with the known dimensions of the gauge. If the difference is $\geq 4 \mu\text{m}$, further calibration or maintenance is required. Report the calibration constants ($\mu\text{m}/\text{mV}$) for the displacement transducers to three significant figures. The calibration constants should be repeatable from day to day. Otherwise, the operation of the system may be suspect.

11.1.2 Verify calibration of the load cell using four standard dead masses evenly distributed over the range of the load cell. Perform the verification by resting the loading shaft against the 6.35-mm thick standard steel beam, loading it with the four standard masses sequentially in four steps, while recording the load after each step. If the load indicated by the data acquisition system does not agree with the force imposed by the standard masses within $\pm 2 \text{ mN}$ at all steps, further calibration or maintenance is required. Report the calibration constants (mN/m) for the load transducers to three significant figures. The calibration constants should be repeatable from day to day. Otherwise, the operation of the system may be suspect.

11.1.3 Verify calibration of the temperature detector by using a calibrated thermometer of suitable range meeting the requirements of section 7.6. Immerse the thermometer in the liquid bath close to the thermal detector and compare the temperature indicated by the calibrated thermometer to the detector signal being displayed. If the temperature indicated by the thermal detector does not agree with the liquid-in-glass thermometer within $\pm 0.1^\circ\text{C}$, further calibration or maintenance is required.

11.2 Determine the compliance of the loading system by placing the 6.35-mm-thick stainless steel beam on the testing supports, resting the loading tip of the loading shaft against the stainless steel beam, and applying a load to the shaft of $980 \pm 50 \text{ mN}$ measured to the nearest 2 mN. The beam is relatively rigid within the range of loading applied and the range of deflection measurement specified. Therefore, any measured deflection is caused by the load cell or other parts of the test system. Divide the deflection measured under this load by the applied load. The quotient is the compliance of the loading system in $\mu\text{m}/\text{mN}$. Use this result to calculate the deflection component that is not due to the compliance of the system. This component is automatically subtracted from the deflection measured during a test.

11.3 Perform a daily quality control check on the operation of the overall system using the 1.0- to 1.6-mm-thick stainless steel beam of known modulus. Load the steel beam with 981 and 1961 mN using the standard masses (100 and 200 g) and measure the deflection at the midpoint. Using the load applied and deflection measured, calculate the elastic modulus of the beam. Compare the calculated modulus to the known modulus of the beam. If the calculated modulus differs from the known modulus by 10% or more, the operation of the system is suspect. Perform required maintenance on the system and then repeat section 11.

12. PREPARATION OF MOLDS AND TEST SPECIMENS

12.1 To prepare aluminum molds, spread a very thin layer of petroleum-based grease, only sufficient to hold the plastic strips to the aluminum, on the interior faces of the three long aluminum mold sections. Place the plastic strips over the aluminum faces and rub the plastic with firm finger pressure. Assemble the mold as shown in figure 2 using the rubber O-rings to hold the pieces of the mold together. Inspect the mold and press the plastic film against the aluminum to force out any air bubbles. If air bubbles remain, disassemble the mold and recoat the aluminum faces with grease. Cover the inside faces of the mold's two end pieces with a thin film of glycerol to prevent the asphalt binder from sticking to the aluminum end pieces. After assembly, keep the mold at room temperature until pouring the asphalt binder.

12.2 To prepare silicone rubber molds, assemble the two mold sections.

12.3 If unaged binder is to be tested, obtain test samples according to T40.

12.4 Heat the material until it is sufficiently fluid to pour.

NOTE 4.—Minimum pouring temperatures that produce a consistency equivalent to that of SAE 10W30 motor oil (readily pours but not overly fluid) at room temperature are recommended. Heating unaged asphalt binders to temperatures above 135°C should be avoided. Some modified asphalts or heavily aged binders, however, may require pouring temperatures above 135°C may be required. PAV residues shall be placed in TFOT pans and may be heated up to 163°C. In all cases, heating time should be minimized. These precautions avoid oxidative hardening and volatile loss that will further harden the sample. During the heating process, the sample should be covered and stirred occasionally to ensure homogeneity.

12.5 Molding (aluminum mold)—If an aluminum mold is used, begin pouring the binder from one end of the mold and move toward the other end, slightly overfilling the mold. When pouring, hold the sample container 20 to 100 mm from the top of the mold and pour continuously toward the other end in a single pass. After pouring, allow the mold to cool 45 to 60 minutes to room temperature. Trim the exposed face of the cooled specimens flush with the top of the mold using a hot knife or a heated spatula. Discard the plastic sheeting (lining the mold sections) if it becomes distorted.

12.6 Molding (silicone rubber mold)—If a silicone rubber mold is used, fill the mold from the top of the mold in a slow, steady manner, taking care not to entrap air bubbles. Fill

the mold to the top with no appreciable overfilling. After pouring, allow the mold to cool to room temperature for at least 45 minutes.

12.7 Store all test specimens in their molds at room temperature prior to testing. Schedule testing so that it is completed within 4 hours after specimens are poured.

NOTE 5.—Time-dependent increases in stiffness can occur when asphalt binders are stored at room temperature for even short periods of time. This increase in stiffness is the result of molecular associations and is referred to as steric hardening in the literature.

12.8 Just prior to testing, cool the aluminum or silicone mold containing the test specimen in a freezer or ice bath at $-5^{\circ}\text{C} \pm 5^{\circ}\text{C}$ for 5 to 10 minutes, only long enough to stiffen the asphalt binder beam so that it can be readily demolded without distortion (note 6). Some softer grades may require lower temperatures. Do not cool the molds containing the specimens in the test bath because it may cause temperature fluctuations in the bath to exceed $\pm 0.2^{\circ}\text{C}$.

NOTE 6.—Excessive cooling may cause unwanted hardening of the beam, thereby causing increased variability in the test data.

12.9 Immediately demold the specimen when it is sufficiently stiff to demold without distortion by disassembling the aluminum mold or by removing the test specimen from the silicone rubber mold.

NOTE 7.—Minimize distortion of the specimen during demolding. Full contact at specimen supports is assumed in the analysis. A warped test beam yields a measured stiffness less than the actual stiffness.

13. PROCEDURE

13.1 When testing a specimen for compliance with MP1, select the appropriate test temperature from table 1 of MP1. After demolding, immediately place the test specimen in the testing bath and condition it at the testing temperature for 60 ± 5 minutes.

NOTE 8.—Asphalt binders may harden rapidly when held at low temperatures. This effect, which is called physical hardening, is reversible when the asphalt binder is heated to room temperature or slightly above. Because of physical hardening, conditioning time must be carefully controlled if repeatable results are to be obtained.

13.2 After conditioning, place the test beam on the test supports and initiate the test. Maintain the bath at test temperature $\pm 0.2^{\circ}\text{C}$ during testing.

13.3 Enter the specimen identification information, test load, test temperature, time the specimen is placed in bath test temperature, and other information as appropriate into the computer that controls the test system.

13.4 Manually apply a 30 ± 5 mN preload to the beam to ensure contact between the beam and the loading head.

NOTE 9.—The specified preload on the specimen is required to ensure continuous contact between the loading shaft and the specimen. Failure to establish continuous contact within the required load range gives misleading results.

13.5 Activate the automatic test system that is programmed to proceed as follows.

13.5.1 Apply a 980 ± 50 mN initial seating load for 1 ± 0.1 second.

NOTE 10.—The actual load on the beam as measured by the load cell is used in calculating the stress in the beam. The 980 ± 50 mN initial seating and test load includes the 30 ± 5 mN preload.

13.5.2 Reduce the load to 30 ± 5 mN and allow the beam to recover for 20 ± 0.1 seconds.

NOTE 11.—The initial seating loads described in sections 13.5.1 and 13.5.2 are applied and removed automatically by the computer-controlled loading system and are transparent to the operator. Data are not recorded during initial loading.

13.5.3 Apply a test load ranging from 980 ± 50 mN, and maintain the load constant to ± 5 mN for 240 s.

13.5.4 Remove the test load and terminate the test.

13.5.5 At the end of the initial seating, load and at the end of the test, monitor the computer screen to verify that the load on the beam in each case returns to 30 ± 5 mN.

13.6 Remove the specimen from the supports and proceed to the next test.

14. CALCULATION AND INTERPRETATION OF RESULTS

See Annex.

15. REPORT

15.1 Report data as shown in figure A1 that describes individual tests, including:

15.1.1 Temperature of the test bath measured 60 s after the test load is first applied, to the nearest 0.1°C ;

15.1.2 Date and time when test load is applied;

15.1.3 File name of test data;

15.1.4 Name of operator;

15.1.5 Sample identification number;

15.1.6 Any flags issued by software during test;

15.1.7 Correlation coefficient, R^2 for log stiffness versus log time, expressed to nearest 0.000001;

15.1.8 Anecdotal comments (maximum 256 characters);

15.1.9 Report constants A, B, and C to three significant figures;

15.1.10 Difference between measured and estimated stiffness calculated as:

$$(\text{Measured} - \text{Estimated}) \times 100\% / \text{Estimated}$$

15.2 Report data as shown in figure A1 for time intervals of 8, 15, 30, 60, 120, and 240 seconds including:

15.2.1 Time beam is placed in bath;

15.2.2 Time test started;

15.2.3 Loading time, to the nearest 0.1 second;

15.2.4 Load, to the nearest 0.1 mN;

15.2.5 Beam deflection, to the nearest 2 μm ;

15.2.6 Measured Stiffness modulus, in MPa, expressed to three significant figures;

15.2.7 Estimated Stiffness modulus, in MPa, expressed to three significant figures;

15.2.8 Estimated m , to the nearest 0.001.

16. PRECISION AND BIAS

16.1 *Precision*—The research required to develop precision values in accordance with ASTM C802 has not been conducted.

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

17. KEY WORDS

Bending beam rheometer, flexural creep compliance, flexural creep stiffness.

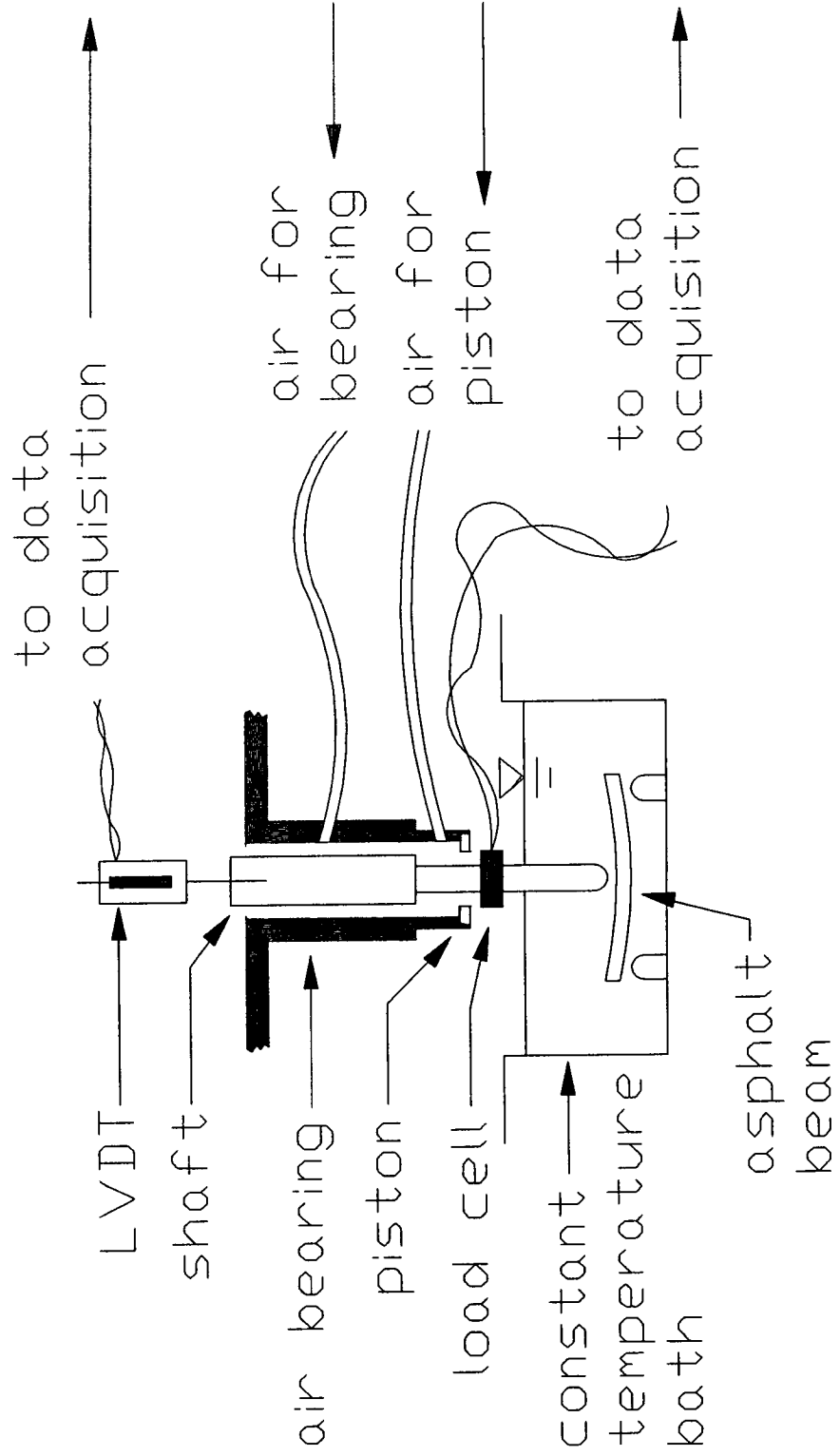
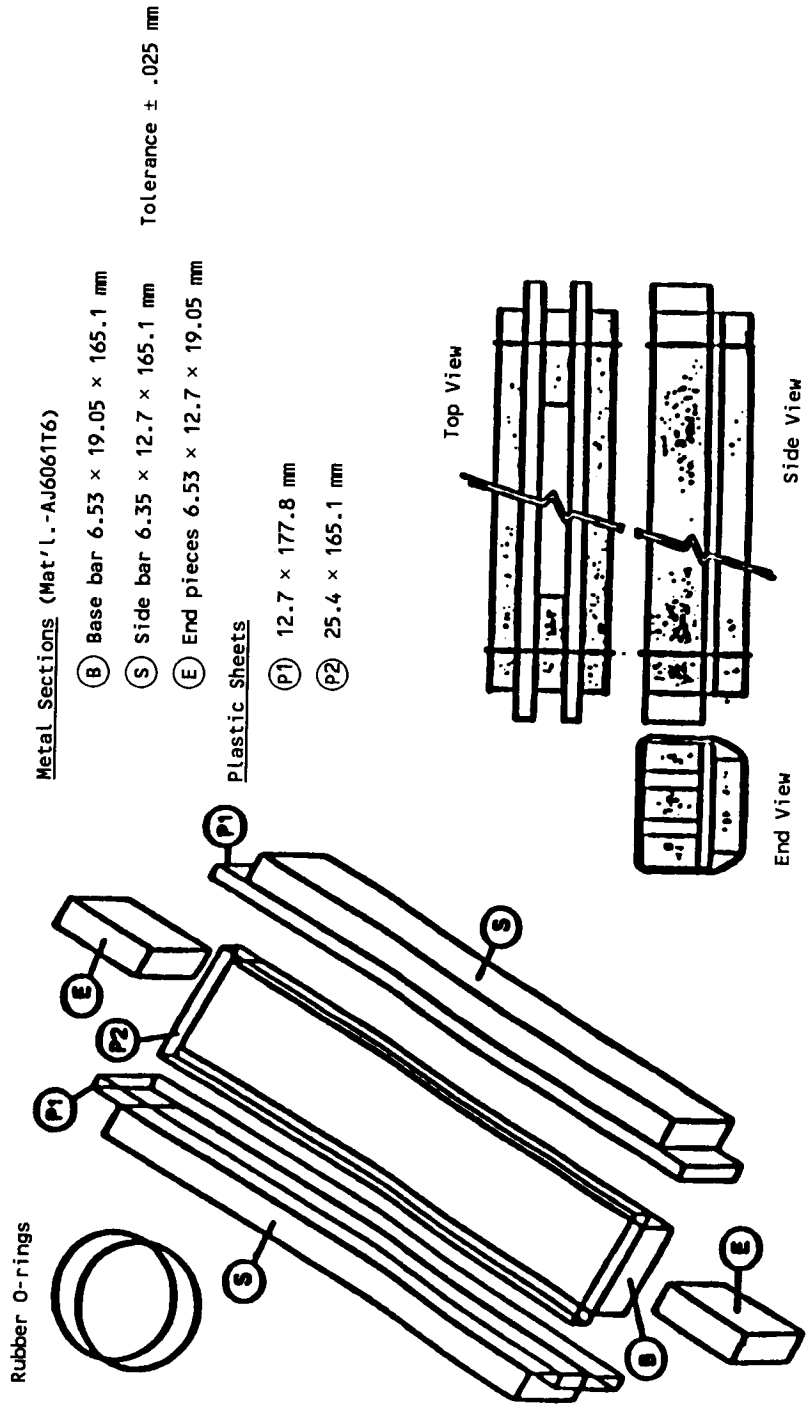


Figure 1 Schematic of the bending beam rheometer



Metal Sections (Mat'L.-AJ6061T6)

- (B) Base bar 6.53 × 19.05 × 165.1 mm
 - (S) Side bar 6.35 × 12.7 × 165.1 mm
 - (E) End pieces 6.53 × 12.7 × 19.05 mm
- Tolerance ± .025 mm

Plastic Sheets

- (P1) 12.7 × 177.8 mm
- (P2) 25.4 × 165.1 mm

Rubber O-rings

Figure 2 Dimensions and specifications for aluminum molds

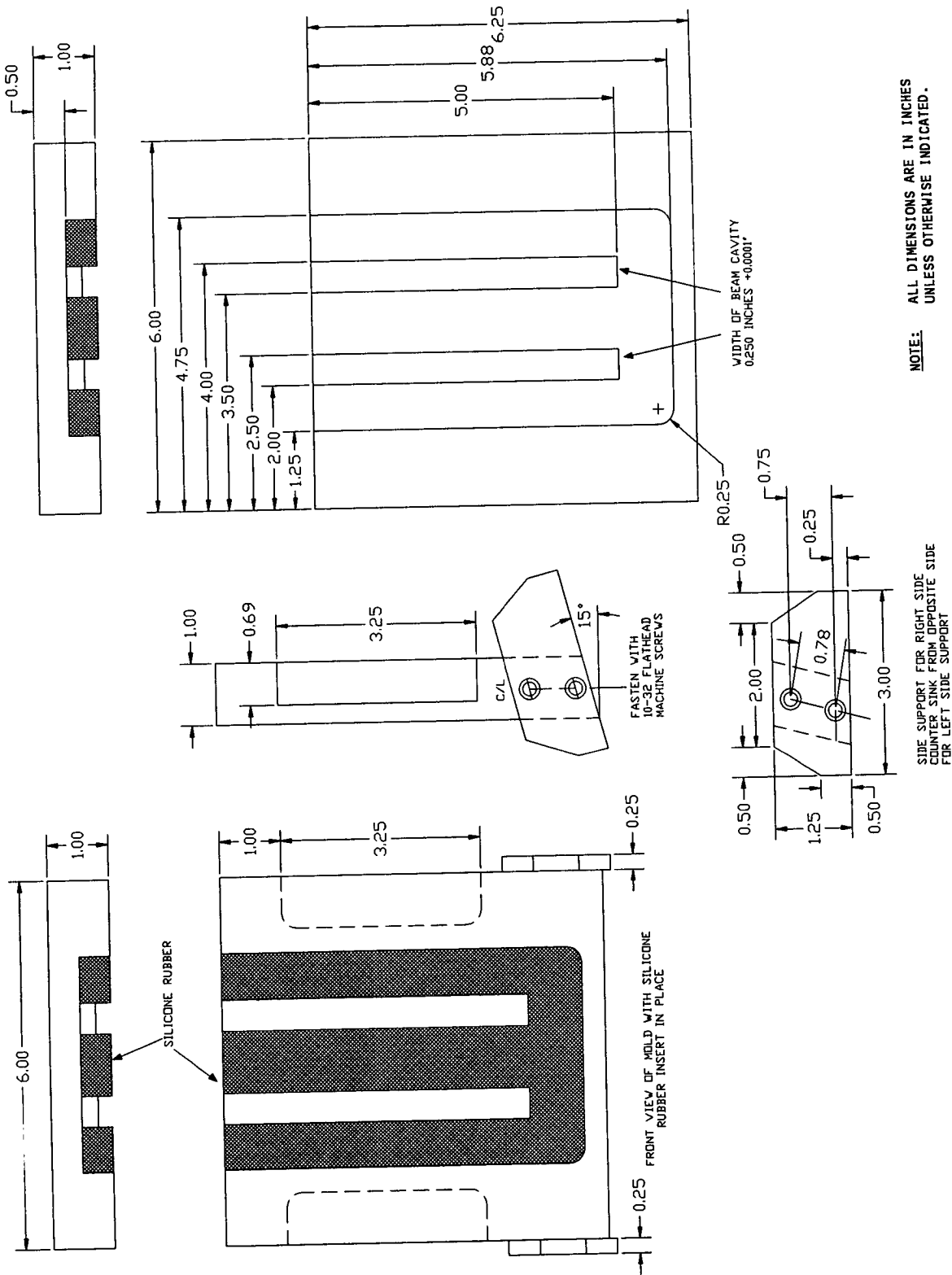


Figure 3 Schematic of silicone rubber molds

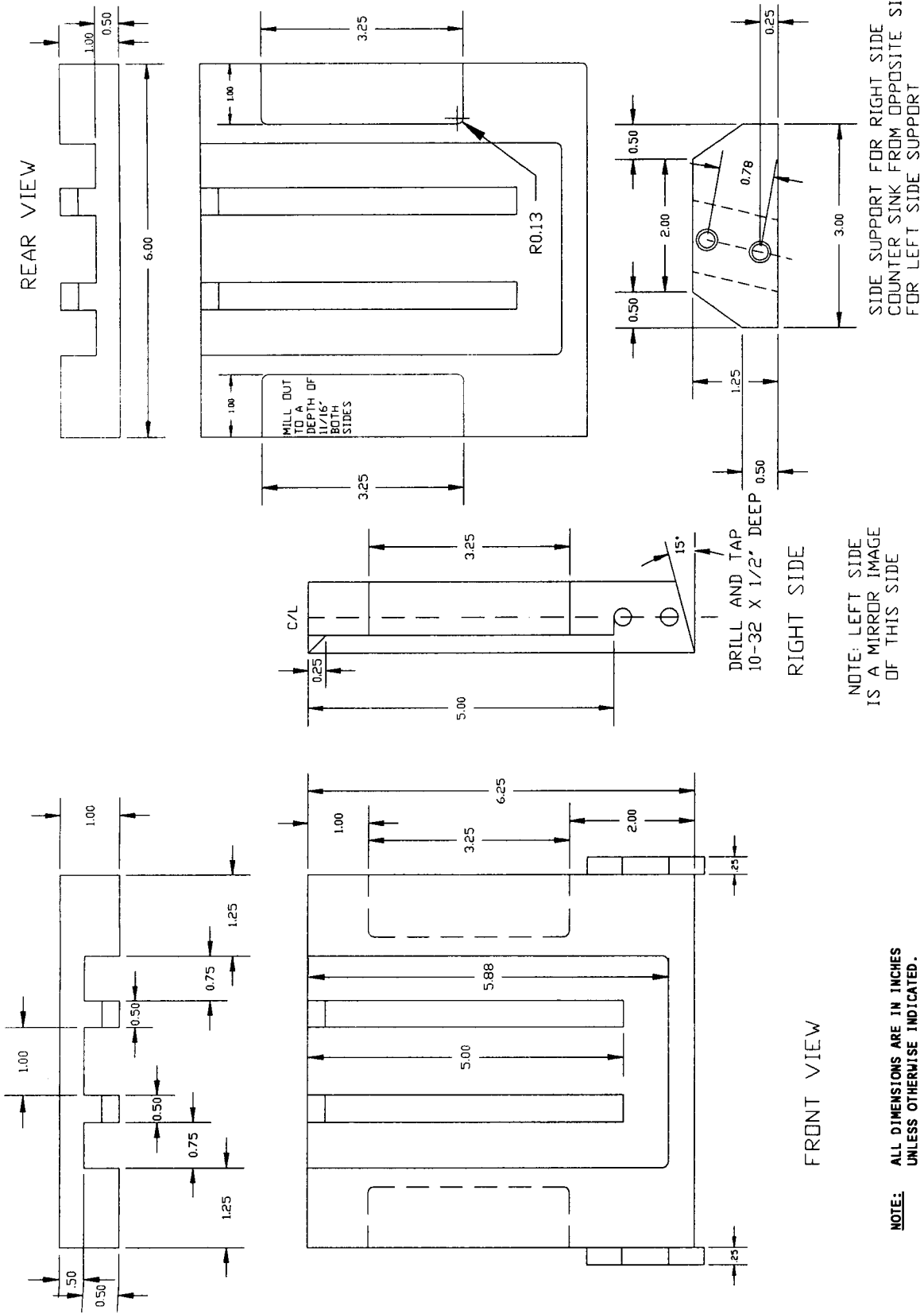


Figure 3 Schematic of silicone rubber molds (cont.)

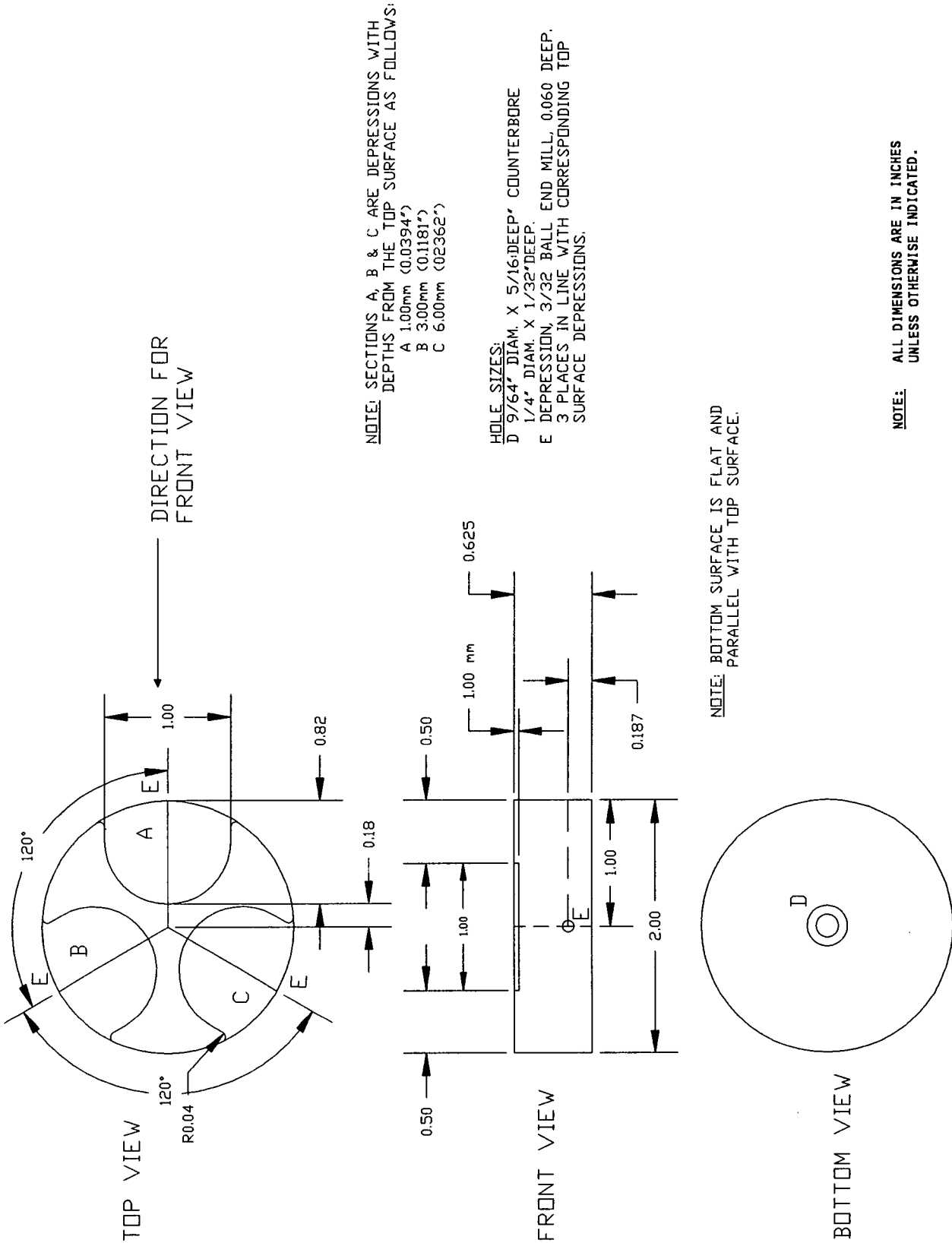


Figure 4 Schematic of thickness gauge used to calibrate deflection detector

ANNEX

1.1 A typical test result is shown in figure A1. Disregard measurements obtained and the curves projected on the computer screen during the initial 8 s application of the test load. Data from a creep test obtained immediately after the application of the test load may not be valid because of dynamic loading effects and the finite rise time. Use only the data obtained between 8 and 240 s loading time for calculating $S(t)$ and m .

1.2 *Deflection of an elastic beam*—Using the elementary bending theory, the midpoint deflection of an elastic prismatic beam of constant cross section loaded in three-point loading can be obtained by applying equations (1) and (2) as follows:

$$\delta = PL^3/48EI \quad (1)$$

where

δ = deflection of beam at the midpoint, mm

P = load applied, N

L = span length, mm

E = modulus of elasticity, MPa

I = moment of inertia, mm⁴

and

$$I = bh^3/12 \quad (2)$$

where

I = moment of inertia of cross section of test beam, mm⁴

b = width of beam, mm

h = thickness of beam, mm

NOTE 12.—The test specimen has a span-to-depth ratio of 16 to 1 and the contribution of shear to deflection of the beam can be neglected.

1.3 *Elastic flexural modulus*—According to elastic theory, calculate the flexural modulus of a prismatic beam of constant cross section loaded at its midpoint thus:

$$E = PL^3/4bh^3\delta \quad (3)$$

where

E = time-dependent flexural creep stiffness, MPa

P = constant load, N

L = span length, mm

b = width of beam, mm

h = depth of beam, mm

δ = deflection of beam, mm

1.4 Maximum bending stress—The maximum bending stress in the beam occurs at the midpoint at the top and bottom of the beam. Calculate σ thus:

$$\sigma = 3PL/2bh^2 \quad (4)$$

where

σ = maximum bending stress in beam, MPa
 P = constant load, N
 L = span length, mm
 b = width of beam, mm
 h = depth of beam, mm

1.5 Maximum bending strain—The maximum bending strain in the beam occurs at the midpoint at the top and bottom of the beam. Calculate ϵ thus:

$$\epsilon = 6\delta h/L^2 \text{ mm/mm} \quad (5)$$

where

ϵ = maximum bending strain in beam, mm/mm
 δ = deflection of beam, mm
 h = thickness of beam, mm
 L = span length, mm

1.6 Linear Viscoelastic Stiffness Modulus—According to the elastic-viscoelastic correspondence principle, it can be assumed that if a linear viscoelastic beam is subjected to a constant load applied at $t = 0$ and held constant, the stress distribution is the same as that in a linear elastic beam under the same load. Further, the strains and displacements depend on time and are derived from those of the elastic case by replacing E with $1/D(t)$. Since $1/D(t)$ is equivalent to $S(t)$, rearranging the elastic solution results in the following relationship for the stiffness:

$$S(t) = PL^3/4bh^3\delta(t) \quad (6)$$

where

$S(t)$ = time-dependent flexural creep stiffness, MPa
 P = constant load, N
 L = span length, mm
 b = width of beam, mm
 h = depth of beam, mm
 $\delta(t)$ = deflection of beam, mm, and
 $\delta(t)$ and $S(t)$ indicate that the deflection and stiffness, respectively, are functions of time.

1.7 Presentation of Data

1.7.1 Plot the response of the test beam to the creep loading as the logarithm of stiffness with respect to the logarithm of loading time. A typical representation of test data is shown in figure A2. Over the limited testing time from 8 to 240 s, the plotted data shown in figure A2 can be represented by a second order polynomial as follows:

$$\log S(t) = A + B[\log(t)] + C[\log(t)]^2 \quad (7)$$

and, the slope, m , of the logarithm of stiffness versus logarithm time curve is equal to (absolute value):

$$|m(t)| = d[\log S(t)]/d[\log(t)] = B + 2C[\log(t)] \quad (8)$$

where

$S(t)$ = time-dependent flexural creep stiffness, MPa

t = time in seconds

A , B , and C = regression coefficients

Smoothing the data may be required to obtain smooth curves for the regression analysis as required to determine an m value. This can be done by averaging 5 readings taken at the reported time ± 0.1 and ± 0.2 seconds.

1.7.2 Obtain the constants A , B , and C from the least squares fit of equation 7. Use data equally spaced with respect to the logarithm of time to determine the regression coefficients in equations 7 and 8. Determine experimentally the stiffness values used for the regression to derive the coefficients A , B , and C and to, in turn, calculate values of m after loading times of 8, 15, 30, 60, 120, and 240 s.

1.8 Calculation of Regression Coefficients, estimated stiffness values and m .

1.8.1 Calculate the regression coefficients A , B , and C in equations 7 and 8 and the denominator D as follows:

$$A = [S_y(S_{x2}S_{x4} - S_{x3}^2) - S_{xy}(S_{x1}S_{x4} - S_{x2}S_{x3}) + S_{xy}(S_{x1}S_{x3} - S_{x2}^2)] / D \quad (9)$$

$$B = [6(S_{xy}S_{x4} - S_{xy}S_{x3}) - S_{x1}(S_yS_{x4} - S_{xy}S_{x2}) + S_{x2}(S_yS_{x3} - S_{xy}S_{x2})] / D \quad (10)$$

$$C = [6(S_{x2}S_{xy} - S_{x3}S_{xy}) - S_{x1}(S_{x1}S_{xy} - S_{x3}S_y) + S_{x2}(S_{x1}S_{xy} - S_{x2}S_y)] / D \quad (11)$$

$$D = 6(S_{x2}S_{x4} - S_{x3}^2) - S_{x1}(S_{x1}S_{x4} - S_{x2}S_{x3}) + S_{x2}(S_{x1}S_{x3} - S_{x2}^2) \quad (12)$$

where, for loading times of 8, 15, 30, 60, 120, and 240 seconds:

$$S_{x1} = \log 8 + \log 15 + \dots \log 240$$

$$S_{x2} = (\log 8)^2 + (\log 15)^2 + \dots (\log 240)^2$$

$$S_{x3} = (\log 8)^3 + (\log 15)^3 + \dots (\log 240)^3$$

$$S_{x4} = (\log 8)^4 + (\log 15)^4 + \dots (\log 240)^4$$

$$\begin{aligned}
S_y &= \log S(8) + \log S(15) + \dots \log S(240) \\
S_{xy} &= \log S(8)(\log(8)) + \log S(15) \log(15) + \dots \log S(240) \log(240) \\
S_{xxy} &= [\log(8)]^2 \log S(8) + [\log(15)]^2 \log S(15) + \dots [\log(240)]^2 \log S(240)
\end{aligned}$$

1.8.2 Calculate the estimated stiffness at 8, 15, 30, 60, 120, and 240 seconds as:

$$\log S(t) = A + B[\log(t)] + C[\log(t)]^2 \quad (13)$$

1.8.3 Calculate the estimated m value at 8, 15, 30, 60, 120, and 240 s as the absolute value of

$$|m| = B - 2C[\log(t)] \quad (14)$$

1.8.4 Calculate the fraction of the variation in the stiffness explained by the quadratic model as:

$$R^2 = 1.00 - \left[\frac{[\log S(8) - \log S(8)]^2 + \dots [\log S(240) - \log S(240)]^2}{[\log S(8) - \log(\bar{S})]^2 + \dots [\log S(240) - \log(\bar{S})]^2} \right] \quad (15)$$

1.8.5 Calculate \bar{S} the average of the stiffness values at 8, 15, 30, 60, 120, and 240 s as:

$$\log \bar{S} = [\log S(8) + \dots \log S(240)]/6 \quad (16)$$

1.8.6 Use the estimated values of the stiffness and m at 60 s for specification purposes. Measured and estimated stiffness values should agree to within 2%. Otherwise, the test is considered suspect.

Test Information

Project: testing	Target Temp: 23.0°C	Conf. Test: 2.199e+008
Operator: jsy	Actual Temp: 14.8°C	Date: 09/17/93
Specimen: plastic beam b	Soak Time: 0.0 sec	Load Const: 0.24
Time: 11:47:03	Beam Width: 12.70 mm	Defl Const: 0.0024
Date: 09/18/93	Thickness: 6.35 mm	Date: 09/17/93
File: 0818934.DAT		

Results

<i>t</i> Time (sec)	<i>P</i> Force (N)	<i>d</i> Defl (mm)	Measured Stiffness (kPa)	Estimated Stiffness (kPa)	Difference %	<i>m</i> -value
8	.9859	.9126	87030.0	87060.0	.03532	0.176
15	.9894	1.022	77990.0	77930.0	-.08120	0.175
30	.9913	1.158	68960.0	68990.0	.04809	0.175
60	.9910	1.308	61110.0	61110.0	.004487	0.174
120	.9908	1.475	54150.0	54150.0	-.001551	0.174
240	.9906	1.664	48010.0	48000.0	-.005077	0.174

Regression Coefficients:

$a = 5.100$ $b = -.1784$ $c = .001020$ $R^2 = 0.999996$

Figure A1 Typical Test Report

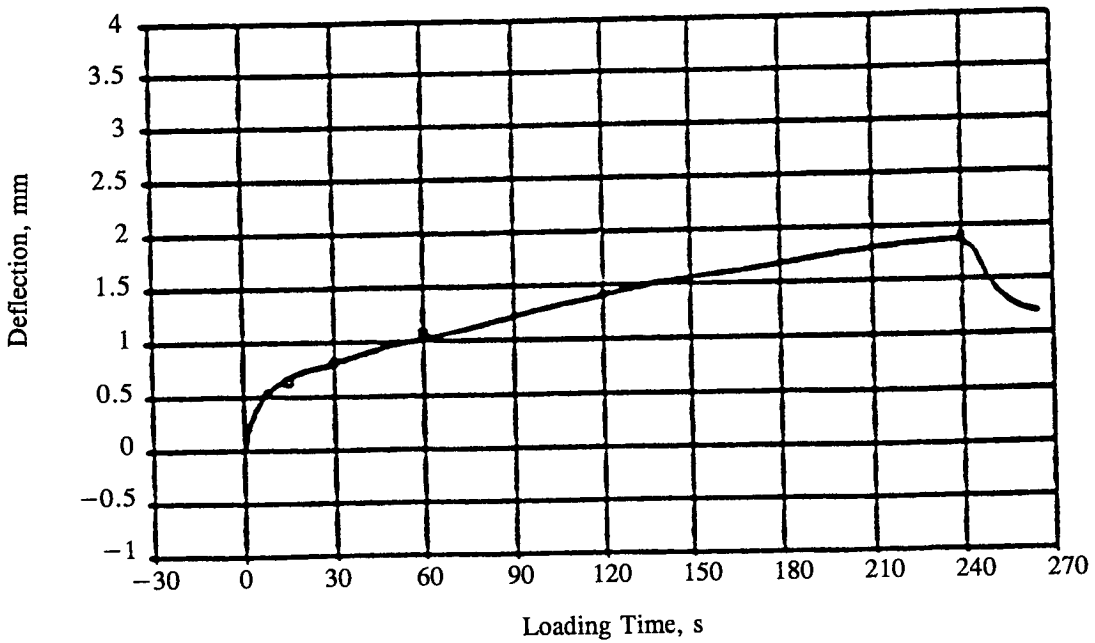
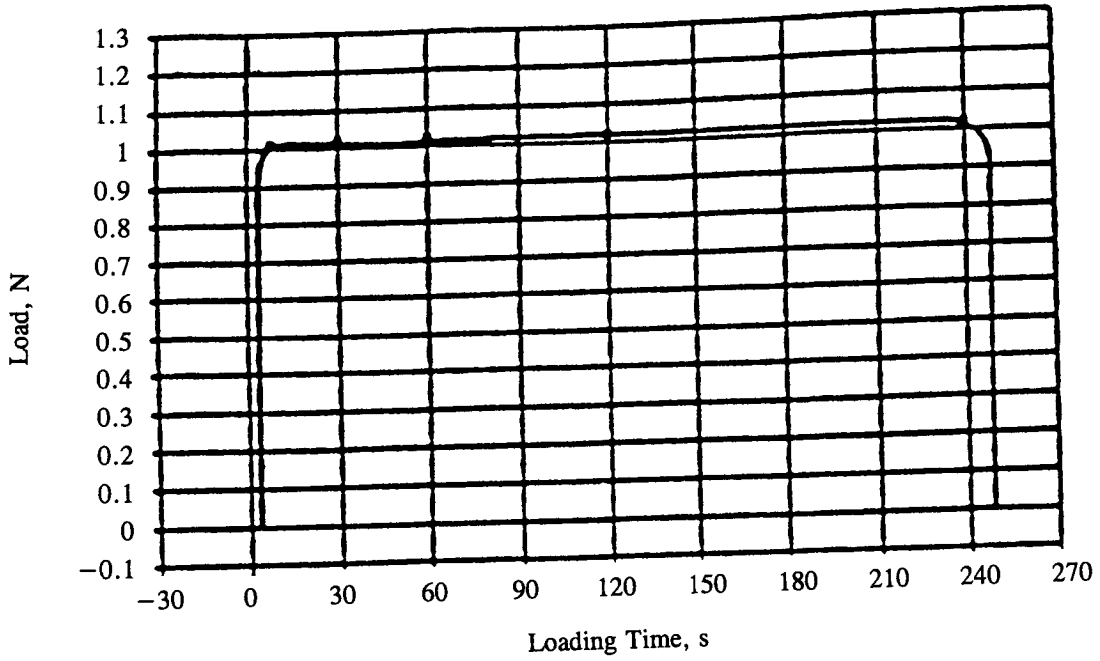


Figure A2 Typical Load and Deflection Plots for the Bending Beam Rheometer

Standard Method of Test for

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

AASHTO Designation: TP5¹

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 that have dynamic shear modulus values from 100 Pa to 10 MPa. This range in modulus is typically obtained between 5°C and 85°C. 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 T240, T179, or PP1.

1.3 Particulate material in the asphalt binder is limited to particles with longest dimensions less than 250 μm .

1.4 The values stated in SI units are to be regarded as the standard.

1.5 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the 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.*

2. REFERENCE DOCUMENTS

2.1 AASHTO Standards

MP1 Test Method for Performance-Graded Asphalt Binder

T40 Practice for Sampling Bituminous Materials

T179 Test Method for Effect of Heat and Air on Asphalt Materials (Thin Film Oven Test)

¹ This standard is based on SHRP Product 1007.

- T240 Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin Film Oven Test)
- TP1 Test Method for Determining the Flexural Creep Stiffness of an Asphalt Binder Using the Bending Beam Rheometer
- PP1 Practice for Accelerated Aging of an Asphalt Binder Using a Pressurized Aging Vessel
- PP6 Practice for Grading or Verifying the Performance Grade of an Asphalt Binder

2.2 *ASTM Standards*

- E1 Specification for ASTM Thermometers
- E220 Method for Calibration of Thermocouples by Comparison Techniques

2.3 *DIN Standards*

43760

3. TERMINOLOGY

3.1 *Definitions*

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

3.2 *Descriptions of Terms Specific to this Standard*

3.2.1 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 .

3.2.2 phase angle, δ —the angle in radians or degrees 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.

3.2.3 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).

3.2.4 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.

3.2.5 parallel plate geometry, *n*—a testing geometry in which the test sample is sandwiched between two relatively rigid parallel plates and subjected to oscillatory shear.

3.2.6 oscillatory shear, *n*—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 about zero in a sinusoidal manner.

3.2.7 linear viscoelastic, *adj*—refers to a region of behavior in which the dynamic shear modulus is independent of shear stress or strain.

3.2.8 molecular association, *n*—refers to associations that occur between asphalt binder molecules during storage at ambient temperature. Often referred to as steric hardening in the asphalt literature, molecular associations can increase the dynamic shear modulus of asphalt binders. The extent of molecular association is asphalt specific and may be apparent even after a few hours of storage.

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 5°C and 85°C, dependent upon 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 (or torque amplitudes). The required amplitude depends upon 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 $\pm 0.1^\circ\text{C}$ by positive heating and cooling of the upper and lower plates.

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.

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. Other linear viscoelastic properties, such as the storage modulus (G'), or the loss modulus (G''), can be calculated from the complex modulus and the phase angle. The loss modulus is a measure of the energy dissipated during each loading cycle.

5.3 The complex modulus and the phase angle are used to calculate performance-related criteria in accordance with MP1.

6. APPARATUS

6.1 *Dynamic Shear Rheometer Test System*—A dynamic shear rheometer 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*—Metal test plates with smooth polished surfaces. One 8.00 ± 0.05 mm in diameter and one 25.00 ± 0.05 mm in diameter. The base plate in some rheometers is a flat plate. A raised portion 2 to 5 mm high with the same radius as the upper plate is recommended. The raised portion makes it easier to trim the specimen and may improve test repeatability.

6.1.2 *Environmental Chamber*—A chamber for controlling the test specimen temperature, by heating (in steps or ramps), or cooling (in steps or ramps), to maintain a constant specimen environment. The medium for heating and cooling the specimen in the environmental chamber is a gas or liquid (note 1) that will not affect asphalt binder properties. The temperature in the chamber may be controlled by the circulation of fluid or conditioned gas; nitrogen or water is acceptable. When air is used, a suitable drier must be included to prevent condensation of moisture on the plates and fixtures and, if operating below freezing, 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 1.—A circulating bath unit separate from the dynamic shear rheometer which pumps the bath fluid through the test chamber may be required if a fluid medium is used.

6.1.2.1 *Temperature Controller*—A temperature controller capable of maintaining specimen temperatures within 0.1°C for test temperatures ranging from 5 to 85°C .

6.1.2.2 *Temperature Detector*—A reference thermal detector (RTD) mounted inside the environmental chamber, in intimate contact with the fixed plate, with a range of 5 to 85°C , readable and accurate to the nearest 0.1°C . This detector shall be used to control the temperature in the chamber and provide a continuous readout of temperature during the mounting, conditioning, and testing of the specimen.

NOTE 2.—Platinum RTDs meeting DIN Standard 43760 (Class A) or equal are recommended for this purpose. The RTD shall be calibrated as an integral unit with its respective meter or electronic circuitry.

6.1.2.3 Reference Temperature Sensing Device—A thermistor, RTD, or thermocouple as described in sections 9.1.1.2.1, 9.1.1.2.2, or 9.1.1.2.3 shall be used.

6.1.3 Loading device—The loading device shall apply 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%. 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 μ 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 torque shall be < 2 mrad/N·m.

6.1.4 Control and Data Acquisition System—The control and data acquisition system shall provide 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 0.5% or less. The system shall measure and record the phase angle, in the range from 0 to 90°, $\pm 0.1^\circ$.

Table 1. Control and Data Acquisition System Requirements

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

6.2 Specimen Mold (Optional)—A silicone rubber mold for forming asphalt binder test specimens having a diameter approximately equal to the diameter of the upper test plate and a height approximately equal to 1.5 times the width of the test gap.

6.3 Specimen Trimmer—A specimen trimmer with a straight edge at least 4 mm wide.

6.4 Calibrated Temperature Detector—A calibrated thermocouple, thermistor, or RTD with a thickness or diameter ≤ 2.0 mm is suitable for measuring the temperature of a dummy specimen or sample of asphalt binder. Thermocouples and thermistors are not reliable to $\pm 0.1^\circ\text{C}$ unless calibrated to a standard traceable to the National Institute of Standards and Technology (NIST) and must be calibrated with associated meters or electronic circuitry. Platinum RTDs are typically not suitable because they are too large to fit in the gap between the test plates in the DSR.

7. HAZARDS

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

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 Mount the test plates on the test fixtures and tighten firmly.

8.3 Select the testing temperature according to the grade of the asphalt binder or according to the preselected testing schedule (note 3). Allow the DSR to reach a stabilized temperature $\pm 0.1^{\circ}\text{C}$ of the test temperature.

NOTE 3.—Specification MP1 and Practice PP6 provide guidance on the selection of test temperatures.

8.4 With the test plates at the test temperature or the middle of the expected testing range, establish the zero gap level by one of two methods. One method is to manually spin the moveable plate. While the moveable plate is spinning, close the gap until the movable plate touches the fixed plate. The zero gap is reached when the plate stops spinning completely. The other method, for rheometers with normal force transducers, is to close the gap and observe the normal force. After establishing contact between the plates, set the zero gap at approximately zero normal force.

8.5 Move the plates apart and establish a gap setting of 1 mm plus 0.05 mm (for 25-mm diameter test specimens) or 2 mm plus 0.05 mm (for 8-mm diameter test specimens).

NOTE 4.—The frame, detectors, and fixtures in the DSR change dimension with temperature, which causes the zero gap. Adjustments in the gap are not necessary when measurements are made over a limited range of temperatures. The gap should be set with the test apparatus at the test temperature. When tests are to be conducted over a range of temperatures, the gap should be set with the test apparatus at the middle of the expected range of test temperatures. For most instruments, no gap adjustment is needed if the test temperature will be $\pm 12^{\circ}\text{C}$ of the temperature at which the gap is set.

9. CALIBRATION AND STANDARDIZATION

9.1 Perform the following calibration and verification procedures at least every six months:

9.1.1 *Temperature*—Prepare a dummy specimen of asphalt binder or use a silicone wafer following standard procedures. Use the dummy specimen only for temperature verification measurements. (Dynamic shear measurements are not valid if a temperature

detector is inserted into the asphalt binder.) Verify the specimen temperature indicated by the DSR RTD in trial runs by using a calibrated temperature detector inserted into the dummy specimen.

9.1.1.1 Compare temperature measurements obtained from the dummy specimen and the DSR RTD. Use the temperature measured inside the dummy specimen as the reference temperature. If the temperatures are not equal, apply an appropriate temperature correction to the temperature measurement indicated by the DSR RTD.

9.1.1.2 Thermal gradients within the rheometer and the difficulty of calibrating the instrument RTD while it is mounted in the rheometer (see note 5) require a direct measurement of the temperature between the plates using a dummy specimen and a reference temperature sensing device. This is accomplished by placing a dummy specimen between the plates and reading the temperature in the dummy specimen with a reference temperature sensing device. A thermistor, RTD, or thermocouple as described in sections 9.1.1.2.1, 9.1.1.2.2, or 9.1.1.2.3 shall be used as the reference temperature sensing device. Adjust the temperature in the chamber to the minimum temperature that will be used for testing and allow the chamber to come to thermal equilibrium. Read the instrument RTD and the temperature of the dummy specimen. Increase the temperature in increments of no more than 6°C and repeat the measurements to cover the range of test temperatures. Using these measurements, obtain the temperature difference between the instrument RTD and the reference temperature sensing device inserted between the plates. This difference will not be a constant but will vary with test temperature. Offset the thermal controller on the rheometer so that the target test temperature is obtained between the plates.

NOTE 5.—The RTD and its meter can be calibrated by a commercial vendor. Verification of calibration can be obtained by comparing the output from the RTD with a calibrated ASTM mercury-in-glass thermometer in accordance with ASTM E220. A stirred water bath is suitable for calibrating the thermal detector. Select a partial immersion mercury-in-glass thermometer with an appropriate range (ASTM 90C; 0 to 30°C or ASTM 91C; 20 to 50°C) and place the thermal detector and the thermometer in the stirred water bath. Fasten the detector to the glass thermometer with a rubber band or rubber O-ring. Allow the bath, detector, and thermometer to come to thermal equilibrium and record the temperature of the glass thermometer and the readout from the thermal detector. The temperature in the bath shall be constant to within 0.1 degree.

9.1.1.2.1 A silicone wafer 2 mm thick by 25 mm in diameter containing a thermistor calibrated to the nearest 0.1°C shall be inserted between the plates as the dummy specimen. Use a thin coating of petroleum jelly to ensure good thermal contact. A suitable thermistor mounted in a silicone wafer is available from Cannon Instruments as part number 9728-V95.

9.1.1.2.2 A wafer-shaped RTD shall be mounted between the plates and used as described in section 6.1.2.2. The RTD must be calibrated as described in note 5 to the nearest 0.1°C. A suitable RTD is available from Omega as part number RTD FN105. This RTD is not waterproof and must be dipped in hot asphalt prior to calibration. To obtain measurements, the RTD is mounted in the rheometer within the asphalt binder sample. After mounting the sample and trimming excess asphalt binder, proceed with the temperature measurements as described in section 6.1.2.2.

9.1.1.2.3 A thermocouple probe shall be used to measure the sample temperature by inserting the probe into a sample that has been mounted in the rheometer (this procedure is described in section 10). The thermocouple must be calibrated at 3 month intervals using the procedure described in note 5 to the nearest 0.1°C. When obtaining the sample temperature the cabling and instrumentation must remain unchanged from that used during the calibration. To make a sample temperature reading insert the thermocouple in the asphalt binder between the plates and proceed as described in section 6.1.2.3. A suitable thermocouple probe is available from Omega as part number HYP1-30-1/2-T-G-60-SMP-M.

9.1.2 Calibrate the load transducer in accordance with the directions and fixtures supplied with the apparatus.

9.1.3 Calibrate the strain transducer in accordance with the directions and fixtures supplied with the apparatus.

9.1.4 Verify the overall calibration of the DSR using suitable reference fluids with viscoelastic properties similar to asphalt binder. Do not attempt to verify individual load or deflection detectors with a reference fluid. Suitable standards have not been identified.

NOTE 6.—Reference fluids exhibiting moduli and phase angles within the range of measurement may be used for verification purposes. Because reference fluids do not have the same temperature dependency as asphalt binder, caution must be used when interpreting the results obtained from such fluids.

10. PREPARING SAMPLES AND TEST SPECIMENS

10.1 *Preparing Test Samples*—If unaged binder is to be tested, obtain test samples according to T40.

10.1.1 Anneal the asphalt binder from which the test specimen is to be obtained by heating until it is sufficiently fluid to pour the required specimens. Annealing prior to testing removes reversible molecular associations (steric hardening) that occur during normal storage at ambient temperature. Do not exceed a temperature of 163°C. Cover the sample and stir it occasionally during the heating process to ensure homogeneity and to remove air bubbles. Minimize the heating temperature and time to avoid hardening the sample.

NOTE 7.—Minimum pouring temperatures that produce a consistency equivalent to that of SAE 10W30 motor oil (readily pours but not overly fluid) at room temperature are recommended. Heating unaged asphalt to temperatures above 135°C should be avoided. With some modified asphalts or heavily aged binders, however, pouring temperatures above 135°C may be required.

10.1.2 Cold material from storage containers must be annealed prior to usage. Structure developed during storage can result in overestimating the modulus by as much as 50%.

10.2 *Preparing Test Specimens*—Carefully clean and dry the surfaces of the test plates so that the specimen adheres to both plates uniformly and strongly. Bring the chamber to approximately 45°C so that the plates are preheated prior to the mounting of the test

specimen. This will provide sufficient heat so that the asphalt binder may be squeezed between the plates for trimming and to ensure that the asphalt binder adheres to the plates. Serrated plates or otherwise roughened plates are not necessary to ensure load transfer between the asphalt binder and the plates as long as the plates are clean and dry when the test specimen is prepared. Prepare a test specimen using one of the methods specified in sections 10.2.1 or 10.2.2.

10.2.1 Alternate 1—Remove the removable plate and, while holding the sample container approximately 15 mm above the test plate surface, pour the asphalt binder at the center of the upper test plate continuously until it covers the entire plate except for an approximate 2-mm-wide strip at the perimeter (note 8). Carefully insert the RTD. Wait several minutes for the specimen to stiffen, then mount the test plate in the rheometer for testing.

NOTE 8.—An eye dropper or syringe may be used to transfer the hot asphalt binder to the plate.

10.2.2 Alternate 2—Pour the hot asphalt binder into a silicone rubber mold that will form a pellet that has a diameter approximately equal to the diameter of the upper test plate and a height approximately equal to 1.5 times the width of the test gap. Carefully insert the RTD. Allow the silicone rubber mold to cool to room temperature. Remove the specimen from the mold and center the pellet on the lower plate of the DSR.

NOTE 9.—The filled mold may be chilled in a freezer to facilitate demolding of softer grades of asphalt binder. Chill the mold in the freezer for only the minimum time needed to facilitate demolding the specimen.

10.3 Test Specimen Trimming—After the specimen has been placed on one of the test plates as described above, move the test plates together to squeeze the asphalt mass between the two plates. Move the plates together until the gap between plates equals the testing gap plus 0.05 mm.

10.3.1 Trim excess asphalt from the specimen by moving a heated trimming tool around the upper and lower plate perimeters. The tool may be heated on a hot plate or with a flame.

NOTE 10.—The calculated modulus is proportional to the fourth power of the specimen radius. Carefully trim the specimen to insure that the measurements are reliable.

10.3.2 When the trimming is completed, decrease the gap by 0.05 mm to the desired testing gap. This will cause a slight bulging of the asphalt binder at the periphery of the test specimen.

11. PROCEDURE

11.1 Bring the specimen to the test temperature $\pm 0.1^\circ\text{C}$. See note 4.

NOTE 11.—The gap should be set at the starting test temperature (section 11.1.1) or at the middle of the expected range of test temperatures (section 11.1.2). See sections 8.4 and 8.5 for guidance on setting the gap.

Typically, reliable test results may be obtained with a single sample, in an 8-mm or 25-mm plate, using temperatures within 12°C of the temperature at which the gap is set.

11.1.1 When testing a binder for compliance with MP1, select the appropriate test temperature from table 1 of MP1.

11.1.2 When conducting a temperature sweep, start at a mid-range test temperature and increase or decrease the test temperature to cover the desired range of test temperatures. (See sections 6 and 7 in PP6.)

11.2 Set the temperature controller to the desired test temperature, including any difference as required by section 9.1.1.2. Allow the temperature indicated by the RTD to come to the desired temperature. The test shall be started only after the temperature has remained at the desired temperature $\pm 0.1^\circ\text{C}$ for at least 10 minutes. After temperature equilibration, anneal the specimen for 5 minutes.

NOTE 12.—It is impossible to specify a single equilibration time that is valid for different manufacturers' DSRs. The design (fluid bath or air oven) of the environmental control system and the starting temperature will dictate the time required to reach the test temperature.

11.3 Strain Control Mode—When operating in a strain controlled mode, determine the strain value according to the value of the complex modulus. Control the strain within 20% of the target value calculated by equation 1.

$$\gamma = 12.0/(G^*)^{0.29} \quad (1)$$

where

γ = shear strain in percent
 G^* = complex modulus in kPa

11.3.1 When testing specimens for compliance with MP1, select an appropriate strain value from table 2. Software is available with the dynamic shear rheometers that will control the strain automatically.

Table 2. Target Strain Values

Material	G* (kPa)	Strain (%)	
		Target Value	Range
Original Binder	1.0	12	9 to 15
RTFO Residue	2.2	10	8 to 12
PAV Residue	5.0	1	0.8 to 1.2

11.4 Stress-Controlled Mode—When operating in a stress-controlled mode, determine the stress level according to the value of the complex modulus. Control the stress within 20% of the target value calculated by equation 2.

$$\tau = 0.12(G^*)^{0.71} \quad (2)$$

where

τ = shear stress in kPa

G^* = complex modulus in kPa

11.4.1 When testing specimens for compliance with MP1, select an appropriate stress level from table 3. Software is available with the dynamic shear rheometers that will control the stress level automatically without control by the operator.

Table 3. Target Stress Levels

Material	G^* (kPa)	Stress (kPa)	
		Target Level	Range
Original Binder	1.0	0.12	0.09 to 0.15
RTFO Residue	2.2	0.22	0.18 to 0.26
PAV Residue	5.0	50.0	40 to 60

11.5 When the temperature has equilibrated, condition the specimen by applying the required strain for 10 cycles at a frequency of 10 rad/s (note 13). Obtain test measurements by recording data for an additional 10 cycles. Reduce the data obtained for the second 10 cycles to produce a value for the complex modulus and phase angle. Typically a Fast Fourier Transform (FFT) is used to reduce the data. The data acquisition system automatically acquires and reduces the data when properly activated. When conducting tests at more than one frequency, start testing at the lowest frequency and increase to the highest frequency.

NOTE 13.—The standard frequency of 10 rad/s is used when testing binder for compliance with MP1.

11.6 The data acquisition system specified in section 6.1.4 automatically calculates G^* and δ from test data acquired when properly activated.

11.7 Initiate the testing immediately after preparing and trimming the specimen. The testing at subsequent temperatures should be done as quickly as possible to minimize the effect of molecular associations (steric hardening) that can cause an increase in modulus if the specimen is held in the rheometer for a prolonged period of time. When testing at multiple temperatures, all testing should be completed within 4 hours.

12. INTERPRETATION OF RESULTS

12.1 The dynamic modulus and phase angle depend upon the magnitude of the shear strain; the modulus and phase angle for both unmodified and modified asphalt cement decrease with increasing shear strain as shown in figure 1. A plot such as that shown in

figure 1 can be generated by gradually increasing the load or strain amplitude, thereby producing a strain sweep. It is not necessary to generate such sweeps during normal specification testing; however, such plots are useful for verifying the limits of the linear region.

12.2 A linear region may be defined at small strains where the modulus is relatively independent of shear strain. This region will vary with the magnitude of the complex modulus. The linear region is defined as the range in strains where the complex modulus is 95% or more of the zero-strain value.

12.3 The shear stress varies linearly from zero at the center of the plates to a maximum at the extremities of the plate perimeter. The shear stress is calculated from the applied or measured torque, measured or applied strain, and the geometry of the test specimen.

13. REPORT

13.1 Provide a complete identification and description of the material tested including name code, source, and type of sample container.

13.2 Describe the instrument used for the test. Include the model number, whether it is a constant strain or constant stress rheometer, the type of environmental chamber, and other information needed to describe the rheometer.

13.3 The strain and stress levels specified in tables 2 and 3 have been selected to ensure a common reference point that has been shown to be within the linear region for plain and modified asphalt binders. Some systems may not be linear within this region. When this situation is observed, report the modulus at the recommended stress or strain levels but report that the test conditions were outside the linear region.

13.4 For each test, report the following:

13.4.1 the test plate diameter, to the nearest 0.1 mm;

13.4.2 the test gap, to the nearest $1\mu\text{m}$;

13.4.3 the test temperature, to the nearest 0.1°C ;

13.4.4 the test frequency, to the nearest 0.1 rad/s;

13.4.5 the strain amplitude, to the nearest 0.01%, or the torque, to the nearest $\text{mN}\cdot\text{m}$;

13.4.6 the complex modulus (G^*) for the ten measurements, in kPa to three significant figures; and

13.4.6 the phase angle (δ) for the second ten cycles, to the nearest 0.1 degrees.

14. PRECISION AND BIAS

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

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

15. KEY WORDS

Asphalt binder, complex modulus, dynamic shear rheometer.

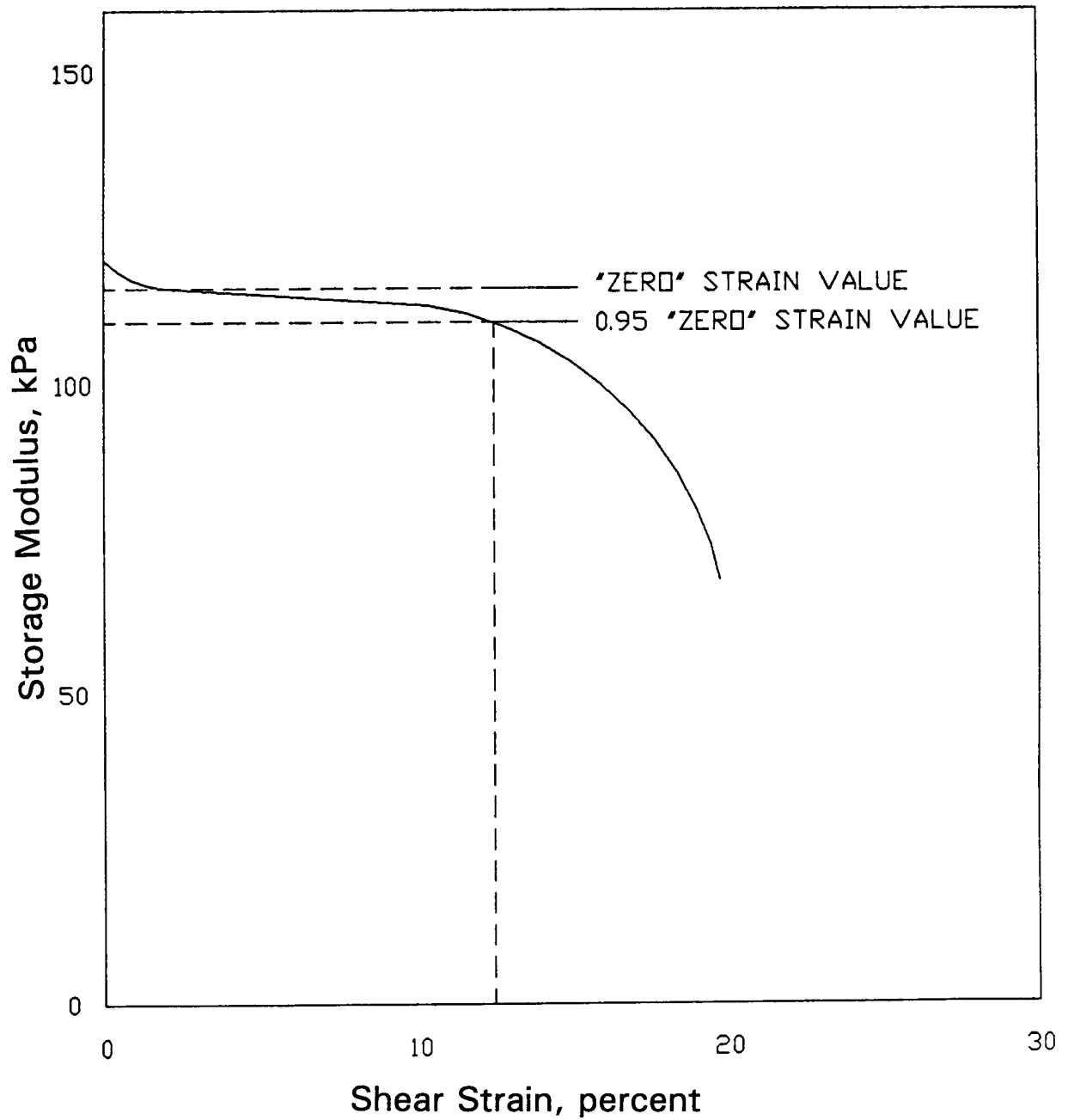


Figure 1. Example of a Strain Sweep Test Used to Define the Linear Viscoelastic Limit for Dynamic Mechanical Testing of Asphalt

Standard Method of Test for
**Determining the Fracture Properties of
Asphalt Binder in Direct Tension**

AASHTO Designation: TP3¹

1. SCOPE

1.1 This test method covers the determination of the failure strain and failure stress of asphalt binders by means of a direct tension test. It is applicable to material that has a failure strain less than 10% and can be used with unaged material or with material aged using T240 (RTFOT), T179 (TFOT), or PP1 (PAV). The test apparatus is designed for testing within the temperature range from -40°C to 25°C .

1.2 This test method is limited to asphalt binders that contain particulate material less than $250\ \mu\text{m}$ in diameter.

1.3 This test method is not valid for specimens that exhibit a strain to failure outside the defined brittle-ductile range ($\geq 10\%$).

1.4 The values stated in SI units are to be regarded as the standard.

1.5 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the 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.*

2. REFERENCE DOCUMENTS

2.1 AASHTO Standards:

- MP1 Specification for Performance-Graded Asphalt Binder
- PP1 Practice for Accelerated Oxidative Aging of Asphalt Binder
Using a Pressurized Aging Vessel
- T40 Practice for Sampling Bituminous Materials

¹This standard is based on SHRP Product 1005.

- T179 Test Method for Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)
T240 Test Method for Effect of Heat and Air on Rolling Film of Asphalt (Rolling Thin-Film Oven Test)

2.2 *ASTM Standards:*

- E1 Specification for ASTM Thermometers
E4 Practice for Load Verification of Testing Machines
E83 Method of Verification and Classification of Extensometers
E220 Method for Calibration of Thermocouples by Comparison Techniques

2.3 *DIN Standards*

43760

2.4 *MIL Standards*

5545

45662

45662A

3. TERMINOLOGY

3.1 *Definitions*

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

3.2 *Description of Terms Specific to This Standard*

3.2.1 brittle, *adj*—refers to a type of failure in a direct tension test where the stress-strain curve is essentially linear up to the point of failure and the failure is by sudden rupture of the test specimen without appreciable reduction in the cross section of the specimen.

3.2.2 brittle-ductile, *adj*—refers to type of failure in a direct tension test where the stress-strain curve is curvilinear and the failure is by sudden rupture of the test specimen. A limited reduction in the cross section of the specimen occurs before rupture.

3.2.3 ductile, *adj*—refers to a type of failure in a direct tension test where the specimen does not rupture but fails by flow at large strains.

3.2.4 engineering strain, n —refers to the axial strain resulting from the application of a tensile load and calculated as the change in length caused by the application of the tensile load divided by the original unloaded length of the specimen without any correction for reduction in its cross section.

3.2.5 failure, n —refers to the point at which the tensile load reaches a maximum value as the test specimen is pulled at a constant rate of elongation.

3.2.6 failure stress, n —the tensile stress on the test specimen when the load reaches a maximum value during the test method specified in this standard.

3.2.7 failure strain, n —the tensile strain corresponding to the failure stress.

4. SUMMARY OF TEST METHOD

4.1 This method describes the procedure used to measure the strain at failure and stress at failure in an asphalt binder test specimen pulled at a constant rate of elongation. Test specimens are prepared by pouring hot asphalt binder into a suitable mold. Two plastic inserts are used to grip the asphalt binder during the test and to transfer the tensile load from the test machine to the test specimen.

4.2 This test procedure was developed for asphalt binders at temperatures where they exhibit brittle or brittle-ductile failure. A brittle or brittle-ductile failure will result in a fracture of the test specimen as opposed to a ductile failure in which the specimen simply stretches without fracturing. The test is not applicable at temperatures where failure is by ductile flow.

4.3 A non-contact extensometer is used to measure the elongation of the test specimen as it is pulled in tension at a constant rate of elongation of 1 mm/min. The maximum load developed during the test is monitored. The tensile strain and stress in the test specimen when the load reaches a maximum is reported as the failure strain and failure stress, respectively.

5. SIGNIFICANCE AND USE

5.1 The strain at failure is a measure of the amount of elongation that an asphalt binder can sustain without cracking. Strain at failure is used as a criterion for specifying the low-temperature properties of asphalt binder in accordance with MP1.

5.2 The test is designed to identify the temperature region where the asphalt binder has limited ability to elongate without cracking. In the asphalt binder specification, a lower limit is placed on the allowable strain to failure at a specified temperature and rate of elongation.

5.3 For evaluating an asphalt binder for conformance to MP1, the elongation rate is 1.0 mm/min and the test temperature is selected from table 1 of MP1 according to the grade of asphalt binder. Other rates of elongation and test temperatures may be used to test asphalt binders.

6. APPARATUS

6.1 Direct Tension Test System—A direct tension test system consisting of (1) a displacement-controlled tensile loading machine, (2) a specimen gripping system, (3) a chamber for environmental conditioning and testing, (4) load measuring and recording devices, (5) elongation measuring and recording devices, (6) a temperature detection device, and (7) data acquisition and display devices.

6.1.1 Tensile Loading Machine—A tensile loading machine with a controlled-displacement loading frame capable of producing at least a 500 N load is required. The platen movement shall be controlled with either one or two motor-driven screws or with a hydraulic-controlled actuator. Screw-type loading frames are typically used for this test, although a hydraulic closed-loop testing frame is acceptable if the requirements specified in this standard are met. The loading frame shall produce a crosshead speed of 1.00 ± 0.05 mm/min. Additional crosshead speeds may be supplied but are not required. The testing frame shall be equipped with an automatic return feature that returns the crosshead to a reference position such that the center-to-center spacing of the loading pins is $100.0 \text{ mm} \pm 0.1 \text{ mm}$. The testing frame shall be equipped with two standards with sufficient clear space between the standards so that an environmentally controlled chamber with dimensions given in section 6.1.3 can be placed between the standards.

6.1.2 Specimen Gripping System—The gripping system shall produce a self-aligning uniaxial test load, accept the plastic end units described in section 6.1.2.1 and be designed so that test specimens can be easily mounted in the machine. The system shall include two grips. Each grip shall include a specially-shaped pin that is mounted rigidly to the upper and lower platens of the testing machine. Figure 1 specifies the dimensions of the top and bottom grips. One grip shall be fixed and remain stationary during the test while the other grip is displaced at the desired rate. Figure 2 specifies the dimensions of the loading pins used with the grips.

6.1.2.1 Specimen Plastic End Inserts—PMMA (Plexiglas®) end inserts having the dimensions specified in figure 3 shall be used on both ends of the test specimen to transfer the tensile load to the asphalt binder. Each end insert contains a precisely machined hole and slot. The diameter of the hole is slightly larger than the diameter of the pin. The slots on the top and bottom inserts allow two spots of laser light to pass the test specimen and shine upon the receiver. Gripping of the specimen is accomplished through the bond (adhesion) between the asphalt binder test specimen and the plastic end insert. Each end insert mounts on a specially shaped pin that is part of the gripping system. The specimen is attached to the top and bottom grips by positioning the end inserts in the test machine such that the plastic inserts fit onto the pins and are indexed against the face of the grips. Matching the coefficient

of thermal expansion of the asphalt binder and the inserts is necessary to reduce thermal shrinkage stresses at the interface that otherwise cause bond failures.

NOTE 1.—PMMA (Plexiglas®), meeting MIL STD-5545, has been found acceptable for making the inserts. It is readily available, opaque to the laser beam, has a satisfactory coefficient of thermal expansion, and is easy to machine.

6.1.3 Environmental Conditioning and Testing Chamber—The environmental conditioning and testing chamber shall be capable of controlling temperature and humidity and performing isothermal conditioning of test specimens prior to testing. It should be on the order of 300 mm wide by 200 mm deep by 450 mm high and shall completely enclose the specimen and gripping system. It shall be capable of controlling test temperatures between -40°C and ambient with variations within the chamber $\leq 0.2^{\circ}\text{C}$. It shall be equipped with a cooling system that has the capacity to reduce the chamber temperature from ambient to -40°C within 40 minutes and to change the chamber temperature from -30 to -40°C or from -40 to -30°C within 10 minutes. Mechanical cooling or liquid nitrogen may be used to cool the chamber. It shall have a dehumidifying system with a capacity such that the formation of frost on the interior of the chamber, the test specimen, or any of the test fixtures is eliminated.

6.1.3.1 The chamber shall be capable of storing a minimum of 16 test specimens on a rack which is thermally isolated from the walls and floors of the chamber such that heat conducted from the walls and floors of the chamber does not affect the temperature of the stored specimens.

NOTE 2.—A demolded test specimen is placed on Plexiglas®, Teflon® or other plastic plate (with approximate dimensions of 6 mm thick by 20 mm wide by 100 mm long) and transferred to the environmentally controlled test chamber for thermal conditioning. The use of a transfer plate will minimize deformation during handling. Each plate, when the above dimensions are used, accommodates up to four demolded test specimens.

6.1.3.2 The chamber shall be fitted with a front-opening door for maintenance and standardization purposes and an access port that allows for insertion of the operator's hand and forearm to position test specimens on the storage shelf for conditioning and to position test specimens on the grips for testing. The access port shall be designed so that changes in chamber temperature are $\leq 0.2^{\circ}\text{C}$ during an operation in which the operator's hand or forearm is inserted into or removed from the chamber. Visual access to the interior of the test chamber shall be provided to permit proper mounting of test specimens and test monitoring. The test specimen elongation is measured with an optical laser. Use of the laser requires optical glass windows on two sides of the temperature chamber so that a beam of laser light can be passed through the chamber without distorting the beam.

6.1.4 Load Measuring and Recording Devices—Load shall be measured with a load cell having a minimum capacity of 500 N and a sensitivity of 0.1 N. The load cell shall be calibrated at least annually in accordance with ASTM E4. The load and elongation shall be monitored with the data acquisition system such that they can be resolved to 1% of the failure load and elongation, respectively. Once the test has started, the data acquisition system shall be able to detect the point in time when the load starts to change as a result of elongation in the sample. This shall be accomplished by monitoring the load cell signal with

time. A change in the load signal equivalent to 1 to 2 N (threshold load) shall be used to mark the point in time where zero reading of the extensometer is obtained. The point in time where the peak load is obtained will be captured by the data acquisition system and the accumulated elongation from the zero reading to the elongation corresponding to the peak load shall be used to calculate the failure strain. Once the test is complete, the device shall display the strain at failure. Peak load typically ranges from 10 to 100 N depending on the test temperature, grade, aging, and source of the binder. Stress and strain shall be displayed to the nearest 0.1 N.

6.1.5 Elongation Measuring and Recording Devices—Specimen elongation shall be measured with a laser light transmitter and receiver. The non-contact laser extensometer shall be calibrated at least annually according to ASTM E83, MIL-STD 45662 and MIL-STD 45662A. The transmitter shall produce a vertical plane of laser light that is monitored by the receiver and shall be arranged so that the test specimen interrupts the plane of laser light except for the slots in the insert. Thus, two spots of laser light are transmitted to the receiver. The receiver shall constantly monitor the relative position of the two spots of laser light to produce a voltage proportional to the distance between the two nearest edges of the spots of light. This voltage shall be converted to elongation by a controller attached to the receiver using a calibration factor determined by the manufacturer and verified when the extensometer is calibrated. The laser measurement range shall be 30 to 60 mm with an accuracy ≤ 0.005 mm. Elongations shall be recorded to the nearest 0.005 mm.

6.1.6 Temperature Detection Device—The temperature detection device shall be a calibrated resistance thermal detector (RTD) readable and accurate to 0.1°C (note 3). The RTD shall be mounted inside the environmental chamber in the immediate vicinity of the test specimen. Cabling to the RTD shall be of sufficient length that the bulb of a total immersion mercury-in-glass thermometer can be held adjacent to the RTD for standardization purposes (See section 9.1.3).

NOTE 3.—Required temperature measurement can be accomplished with an appropriately calibrated platinum resistance thermometer (RTD) or thermistor. Platinum resistance thermometers meeting DIN Standard 43760 (Class A) are recommended for this purpose. The required precision and accuracy cannot be obtained unless each RTD or thermistor is calibrated as a system with its respective meter or electronic circuitry (See section 9.1.3).

6.1.7 Data Acquisition and Display Device—The data acquisition and display device shall display the load and elongation selected by the operator (stress and strain) on an LED (or other appropriate computer controlled display) during the time the test specimen is loaded. It shall detect the peak load and capture the elongation associated with the peak load. The maximum skew time between the load and corresponding elongation shall be 0.015 s.

6.1.7.1 The data acquisition component shall consist of an IBM-compatible computer with three A/D channels; one for load (the load cell), one for elongation (the laser), and one for temperature (the RTD). Data shall be stored in ASCII format.

6.1.7.2 Display of Stress-Strain Curve—The data acquisition and display system shall be capable of displaying a stress-strain curve in units of stress (MPa) versus strain (percent). This may be accomplished using the video screen of the data acquisition computer or with an

x-y recorder. If a recorder is used, the units may be recored in volts but the test file shall contain the calibration factor in megapascals/volt and percent strain/volt for both the *x* and *y* axes.

6.2 Specimen Molds—The specimen molds shall be manufactured from silicone rubber available from Dow Corning (HSII RTV Moldmaking Rubber 20:1 Kit, white in color). Silicone rubber is used because it is dimensionally stable, provides an excellent non-stick surface for asphalt binder, and is easy to clean. Specimens and molds shall have the dimensions specified in figures 4 (silicone rubber molds) and 5 (aluminum molds).

6.3 Specimen Mold Support Plates—Aluminum plates 5 to 10 mm thick to support the rubber molds when molding test specimens are required.

6.4 Specimen Storage Plates—Plexiglas, Teflon, or other plastic plates for transferring and storing test specimens in the environmental chamber.

6.5 Calibrated thermometer—A calibrated liquid-in-glass thermometer of suitable range with subdivisions of 0.1°C is required for verification of the temperature transducer. This thermometer shall be calibrated in accordance with ASTM E77. An ASTM 62C thermometer is suitable.

6.6 Load Verification Equipment—Known dead masses (traceable to NIST) ranging 10 to 500 ±0.1 N (1 to 50 ± 0.1 kg) are required for verifying the calibration of the load cell.

7. MATERIALS

7.1 Solvent (Varsol or mineral spirits) or a degreasing spray cleaner formulated for use on plastic for cleaning molds, plastic end inserts and aluminum plates

7.2 Cleaning cloths (cotton) for wiping molds, end inserts and plates

8. HAZARDS—Use the standard laboratory safety procedures required for handling the hot asphalt binder when preparing test specimens and the required safety procedures when cleaning with solvents or degreasers.

9. CALIBRATION AND STANDARDIZATION

9.1 Verify calibration of the extensiometer, load cell, and temperature transducer.

NOTE 4.—Calibration is usually performed by a calibration service agency. Calibration verification, system standardization, and quality checks may be performed by the manufacturer, other agencies providing such services, or in-house personnel using the procedures described below.

9.1.1 Load cell—Verify calibration of the load cell at least every 6 months using dead masses suspended from the load cell.

9.1.2 Non-Contact Extensometer—Verify calibration of the non-contact extensometer at least every month using the fixture shown in figure 6. Place the fixture in the test machine and apply a 20 to 50 N load on the fixture to hold the fixture firmly in the grips. Insert the gauge in the fixture and measure the short dimension of the gauge with the laser. Remove the gauge from the fixture and measure the long dimension. Check the length of the gauge as measured with a similar reference measurement made on the gauge during the last calibration. If the verification measurement and the reference measurement differ by more than 0.006 mm, either calibration or maintenance is required.

NOTE 5.—Measurements should be made at -12°C . Allow sufficient time for gauge to achieve thermal equilibrium.

9.1.3 Temperature Detector—Verify calibration of the temperature detector at least every six months by comparing the output of the RTD with a calibrated mercury-in-glass thermometer in accordance with ASTM E220. Place the thermometer in the environmentally controlled chamber. Hold the RTD in intimate contact with the bulb of the thermometer with a rubber O-ring or other suitable technique. When the thermometer and the temperature detection device have reached equilibrium, compare the temperature indicated on the detector's readout to the temperature indicated on the thermometer by reading through the observation port on the door of the chamber. If the temperature indicated by the thermal detector does not agree with the mercury-in-glass thermometer $\pm 0.1^{\circ}\text{C}$, further calibration or maintenance is required.

9.1.4 Verify the speed of the crosshead by using a dial gauge and a stopwatch. Mount a dial gauge on a fixed portion of the testing machine in a manner such that the stem of the dial gauge senses the movement of the crosshead. Be careful to ensure that the movement of the stem of the dial gauge is parallel to the movement of the crosshead and that the dial gauge is firmly attached to the fixed portion of the testing machine. Mounting the dial gauge on a magnetic base is a convenient method for attaching the dial gauge to the testing machine. Select the desired crosshead speed and start operating the machine at the desired speed. As the machine is running, start the stopwatch and simultaneously obtain an initial reading of the dial gauge. Approximately one minute later, obtain a second reading and simultaneously stop the stopwatch. Calculate the speed of the crosshead by dividing the difference between the initial and final dial gauge reading in millimeters by the stopwatch time in minutes.

10. PREPARATION OF SAMPLES AND TEST SPECIMENS

10.1 Preparing Test Samples—If unaged binder is to be tested, obtain test samples according to T40.

10.2 Anneal the asphalt binder for the test specimen by heating until it is sufficiently fluid to pour. Annealing prior to testing removes reversible molecular associations (steric hardening) that occur during normal storage at ambient temperature.

NOTE 6.—Minimum pouring temperatures that produce a consistency equivalent to that of SAE 10W30 motor oil (readily pours but not overly fluid) at room temperature are recommended. The specific temperature will depend on the grade of binder and its prior aging history, if any. Temperatures less than 135°C are desirable. Temperatures above 135°C may be required, however, for some modified asphalt binders or heavily aged binders.

10.3 Place the plastic end inserts into both ends of the mold. Place the molds and inserts into a 163°C oven for 30 minutes.

10.4 After heating, place the mold on a 6- to 7-mm-thick aluminum plate. Do not preheat the aluminum plate. Pour hot asphalt binder into the mold by starting at one end of the mold and moving across the mold in a single pass. Pour the specimen in a continuous stream to avoid entraining air bubbles or gaps. Complete the pouring operation as quickly as possible to avoid any excessive drop in the temperature of the asphalt binder. Stop pouring when the asphalt is slightly above the top surface of the mold.

10.5 After pouring the test specimen, allow the entire assembly to cool on the benchtop at ambient temperature for approximately one hour. Do not quench the specimen to achieve ambient temperature.

10.6 As soon as the specimen has cooled to room temperature, trim off the excess asphalt binder with a straight cutting edge (e.g., a flat cheese cutter or spatula) so that the asphalt binder is flush with the top of the mold. Use care during the trimming operation so that the asphalt binder is not pulled away from the mold and that the bond between the plastic inserts and the asphalt binder is not damaged. Trim the specimen in a consistent manner. Pull the cutting edge along the long axis of the sample flush with the surface of the mold to remove the excess asphalt binder. After trimming, remove all debris or extraneous asphalt binder from the holes or slots in the plastic insert.

NOTE 7.—Caution: Excessive downward pressure during trimming will distort the sample mold. If this occurs, discard the sample.

10.7 Immediately prior to demolding, place the mold containing the specimen in a freezer at $-5 \pm 5^\circ\text{C}$ until the specimen is sufficiently stiff to demold without distorting the sample. Some softer grades may require lower temperatures. Time in the freezer should not exceed 15 minutes. After demolding, place the sample on the specimen storage plate (see section 6.4). Measurement of specimen dimensions after demolding is not necessary since dimensional tolerances are closely controlled in the molding process.

11. PROCEDURE

11.1 Set the environmental chamber at the desired testing temperature and wait until it stabilizes to within $\pm 0.2^\circ\text{C}$ of the desired test temperature. When testing for compliance with MP1, use the test temperatures specified in table 1 of MP1.

11.2 Immediately after demolding, place the test specimens in the chamber on the plastic storage plate and condition the specimens at the test temperature for 1 hour \pm 10 minutes. Adhere carefully to time schedule to avoid testing variability that is caused by physical hardening.

11.3 After 1 hour \pm 10 minutes, mount the specimen on the pins using the environmental chamber hand access port, centering the back face of the insert on the mounting pin. Do not open the chamber door to handle or mount the specimen because that will produce excessive temperature fluctuations that will take time to stabilize and lead to variable thermal histories. Handle the specimens with latex surgical gloves to protect the operator's fingers and to minimize heating of the specimen. Handle the specimen by touching only the plastic inserts—do not touch the asphalt binder.

NOTE 8.—Air currents from the circulation fan may cause the inserts to move after being placed on the mounting pins. A silicone rubber or foam washer that remains flexible at the test temperature will help to hold the insert against the face of the grip. It is important that the insert be centered on the pin (flush against the face of the grip) in order for the load to be applied axially through the center of the test specimen. A suitable washer may be cut from silicone rubber or foam sheeting with a cork borer. The washer may be 5–10 mm thick with an outer diameter of approximately 10 mm. The inside diameter of the washer shall be sufficient to provide a friction fit on the 5-mm portion of the pin. The washer should slide easily on the pin providing only sufficient force to hold the insert in place during the test.

11.4 Select the desired deformation rate and load the specimen to failure. Select a deformation rate of 1.00 \pm 0.05 mm/min when testing for compliance with MP1. If a test specimen fails outside the gauge area of the specimen (from throat to throat), discard the test.

11.5 *Alternate loading procedure*—Apply a preload to the test specimen by mounting the specimen as previously described and applying an elongation sufficient to develop a 10 to 20 N load; this may reduce testing variability. As soon as the 10 to 20 N load is reached, stop the movement of the platen and allow the load to relax until it is no longer detectable. The time required to relax the load will depend on the stiffness of the test specimen. Once the load has relaxed, continue the test as described in section 11.4.

11.6 The strain at failure is easily identified as the strain at peak load (maximum stress) when the failure is by fracture (i.e., the specimen breaks into two pieces). However, if the specimen does not fracture but reaches a maximum stress and then flows without fracture, the strain at failure is recorded as the strain corresponding to the maximum stress. In some cases, the maximum stress may occur at strains greater than 10%. In this case, do not continue the test beyond 10% strain. Simply record the failure stress as “greater than 10%.” If the asphalt binder can be stretched to 10% without fracture, it meets the requirements of MP1 at the test temperature.

11.7 If the plastic specimen end inserts are to be reused, break them off the asphalt binder while the asphalt binder is still cold. Discard the asphalt binder and clean the end inserts by soaking them in solvent and wiping with a soft cloth. Do not use acetone, TCE, or toluene, since such solvents will dissolve the plastic inserts. After wiping the inserts, use a detergent solution to remove oil film residue left by the mineral spirit cleaner. Alternatively,

use a degreasing spray cleaner formulated for use on plastic. Clean the plastic inserts thoroughly. Grease on the asphalt bonding area can reduce bonding and cause bond failures.

12. CALCULATION

12.1 Compute the failure stress by dividing the failure load by the original area of the test specimen cross section as shown in equation 1:

$$\sigma_f = P_f/A \quad (1)$$

where

σ_f = failure stress, MPa

P_f = failure load, N

A = original area of cross section, mm²

NOTE 9.—For specimens used in this test, $A = 3.6 \text{ mm}^2$.

12.2 Compute the failure strain by dividing the elongation at failure by the original gauge length, as shown in equation 2:

$$\epsilon_f = \delta_f/L \quad (2)$$

where

ϵ_f = failure strain, mm/mm

δ_f = elongation at failure, mm

L = gauge length, mm

NOTE 10.—For specimens used in this test, the effective gauge length, L , is assumed to be 27.0 mm. This is an effective gauge length that represents the portion of the specimen that contributes to the majority of the strain. Strain values determined in this test may vary slightly from the actual strain at the point of fracture because of the assumed value for the gauge length.

13. REPORT

13.1 Report the following information:

13.1.1 the sample identification;

13.1.2 the date and time of test;

13.1.3 the test temperature, to the nearest 0.1°C;

13.1.4 the average rate of elongation, to the nearest 0.01 mm/min.;

13.1.5 the average failure strain, to the nearest 0.01 %;

NOTE 11.—Direct tension testing of multiple specimens may produce obvious outliers. Until a statistically valid procedure is developed for considering outliers, discard any strain at failure values that are obvious outliers.

13.1.6 the average failure stress, to the nearest 0.01 MPa;

13.1.7 the average peak load, to the nearest N; and

13.1.8 the type of fracture observed (fracture or no fracture).

14. PRECISION AND BIAS

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

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

15. KEY WORDS

Asphalt binder, direct tension, failure, failure strain, fracture, thermal cracking.

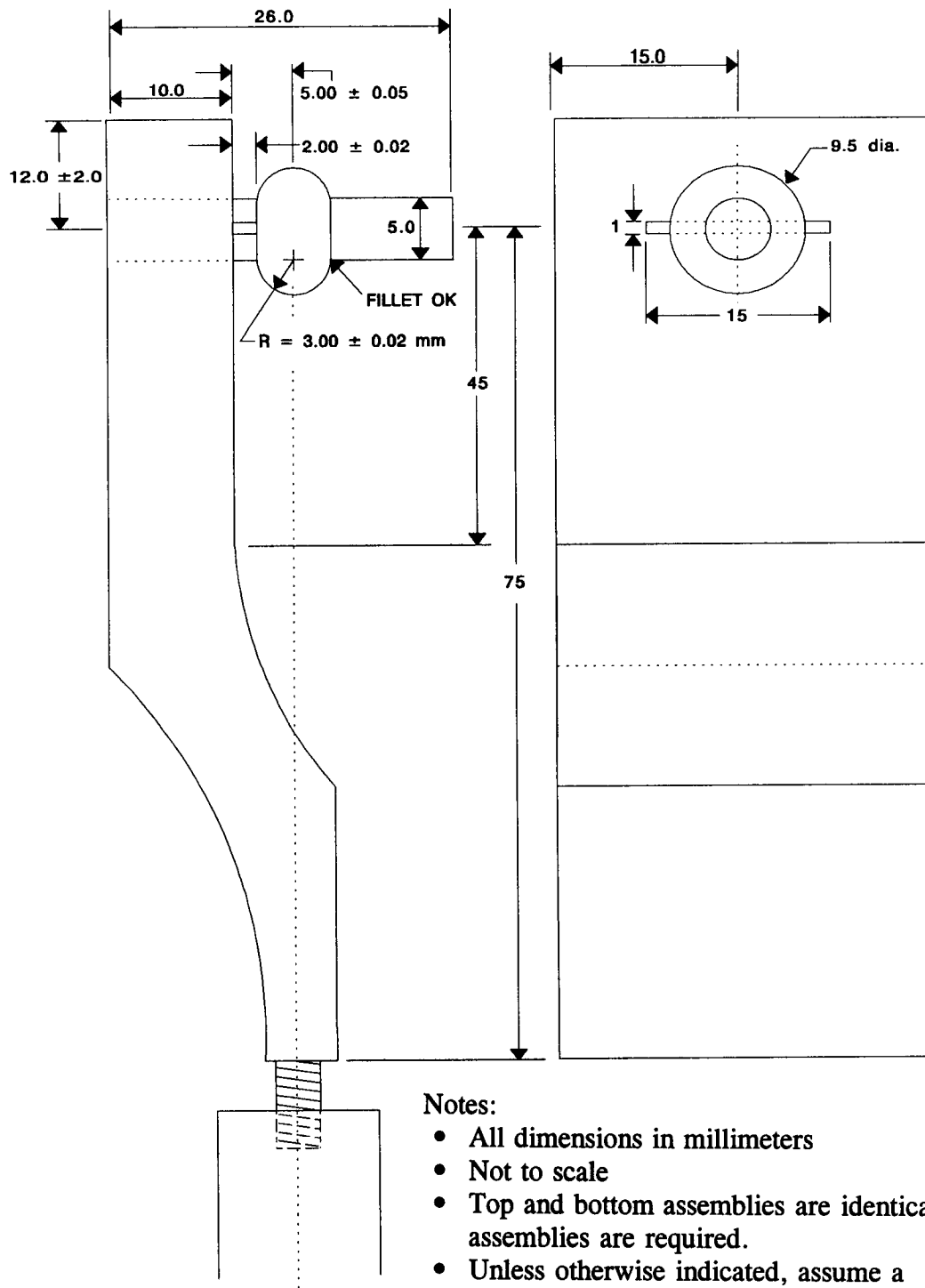


Figure 1. Top and Bottom Grip and Loading Pin Assembly

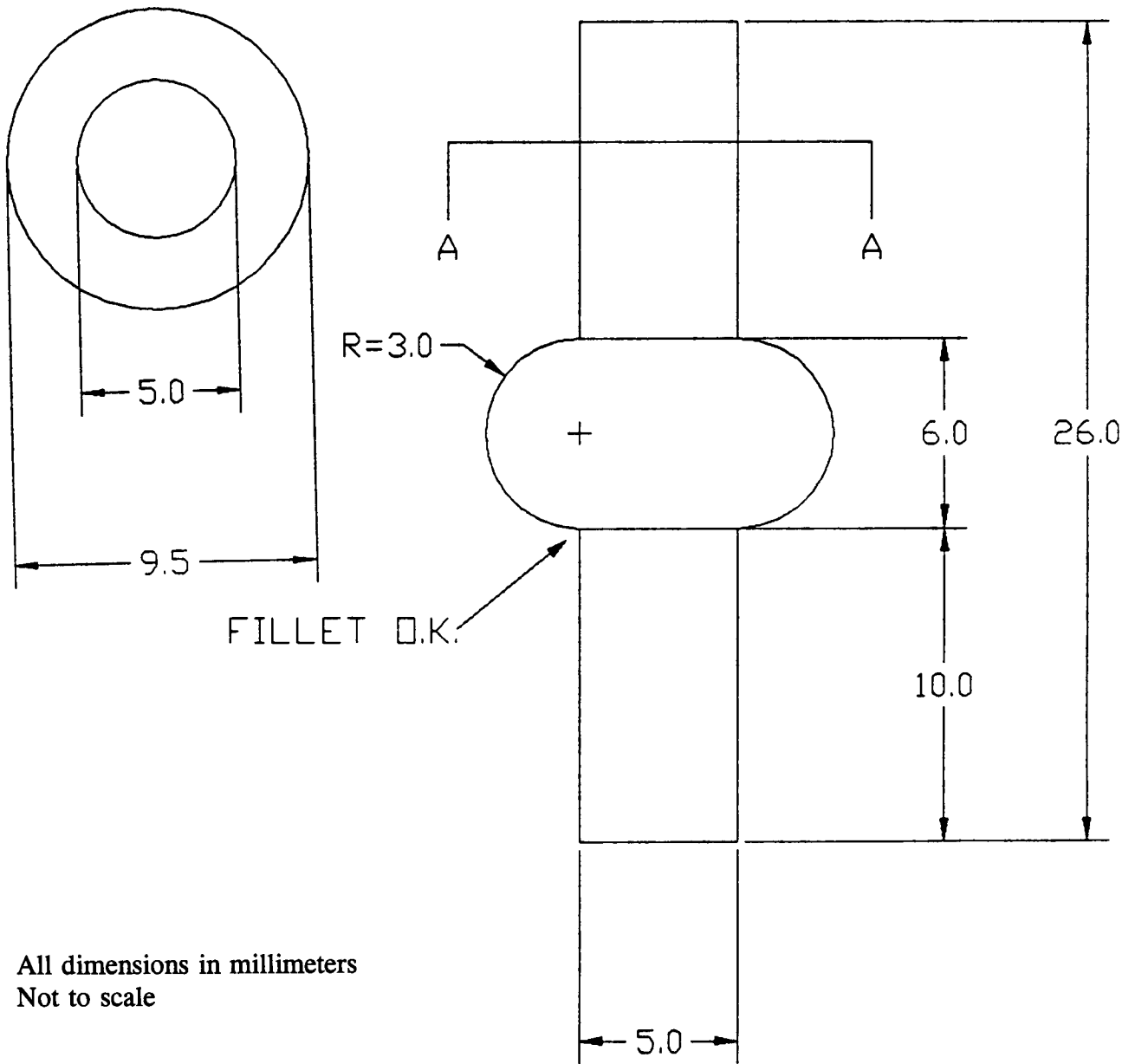
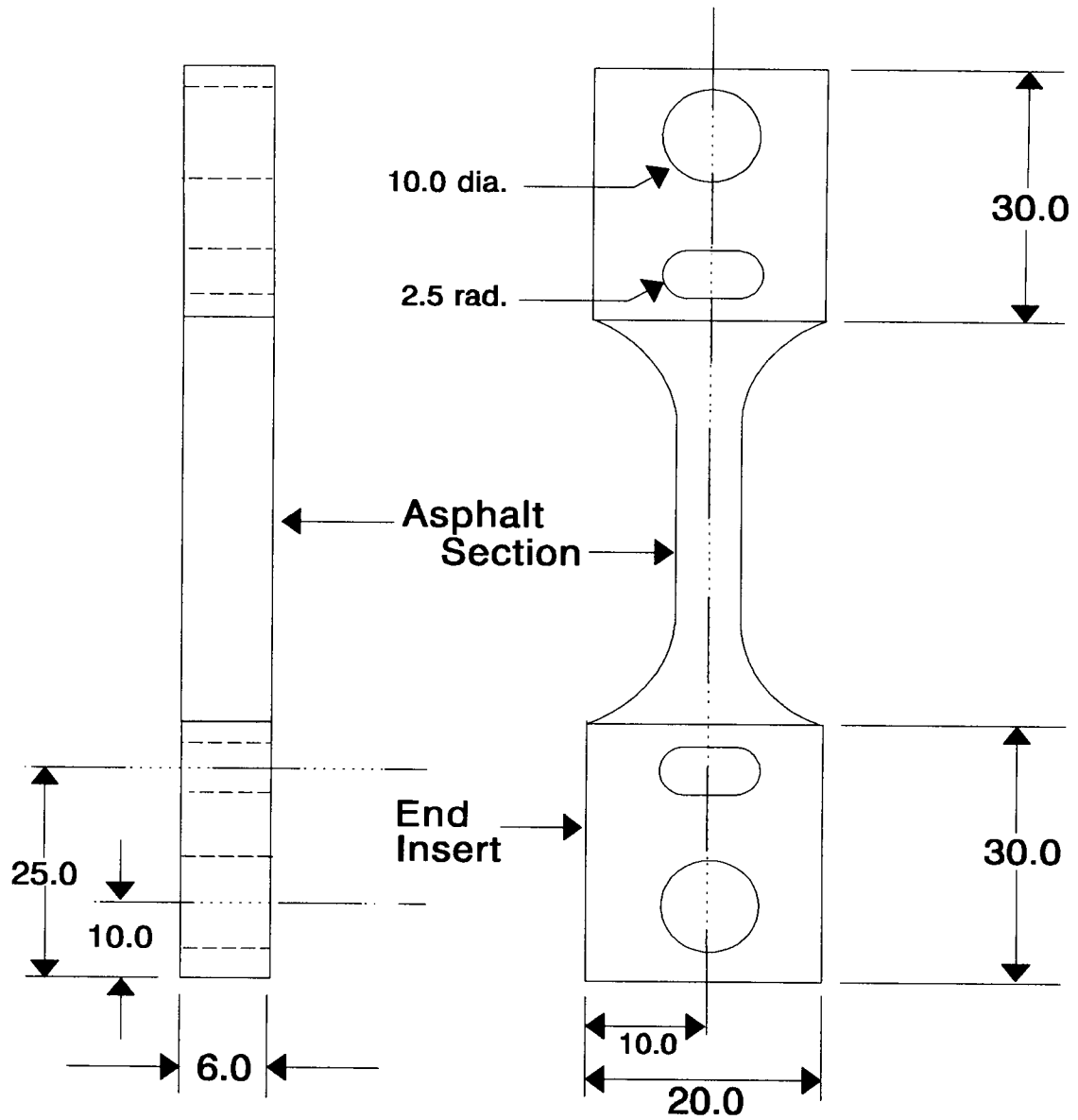


Figure 2. Loading Pins Used to Mount the Direct Tension Specimen



Notes:

- All dimensions in millimeters
- Not to scale
- Unless otherwise indicated, assume a tolerance of ± 0.05 mm

Figure 3. Plastic End Inserts

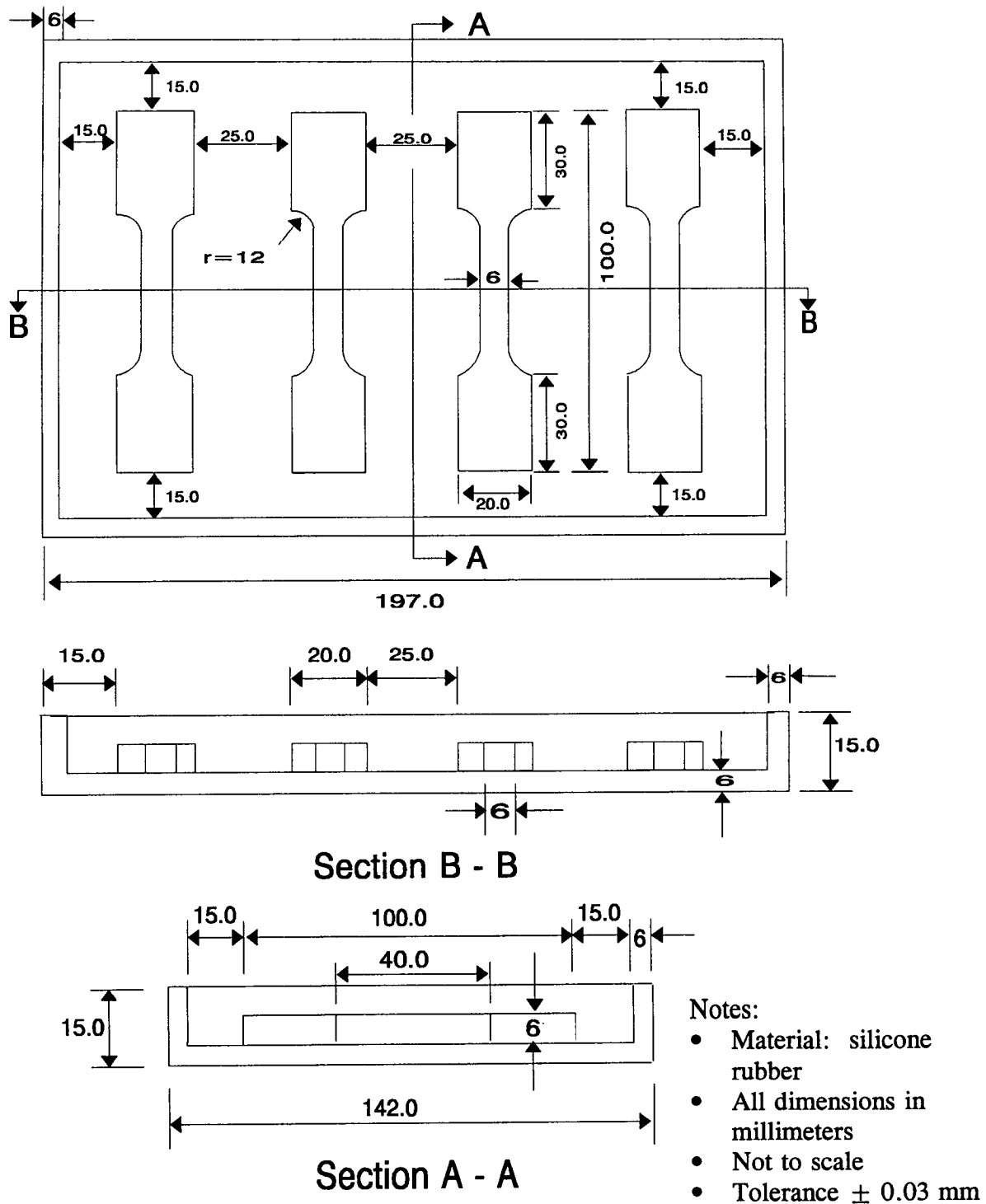
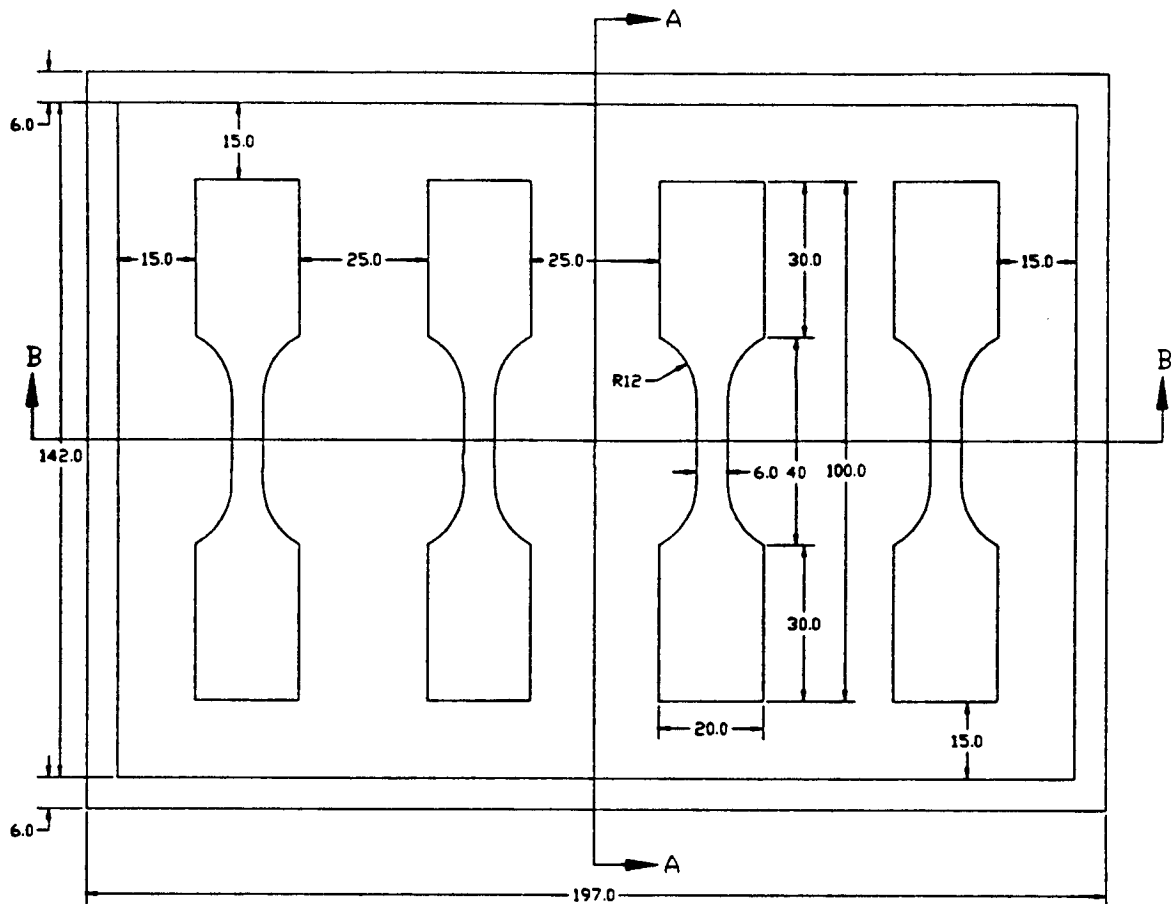
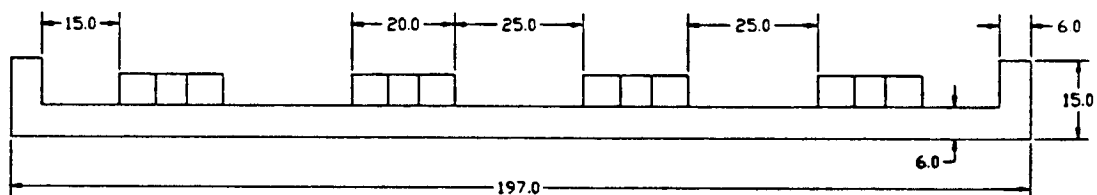


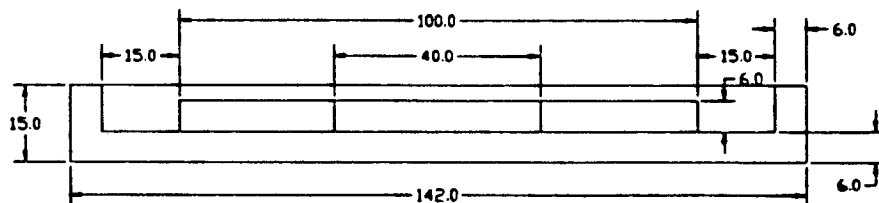
Figure 4. Direct Tension Specimen Mold



DIRECT TENSION TYPE I MOLD



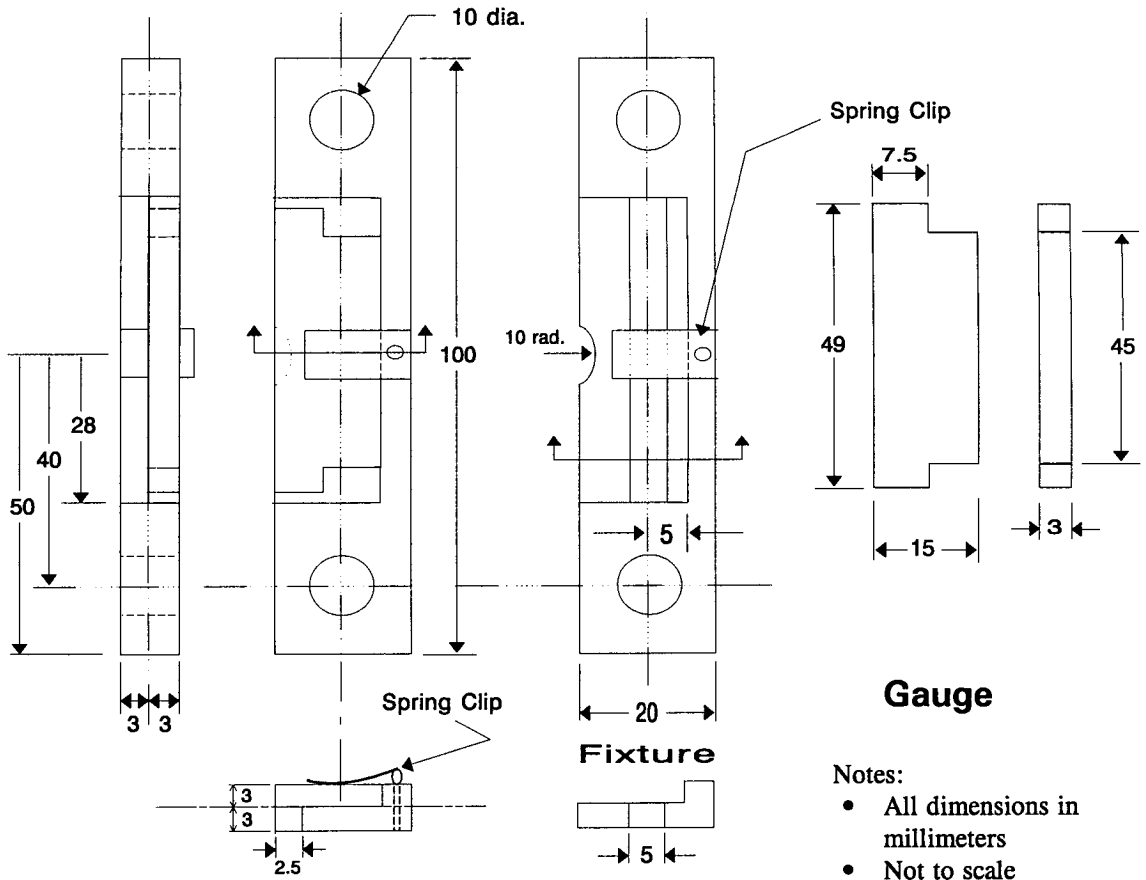
SECTION B-B



SECTION A-A

B1-CO No.: 1992-12
 Material: aluminum
 All dimensions in millimeters
 Tolerance: ± 0.03 mm

Figure 5. Specimen Mold Dimensions



- Notes:
- All dimensions in millimeters
 - Not to scale
 - Unless otherwise indicated, assume a tolerance of ± 0.05 mm

Figure 6. Extensometer Verification Device

Standard Practice for
**Accelerated Aging of Asphalt Binder
Using a Pressurized Aging Vessel**

AASHTO Designation: PP1¹

1. SCOPE

1.1 This practice covers the accelerated aging (oxidation) of asphalt binders by means of pressurized air and elevated temperature in a pressurized aging vessel (PAV). The test method is intended to simulate in-service oxidative aging of asphalt binders and is intended for use with residue from T240 (Rolling Thin Film Oven Test (RTFOT)) or T179 (Thin Film Oven Test (TFOT)).

NOTE 1.—T240 is the recommended procedure. Modified asphalt binders may phase separate or form skins during conditioning with T179 (TFOT); the results from subsequent testing of this residue in TP5, TP1, and TP3 may be distorted.

1.2 The aging of asphalt binders during service is affected by mixture-associated variables such as the volumetric proportions of the mix, the permeability of the mix, properties of the aggregates, and possibly other factors. This test is intended to provide an evaluation of the relative resistance of different asphalt binders to oxidative aging at selected temperatures and cannot account for mixture variables.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the 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.*

2. REFERENCE DOCUMENTS

2.1 AASHTO Standards:

M231 Standard Specification for Standard Masses and Balances Used in the Testing of Highway Materials

MP1 Proposed Standard Specification for Performance-Graded Asphalt Binder

¹ This standard is based on SHRP Product 1003.

- T179 Test Method for Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)
T240 Test Method for the Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin Film Oven Test)

2.2 *ASTM Standards:*

E220 Method for Calibration of Thermocouples by Comparison Techniques

2.3 *DIN Standards:*

43760

3. TERMINOLOGY

3.1 *Definitions*

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

3.1.2 in-service, *adj*—refers to aging of the asphalt binder that occurs in the pavement as a result of the combined effects of time, traffic and the environment.

4. SUMMARY OF TEST METHOD

4.1 Asphalt binder is first aged using T240 (RTFOT) or T179 (TFOT). A specified thickness of residue, from the RTFOT or TFOT, is then placed (or left) in standard TFOT (T179) stainless steel pans and aged at the specified aging temperature for 20 hours in a vessel pressurized with air to 2.10 MPa. Aging temperature is selected according to the grade of the asphalt binder.

5. SIGNIFICANCE AND USE

5.1 This method is designed to simulate the oxidative aging that occurs in asphalt binders during pavement service. Residue from this test may be used to estimate the physical or chemical properties of an asphalt binder after five to ten years of aging in the field.

5.2 Asphalt binders aged using PP1 are used to determine specification properties in accordance with MP1. The asphalt binder is aged with the RTFOT or TFOT prior to this conditioning step. Tank asphalt binders, as well as RTFOT or TFOT, and residue from this test are used to determine specification properties in accordance with MP1.

5.3 For asphalt binders of different grades or from different sources, there is no unique correlation between the aging time and temperature in this test and in-service pavement age and temperature. Therefore, for a given set of in-service climatic conditions, it is not possible to select a single PAV aging time and temperature that will predict the properties of all asphalt binders after a specific set of in-service exposure conditions.

5.4 The relative degree of hardening of different asphalt binders varies at different temperatures in the PAV. Therefore, two asphalt binders may age similarly at one temperature, but age differently at another temperature.

6. APPARATUS

6.1 The test system consists of a pressurized aging vessel (PAV), pressure controlling devices, temperature controlling devices, pressure and temperature measuring devices, and a temperature recording device (figure 1).

6.1.1 *Pressure Vessel*—A stainless steel pressure vessel designed to operate at 2.1 ± 0.1 MPa between 90 and 110°C with interior dimensions no greater than 200 mm in diameter and 215 mm in height (adequate to hold 10 TFOT pans and pan holder). The pressure vessel shall contain a pan holder capable of holding 10 TFOT stainless steel pans in a horizontal (level) position such that the asphalt binder film thickness in the bottom of the pans does not vary by more than 0.1 mm across any diameter of the pan. The holder shall be designed for easy insertion and removal from the vessel when the holder, pans, and asphalt binder are at the test temperature. A schematic that shows the vessel, pan holder and pans, and the specific dimensional requirements is shown in figure 2.

NOTE 2.—The vessel may be a separate unit to be placed in a forced draft oven for conditioning the asphalt binders or an integral part of the temperature control system (for example, by direct heating of the vessel or by surrounding the vessel with a permanently affixed heating unit, forced air oven, or liquid bath).

6.1.2 *Pressure Controlling Devices*

6.1.2.1 A pressure release valve that prevents pressure in the vessel from exceeding 2.2 MPa during the aging procedure

6.1.2.2 A pressure regulator capable of controlling the pressure within the vessel to ± 1 percent of the desired pressure, and with a capacity adequate to reduce the pressure from the source of compressed air so that the pressure within the loaded PAV is maintained at 2.1 ± 0.1 MPa during the test

6.1.2.3 A slow-release bleed valve that allows the pressure in the vessel at the completion of the conditioning procedure to be reduced at an approximately linear rate from 2.1 MPa to local atmospheric pressure within 9 ± 1 minutes

6.1.3 *Temperature Controlling Devices*—A temperature control device as described in section 6.1.3.1 or 6.1.3.2 for maintaining the temperature during the aging procedure at all

points within the pressure vessel at the aging temperature $\pm 0.5^{\circ}\text{C}$ and a digital proportional controller for maintaining the specified temperature control.

6.1.3.1 A forced-draft oven or fluid bath capable of (1) bringing the loaded unpressurized vessel to the desired conditioning temperature $\pm 0.5^{\circ}\text{C}$, as recorded by the resistance thermal detector (RTD) inside the vessel, within 2 hours, and (2) maintaining the temperature at all points within the pressure vessel at the aging temperature $\pm 0.5^{\circ}\text{C}$. The oven shall have sufficiently large interior dimensions to allow forced air to freely circulate within the oven and around the pressure vessel when the vessel is placed in the oven. The oven shall contain a stand or shelf which supports the loaded pressure vessel in a level position above the lower surface of the oven (i.e., maintains the film thickness in the aging pans within the specified tolerance).

6.1.3.2 A PAV with integral temperature control system that is capable of (1) bringing the loaded vessel to the desired conditioning temperature $\pm 0.5^{\circ}\text{C}$ within 2 hours, as recorded by the RTD inside the PAV, and (2) maintaining the temperature at all points within the pressure vessel at the aging temperature $\pm 0.5^{\circ}\text{C}$.

6.1.4 *Temperature and Pressure Measuring Devices*

6.1.4.1 A platinum RTD accurate to the nearest 0.1°C and meeting DIN Standard 43760 (Class A), or equal, for measuring the temperature inside the PAV. The RTD shall be calibrated as an integral unit with its respective meter or electronic circuitry.

NOTE 3.—The RTD or thermistor and its meter may be calibrated by the manufacturer or a commercial vendor. Verification can be obtained by comparing the output from the RTD with a NIST-traceable ASTM 94C mercury-in-glass thermometer in accordance with ASTM E220. A stirred fluid bath is suitable for calibrating the thermal detector. Select a partial immersion mercury-in-glass thermometer with an appropriate range and place the thermal detector and the thermometer in the stirred water bath. Fasten the detector to the glass thermometer with a rubber band or rubber O-ring. Allow the bath, detector, and thermometer to come to thermal equilibrium and record the temperature of the glass thermometer and the readout from the thermal detector. The temperature in the bath shall not change by more than 0.1°C per minute during the calibration process.

6.1.4.2 *Temperature Recording Device*—A strip chart recorder or other data acquisition system capable of recording temperature throughout the test to 0.1°C . As an alternative, an electronic device capable of reporting maximum and minimum temperatures (accurate to $\pm 0.1^{\circ}\text{C}$) may be used. In this case if the test temperature varies by more than $\pm 0.5^{\circ}\text{C}$ of the conditioning temperature during the 20-hour period, the test shall be declared invalid.

6.1.4.3 A pressure gauge capable of measuring the pressure in the PAV to $\pm 1\%$ of the desired pressure during the test.

6.2 *Stainless Steel Pans*—Ten standard stainless steel TFOT pans meeting the requirements of T179.

6.3 *Balance*—A balance conforming to the requirements of M231, Class G2.

7. MATERIALS—Commercial bottled air or equivalent.

8. HAZARDS—Use standard laboratory safety procedures in handling the hot asphalt binder when preparing test specimens and removing the residue from the PAV. Use special precaution when lifting the vessel.

9. CALIBRATION AND STANDARDIZATION

9.1 Temperature Detector—Verify the calibration of the RTD to 0.1°C at least every 6 months using a calibrated thermometer.

9.2 Pressure gauge—Calibrate the pressure gauge to an accuracy of 1% of the desired pressure at least every 6 months.

NOTE 4.—The pressure gauge is usually calibrated by the manufacturer or a commercial calibration service. Verification of the continued stability of the pressure gauge within the specified requirements should be done periodically by checking against another certified pressure measurement device.

10. PROCEDURE

10.1 Condition the asphalt binder and determine the mass change during conditioning in accordance with T240 (RTFOT) or T179 (TFOT).

10.2 Combine the hot residue from the RTFOT into a single container, stir to blend, then transfer into (or leave in) TFOT pans for PAV conditioning or allow the hot residue in the container to cool to room temperature and cover and store at room temperature for PAV conditioning at a later date. If conditioned asphalt binder is allowed to cool to room temperature, heat it until it is sufficiently fluid to pour and stir it before pouring it into the TFOT pans. To remove asphalt binder from RTFOT bottles, scraping of the bottles is allowed, to assure sufficient material is obtained for later testing. Scraping is not currently allowed in T240. If scraping is used, report with the test results.

10.3 Place the pan holder inside the PAV. If an oven is used, place the pressure vessel inside the oven. If an integrated temperature control pressurized aging vessel is used, turn on the heater. Select an aging temperature and preheat the vessel to the aging temperature selected.

NOTE 5.—If conditioning asphalt binders for conformance to MP1, select the appropriate aging temperature from table 1 of MP1.

NOTE 6.—Preheating the vessel 10 to 15°C above the conditioning temperature can be used to reduce the drop in PAV temperature during the loading process and minimize the time required to stabilize the system, after loading, to attain the required temperature.

NOTE 7.—Aging temperature in the PAV is selected to account for different climatic regions. Temperatures in excess of approximately 115°C can change the chemistry of asphalt binders aged in accelerated tests and should be avoided.

10.4 Place the TFOT pan on a balance and add 50 ± 0.5 gram mass of asphalt binder to the pan. This will yield approximately a 3.2-mm-thick film of asphalt binder.

NOTE 8.—The mass change is not measured as part of this procedure. Mass change is not meaningful because the asphalt binder absorbs air as a result of pressurization. Any gain in mass as a result of oxidation is masked by air absorbed by the asphalt binder as a result of the pressurization.

10.5 If the vessel is preheated to other than the desired aging temperature, reset the temperature control on the heating device to the aging temperature.

10.6 Place the filled pans in the pan holder. Pans containing asphalt binders from different sources and grades may be placed in the pressure vessel during a single test. Place the panholder with filled pans inside the vessel and close the vessel.

10.7 If an oven is used, place the loaded and closed vessel in the oven.

10.8 Connect the temperature transducer line and the air pressure supply line to the loaded vessel's external connections.

10.9 Perform the operations described in sections 10.5 to 10.8 as quickly as possible to avoid cooling of the vessel and pan holder.

10.10 Wait until the temperature inside the pressure vessel is within 2°C of the aging temperature. Apply an air pressure of 2.1 ± 0.1 MPa and then start timing the test. If the temperature inside the pressure vessel is not attained within two hours of loading, discontinue the test.

NOTE 9.—Pressures in excess of 2.1 MPa do not substantially increase the rate of aging. Therefore, higher pressures are not warranted.

NOTE 10.—Once pressurized, the temperature inside the pressure vessel will equilibrate rapidly. The time under pressure, not to include any preheating time at ambient pressure, is the aging time. Relatively little aging occurs at ambient pressure during the time that the vessel is being reheated to the test temperature, given that asphalt binder residue under test has been exposed to 163°C in the RTFOT.

10.11 Maintain the temperature and air pressure inside the pressure vessel for 20 hours \pm 10 minutes.

10.12 At the end of the 20-hour test period, slowly begin reducing the internal pressure of the PAV, using the air pressure bleed valve. Adjust the bleed valve to an opening that requires 9 ± 1 minutes to equalize the internal and external pressures on the PAV, thus avoiding excessive bubbling and foaming of the asphalt binder. During this process it may be necessary to adjust the setting of the needle valve as the pressure drops in order to maintain an approximate linear rate of pressure decrease. Do not include the pressure release and equalization time as part of the 20-hour aging period.

10.13 If the temperature indicated by the temperature recording device falls above or below the target aging temperature $\pm 0.5^{\circ}\text{C}$ for more than 10 minutes during the 20-hour aging period, declare the test invalid and discard the material.

10.14 Remove the pan holder and pans from the PAV, and place in an oven set at 163°C . Heat until sufficiently fluid to pour. Stir gently to assist in the removal of air bubbles

NOTE 11.—Minimum pouring temperatures that produce a consistency equivalent to that of SAE 10W30 motor oil (readily pours but not overly fluid) at room temperature are recommended. Heating unaged asphalt binders to temperatures above 135°C should be avoided. Some modified asphalts or heavily aged binders, however, may require pouring temperatures above 135°C . PAV residue may be heated in the TFOT pans to 163°C and stirred to remove air bubbles. In all cases heating time should be minimized. These precautions will help avoid oxidative hardening and volatile loss that will harden the sample. During the heating process the sample should be covered and stirred occasionally to ensure homogeneity.

10.15 Remove pans from oven and pour the hot residue from the pans into a single container. If tests to determine the properties of the PAV residue are not performed immediately, cover the container and store it at room temperature for future testing.

11. REPORT

11.1 Report the following information:

11.1.1 sample identification;

11.1.2 aging test temperature, to the nearest 0.5°C ;

11.1.3 maximum and minimum aging temperature recorded, to the nearest 0.1°C ;

11.1.4 total time during aging that temperature was outside the specified range, to the nearest minute;

11.1.5 total aging time, in hours and minutes.

11.1.6 Report the heating temperature and heating time if temperatures greater than 163°C are required at any time during the handling of the material.

12. PRECISION AND BIAS

12.1 Precision—The research required to develop precision estimates for tests performed on PAV residue has not been conducted.

12.2 Bias—The research required to establish the bias of tests performed on PAV residue has not been conducted.

13. KEY WORDS

Accelerated aging, elevated temperature, in-service aging, PAV, pressure aging, pressure aging vessel.

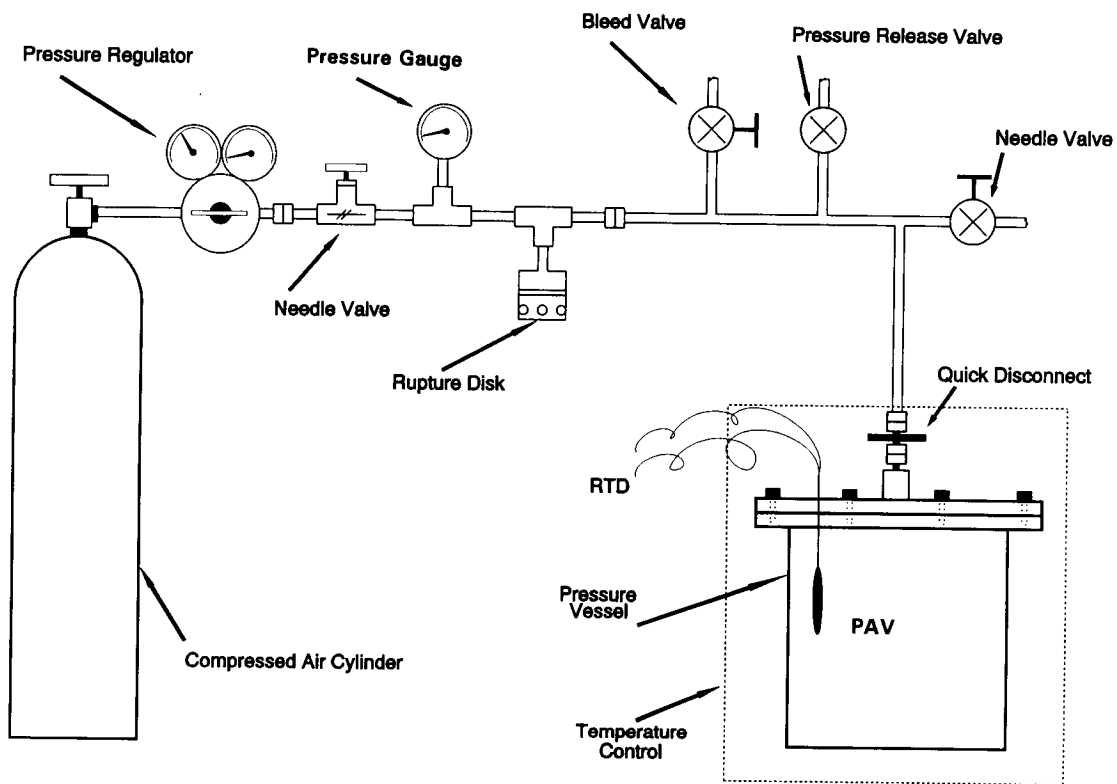
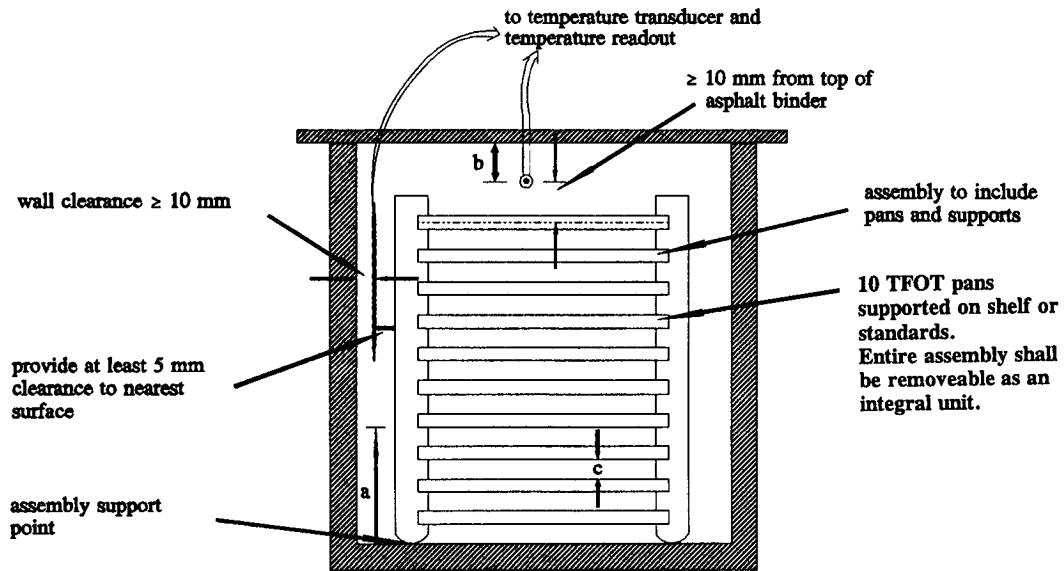


Figure 1. Schematic of Typical PAV Test System



Note 1: Distance a controls the levelness of the pans. The assembly shall be supported at three or more support points. The distance a , measured from each assembly support point to the bottom of the pan (top of shelf or pan support point), shall be controlled to ± 0.05 mm. Provision shall be made to ensure that the bottom of the vessel is leveled so that the thickness of the binder in the pans varies by no more than ± 0.05 mm across the diameter of any pan.

Note 2: Distance b shall be such that any active portion of the temperature transducer is ≥ 10 mm from the top surface of the vessel.

Note 3: Distance c shall be ≥ 12 mm.

Figure 2. Location of Pans and Resistance Thermal Detector within Representative PAV

Standard Practice for
**Extraction and Recovery of Asphalt Cement
for Rheological Testing**

SHRP Designation: B-006¹

1. SCOPE

1.1 This test method describes the extraction and recovery of asphalt from bituminous concrete samples. It is to be used to determine the physical or chemical properties of an asphalt binder. It is *not* recommended for use in determining aggregate gradations.

1.2 *This procedure may involve hazardous materials, operations and equipment. This procedure does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3 The values stated in SI units are to be regarded as the standard.

2. APPLICABLE DOCUMENTS

2.1 AASHTO Documents:

T44 Solubility of Bituminous Materials in Organic Solvents

2.2 ASTM Standards:

D979 Standard Practice for Sampling Bituminous Paving Mixtures

D1856 Recovery of Asphalt from Solution by Abson Method

D2172 Test Methods for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures

2.3 Other Documents:

TRB papers 890445, 910350, 910352

¹This standard is based on SHRP Product 1004.

3. SUMMARY OF METHOD

3.1 The paving mixture is repeatedly washed and filtered with solvents in the extraction/filtration apparatus shown in figure 1. Each filtrate is distilled under vacuum in a rotary evaporator with the asphalt remaining in the flask. After recovery of the final filtrate, the solution is concentrated and centrifuged to remove aggregate fines. The decanted solution is distilled under vacuum to remove the extraction solvents. Nitrogen gas is introduced during the final phase of distillation to drive off any remaining traces of solvents. The recovered asphalt (distillation residue) may then be subjected to further testing as required.

4. SIGNIFICANCE AND USE

4.1 The method can be used both for obtaining asphalt for further analyses and for calculation of asphalt content in pavement samples. **Warning: The aggregate should not be used for sieve analysis because it undergoes prolonged grinding in the extraction device.**

5. APPARATUS AND MATERIALS

5.1 Oven, capable of maintaining the temperature at $110^{\circ}\text{C} \pm 5^{\circ}\text{C}$

5.2 *Utilities*—Vacuum source, nitrogen gas source, and cooling water source

5.3 Balance, having an accuracy of at least .01% of the sample mass

5.4 Extraction vessel (figures 2, 3, 4), a piece of aluminum pipe with removable upstream and downstream plates. The upstream plate (figure 5) has a mixing motor mount and a $\frac{3}{4}$ in addition port. The downstream plate (figure 6) is equipped with a $\frac{1}{4}$ in NDT quick connect fitting. Four 4×1 in baffles (figure 7) are mounted in the extraction vessel, followed by a 10-mesh screen, a glass wool plug, an 8-micron filter, and a 10-mesh backup screen.

5.5 A fine filter (figure 8), consisting of a top (figure 9) and bottom (figure 10), each fabricated from $\frac{1}{2}$ in aluminum plate, which hold a 1-micron woven polypropylene filter and a 10-mesh stainless steel backup screen.

5.6 Flask, suction, 500 mL

5.7 Round bottom flasks, 1000 mL and cork stands

5.8 Gas flowmeter, capable of indicating a gas flow up to 1000 mL/min

5.9 Buchi Rotavapor RE-111A (or equivalent) with transfer and purge tubes

5.9.1 Transfer tube, $\frac{1}{4}$ in polypropylene tubing 17 in long

5.9.2 Purge tube, ¼ in polypropylene tubing 23 in long

5.10 Hot oil bath, capable of heating oil to 177°C

5.11 Copper tubing (note 1), amount adequate to connect apparatus as shown in figure 1

NOTE 1.—The quantity of copper tubing needed will be dependent upon the space utilized in setting up the apparatus.

5.12 Single Speed Mixing Motor, 150 W, 30 rpm

5.13 Polypropylene Tubing (note 2), ¼ in for transferring solution throughout the procedure

NOTE 2.—To avoid contamination of the sample due to solvent degradation of the tubing, do not substitute Nalgene or rubber tubing for the polypropylene tubing specified.

5.14 *Woven polypropylene filter cloths*—Coarse filter made from 2 × 2 twill weave, monofilament, 8 micron or 5 CFM rating, and fine filter made from oxford weave multifilament, 1–2 micron or .5 CFM rating

5.15 Centrifuge, batch unit capable of exerting a minimum centrifugal force of 770 times gravity

5.16 Wide-mouth centrifuge bottles, 250 mL

5.17 Thermometer, having a range of -2 to 300°C

5.18 Glass wool, borosilicate

5.19 Six 3-mm glass boiling beads

6. REAGENTS

6.1 Toluene, reagent grade

6.2 Ethanol, absolute

6.3 Nitrogen gas, at least 99.95% pure, in a pressurized tank, with pressure-reducing valve.

6.4 Argon gas, at least 99.99% pure, in a pressurized tank.

7. PRECAUTIONS

7.1 Solvents should be used only under a hood or with an effective surface exhaust system in a well-ventilated area.

8. SAMPLING AND SAMPLE PREPARATION

8.1 Obtain samples in accordance with ASTM D 979.

8.2 If the mixture is not sufficiently soft to separate with a spatula or trowel, place it in a large, flat pan and warm to $110 \pm 5^\circ\text{C}$ only until it can be handled or mixed. Split or quarter the material until 1000 g or the mass of material (note 3) required for the test is obtained.

NOTE 3.—This procedure works best for quantities of asphalt less than 60 g. Therefore, if the asphalt content of the mix is known, then the mass of sample required is that which yields about 50 to 60 g of asphalt.

9. PROCEDURE

9.1 *Equipment Setup*

9.1.1 Prepare the extraction vessel by first installing the baffle pieces. Place the metal screen downstream of the baffle. Cut several pieces of glass wool and pack them in the space between the screen and the downstream end of the extraction vessel. Place gaskets, filter and aluminum end piece on extraction vessel, as shown in figure 3. Tightly and evenly fasten the end piece with wing nuts.

9.1.2 Weigh an amount of pavement sample that will yield approximately 50 to 60 g of extracted asphalt. Place sample in extraction vessel. Put gasket and upstream end piece on the vessel and tightly and evenly fasten the wing nuts, creating a secure seal.

9.1.3 Prepare the rotary evaporator. Turn on the cooling water. Turn on the oil bath and set the temperature to $100 \pm 2.5^\circ\text{C}$. Place six 3-mm glass boiling beads in a 1000-mL round bottom flask. Attach the recovery flask to the rotary evaporator and immerse $1\frac{1}{2}$ in of the flask into the oil bath. Set the recovery flask at a 15° angle from the horizontal to the bath. Set the flask rotation at 40 rpm. Clamp the empty condensate flask onto the condenser. Attach transfer tube inside neck of rotary evaporator. Apply vacuum of 700 ± 5 -mm Hg to the rotary evaporator. Attach the filtrate transfer line to the external fitting on the neck of the rotary evaporator.

9.2 *Extraction and Filtration*

9.2.1 Charge 600 mL of toluene through the $\frac{3}{4}$ -in port on the upstream end of the extractor. To purge the interior of the extraction vessel, inject nitrogen through the upstream

port at 1000 mL/min for 1 minute. Close the port with a threaded plug. Attach the extractor to the motor. Start the motor and mix for 5 ± 1 minutes at 30 rpm. Shut off the motor.

9.2.2 Remove the extractor, place it on a stand and attach the quick connect fitting to the filtrate receiving flask. Make sure the filtrate transfer line is closed. Remove the upstream port and blanket the extractor with 400 mL/min of nitrogen while filtering. Apply 700 ± 5 mm Hg vacuum to the filtrate receiving flask. Filter until the filtrate flow rate is below 10 mL/min. Shut off the vacuum.

9.2.2.1 If using the fine filter, switch vacuum to a second filtrate receiving flask and apply 700 ± 5 mm Hg vacuum. Filter until filtrate flow rate is below 10 mL/min. Shut off vacuum.

9.2.3 Disconnect the extractor from the quick connect fitting. Repeat the extraction procedure. For the second and third washes, use 400 ± 10 mL of toluene. For subsequent washes (note 4), use 400 ± 10 mL of toluene with 15 volume % ethanol. In addition, mix the second wash for ten minutes and all subsequent washes for 30 minutes or more.

NOTE 4.—It is suggested that after the third wash, the condensate from the primary distillation step be used for extraction solvent. Recycling solvent in this manner allows the entire procedure to use approximately 1500 mL toluene.

9.3 Primary Distillation

9.3.1 After filtration, open the filtrate transfer valve and allow the solution to flow from the filtrate receiving flask to the recovery flask. Continue the transfer until the filtrate receiving flask is empty or the recovery flask is about $\frac{2}{3}$ full.

9.3.2 Close the filtrate transfer valve line and distill solvent at $100 \pm 2.5^\circ\text{C}$ (oil bath temperature) and 700 ± 5 mm Hg vacuum.

9.3.3 If the condensate flask is over half full after the primary distillation step, empty the flask. Save this solvent for use in subsequent washes (note 4). After primary distillation of each filtrate, maintain vacuum, temperature, flask rotation, and cooling water. Repeat the primary distillation after each filtration (note 5).

NOTE 5.—It is important to concentrate the asphalt in the recovery flask after each wash at a low temperature. This minimizes the time and temperature spent in dilute solution and therefore minimizes asphalt hardening in solvent.

9.3.4 After primary distillation of the first three filtrates, remove the recovery flask (which should contain only small amounts of solvent) and set it aside. Replace it with another 1000 mL roundbottom flask containing six 3-mm glass boiling beads.

9.3.5 Carry out the remaining primary distillations using the new recovery flask.

9.4 *Final Extraction and Recovery*

9.4.1 If the filtrate flowing through the transfer tube is a light brown color after a 30-minute wash, proceed to the final recovery step.

9.4.2 Pour contents of the current recovery flask into the original recovery flask. Attach the original recovery flask to the Rotavapor.

9.4.3 Distill the contents of the recovery flask until it is about 1/3 full.

9.4.4 Disconnect the recovery flask and pour the contents into the centrifuge bottles. Fill the bottles so that their weights are equal. Wash any residue from the recovery flask into the centrifuge bottles. Raise the oil bath temperature to $177 \pm 2.5^{\circ}\text{C}$. Centrifuge the bottles at 3600 rpm for 25 minutes.

9.4.5 Decant the asphalt-solvent solution into the recovery flask and add six 3-mm glass boiling beads. Attach the flask to the rotary evaporator. Disconnect the transfer tube from the rotary evaporator and replace it with the gas purge tube. Disconnect the filtrate transfer line from the external rotary evaporator neck fitting and replace it with the nitrogen gas line. Apply 700 mm Hg vacuum. Lower the flask 1½ in into the oil bath.

9.4.6 Distill the solvent.

9.4.7 When the condensation rate falls below 1 drop every 30 seconds, introduce nitrogen gas at 1000 mL/min. Maintain the gas flow, vacuum and bath temperature for 30 ± 1 minutes to reduce the residual solvent concentration to near zero. **Complete removal of residual solvent is very important for obtaining accurate asphalt properties.**

9.4.8 Shut down the oil bath, flask rotation, vacuum, gas flow, and cooling water. Remove the evaporating flask and pour the asphalt into a sample tin.

NOTE 6.—A high temperature annealing step is recommended as a finishing step. This enables the asphalt molecules to "realign" themselves and promotes the attainment of an equilibrium state. Flood the asphalt container with argon and cover. Heat container to 163°C and maintain temperature for 2 hours. Place container in a paint shaker for 5 minutes, and then allow to cool to room temperature.

10. PRECISION AND BIAS

10.1 Repeatability and reproducibility tests have not been established in accordance with standard AASHTO practice.

Extractor and Coarse Filter

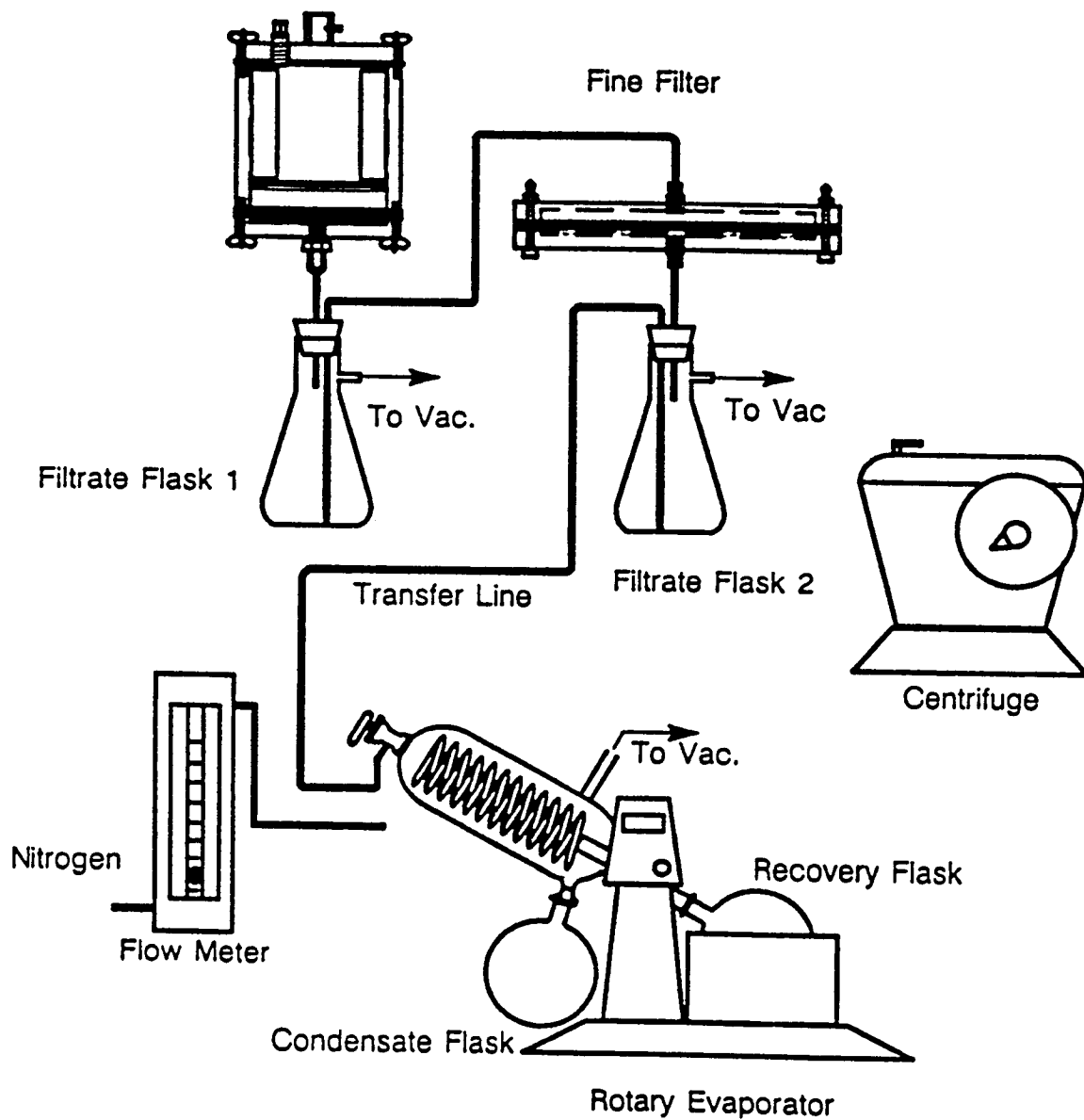


Figure 1. Asphalt Extraction and Recovery Apparatus

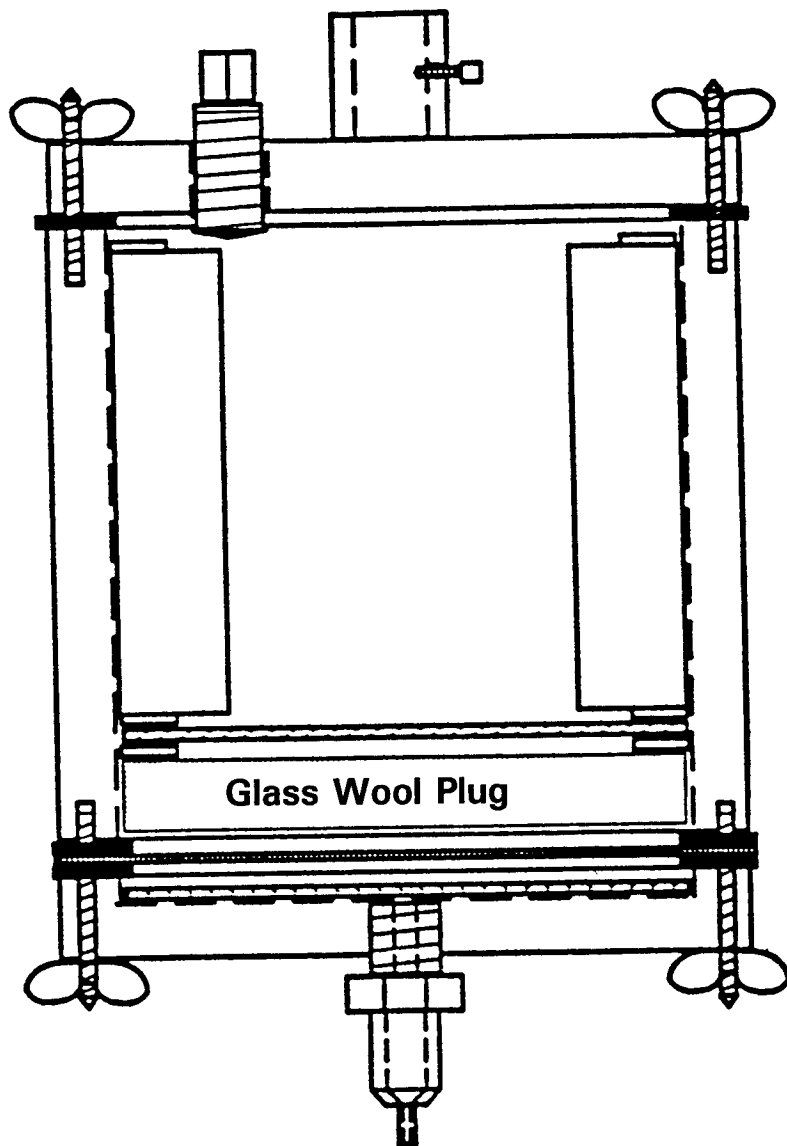


Figure 2. Extraction and Filtration Vessel

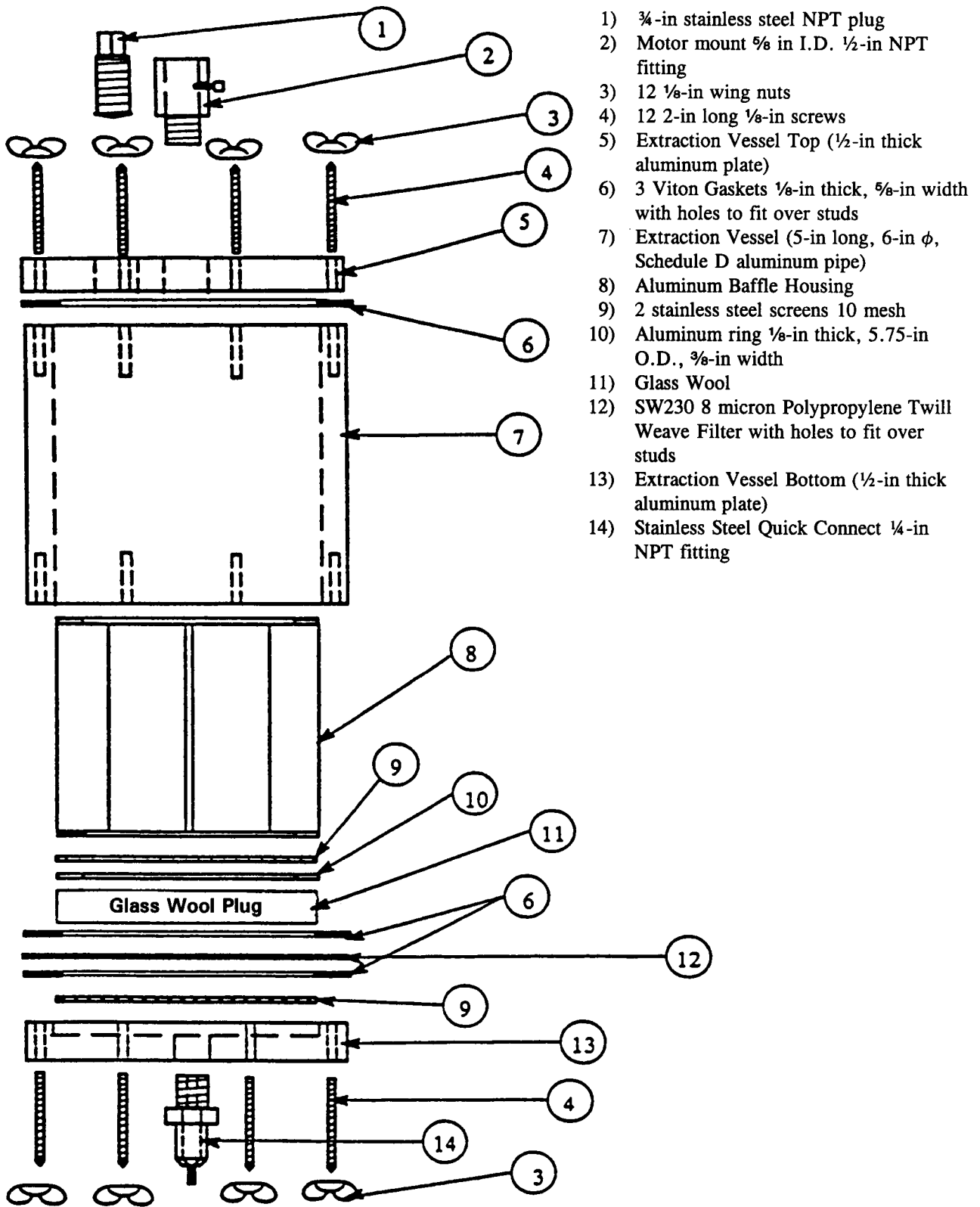


Figure 3. Exploded Diagram of Extraction and Filtration Vessel

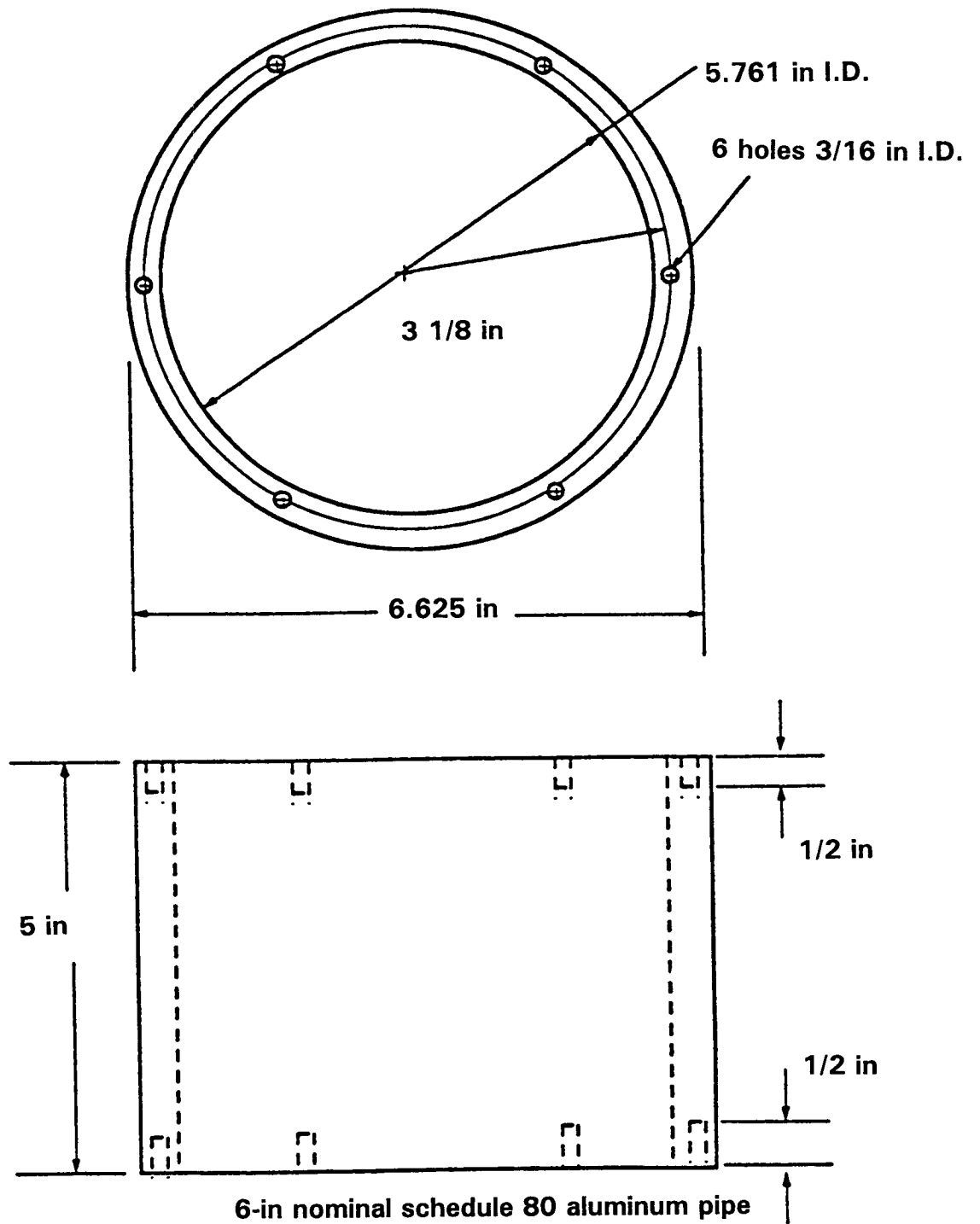


Figure 4. Dimensions for the Extraction Vessel

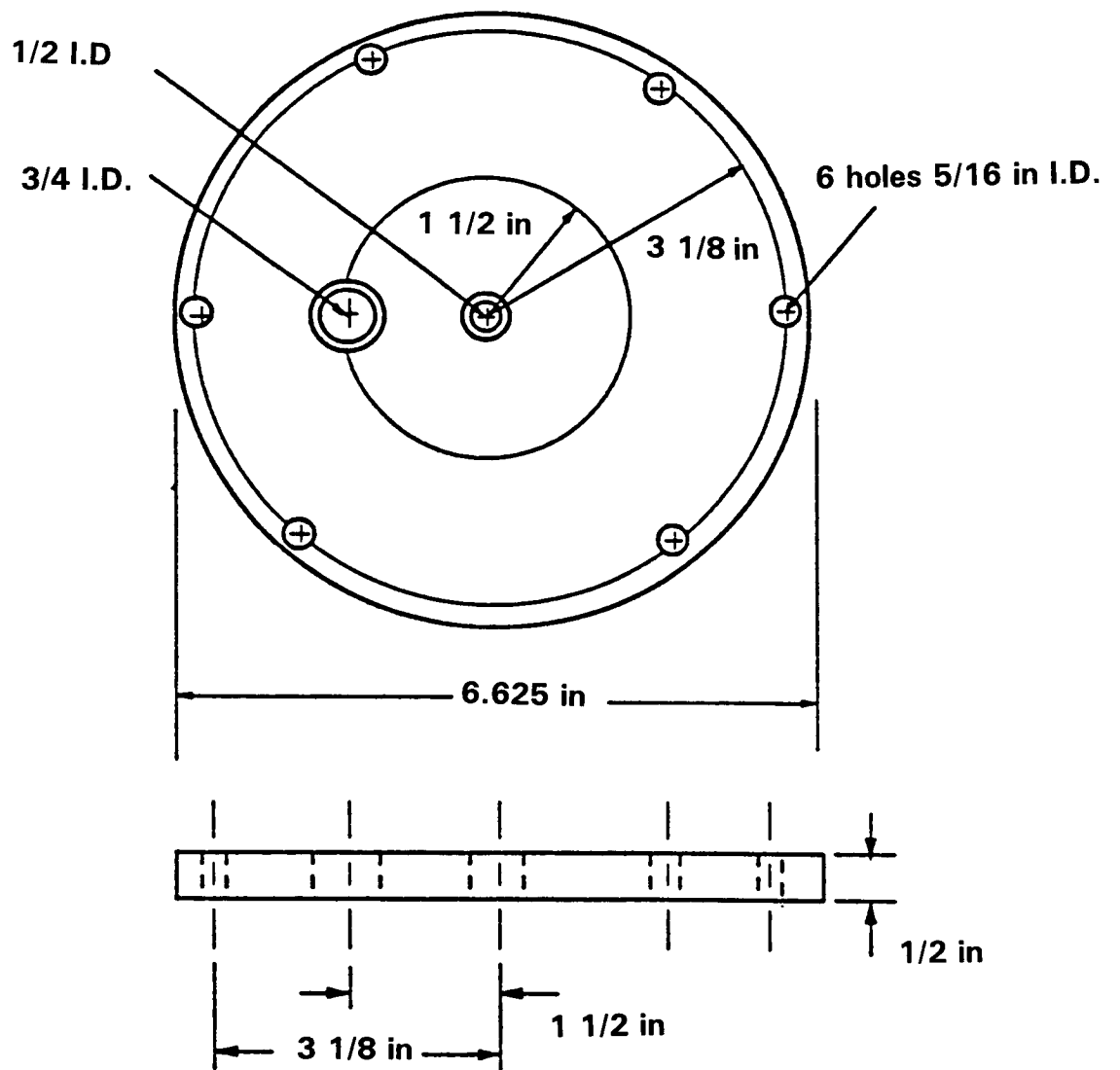


Figure 5. Extraction Vessel Top

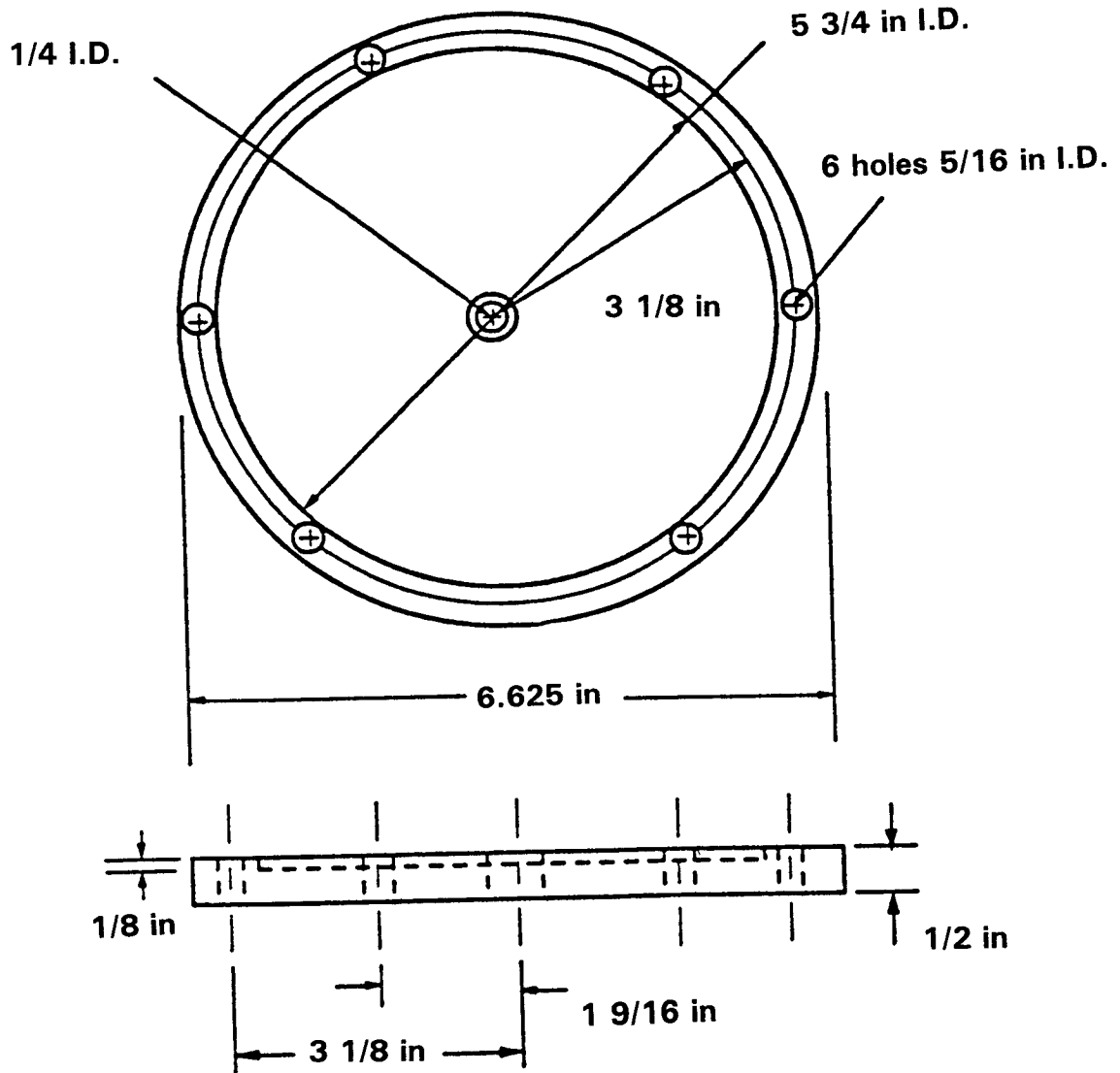
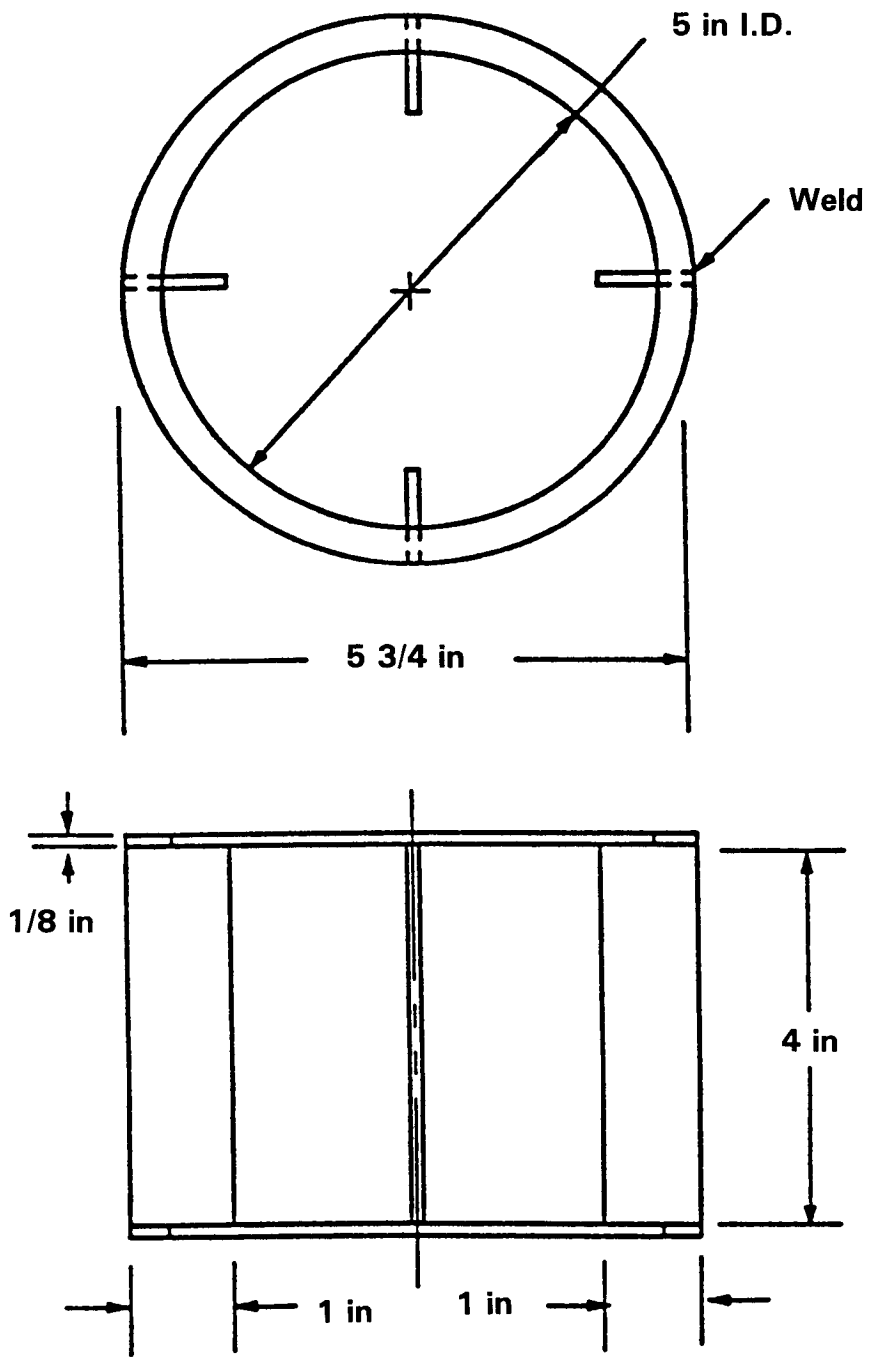


Figure 6. Extraction Vessel Bottom



- 4 aluminum plates 1/8 in thick
- 2 Aluminum rings 5 3/4 in O.D., 5 in I.D.

Figure 7. Baffle Housing

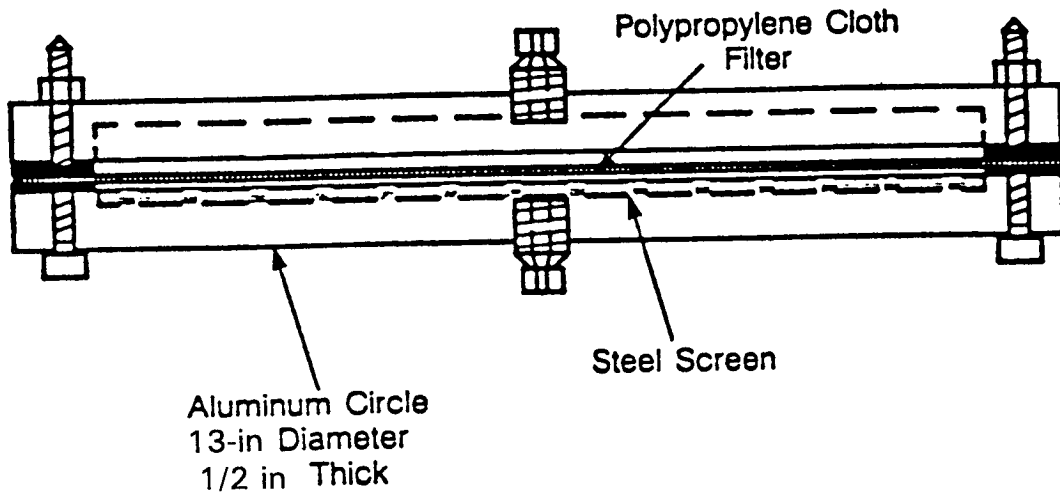


Figure 8. Fine Filter (1 to 2 microns)

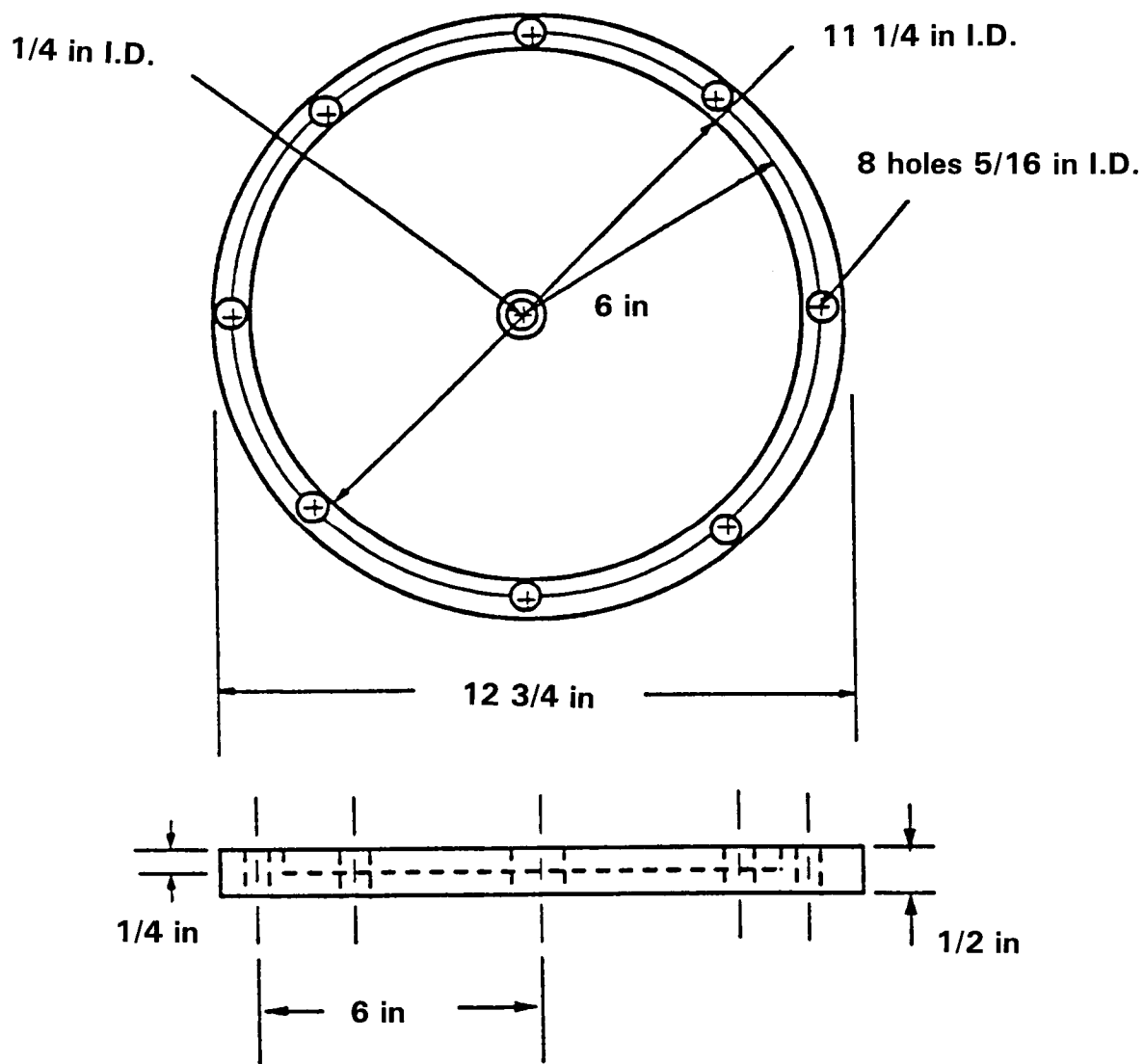


Figure 9. Top of the Fine Filter Housing

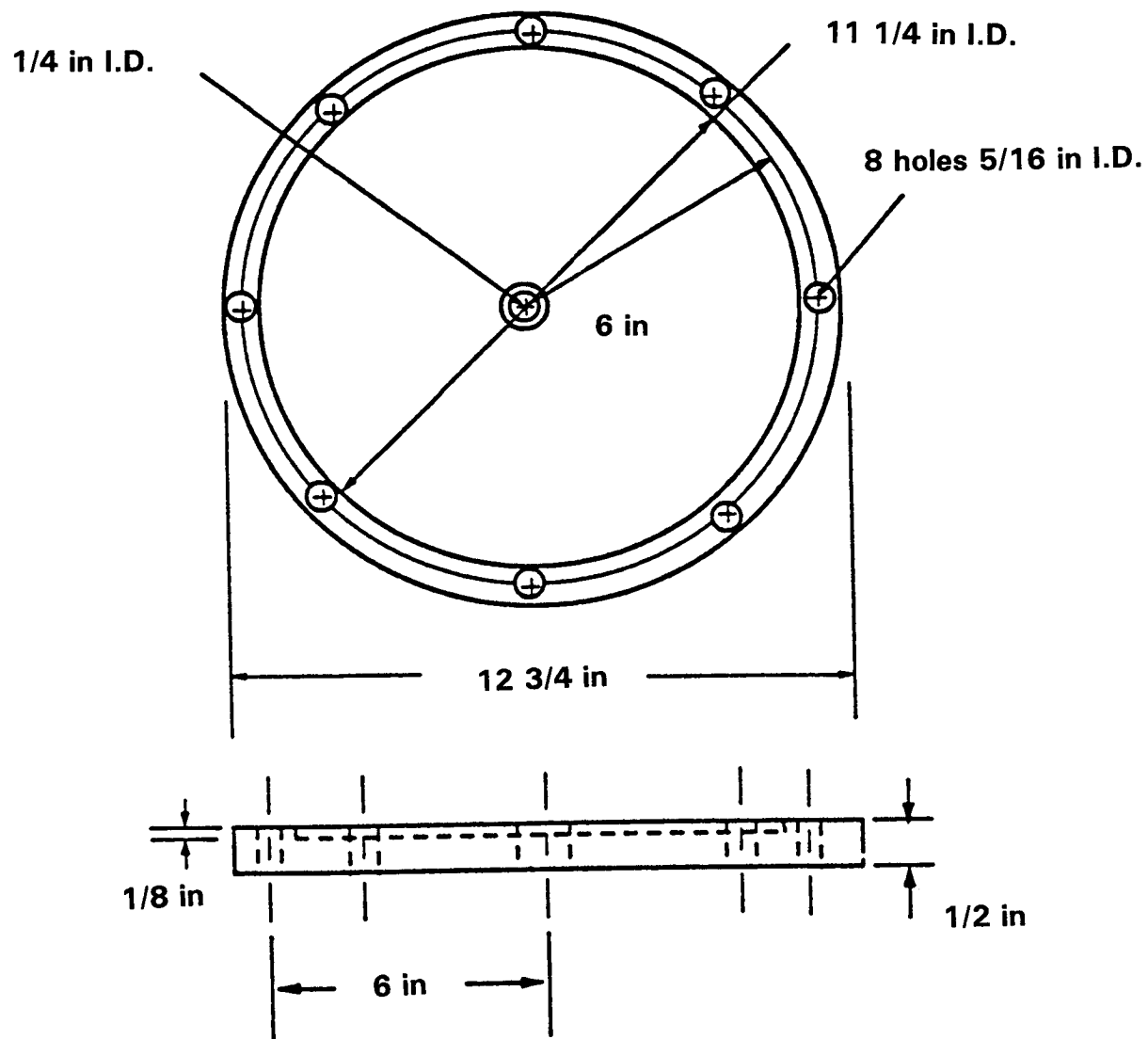


Figure 10. Bottom of the Fine Filter Housing

Standard Method of Test for

**The Measurement of Initial Asphalt Adsorption
and Desorption in the Presence of Moisture**

SHRP Designation: M-001¹

1. SCOPE

1.1 This test method describes a procedure for assessing the ability of an asphalt cement to adhere to the surface of the fine aggregate portion of an asphalt concrete mixture. The strength of the initial adhesion of the asphalt cement to the aggregate in the presence of moisture can also be assessed.

1.2 A sample of aggregate is exposed to a solution of asphalt cement in toluene at room temperature (25°C). After an equilibrium period, the amount of asphalt cement that has adsorbed on the aggregate is measured. Water is then introduced into the system, and it displaces the asphalt cement adsorbed on the aggregate surface. After a period of time, the amount of asphalt cement remaining on the aggregate is measured. This is the net adsorption amount.

NOTE 1.—This test method may not be accurate for modified asphalt binders because of potential differences in toluene solubility and absorbance wavelength between the base asphalt cement and the modifier. Use of the test method is recommended for unmodified asphalt binder-aggregate pairs only.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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 AASHTO Standard Method T40, *Practice for Sampling Bituminous Materials*.

2.2 *Toluene*—Consult manufacturer's or vendor's *Material Safety Data Sheet (MSDS)* for safety and handling precautions.

¹This standard is based on SHRP Product 1013.

3. SUMMARY OF TEST METHOD

3.1 A solution of asphalt cement and toluene (approx 1.0 g/L) is prepared. Four milliliters of the solution is removed, diluted to a total volume of 25 mL in a volumetric flask, and the absorbance at 410 nm determined with a spectrophotometer which has been zeroed with pure toluene.

3.2 Fifty grams of minus 4.75 mm aggregate is then added to a 500-mL Erlenmeyer flask, and 140 mL of the asphalt cement solution is added. The solution and aggregate are swirled on a shaker table for 6 hours.

3.3 At this time a 4-mL sample of the solution is removed from the flask, diluted to 25 ml, and the absorbance is again determined. The difference in the absorbance readings determines the amount of asphalt cement that has been adsorbed from the solution onto the aggregate surface due to the chemical attraction of the molecular components of the asphalt cement.

3.4 Immediately after the second solution sample is taken, 2 mL of water is added to the flask. The solution is then shaken for another 8 or more hours. A final 4 mL of solution is taken from the flask at the end of this time, diluted, and the absorbance at 410 nm again determined. The increase in the absorptivity of the solution is a measure of the amount of asphalt cement that has been displaced by water molecules.

4. APPARATUS

4.1 Shaker Table—orbital shaker table equipped with holders to accept 500 mL Erlenmeyer flasks. The number of 500-mL flasks the shaker can accept will determine the number of samples that can be run in 24 hours. A typical small shaker table can accept nine flasks. The large shaker tables can accept more. A nine-position table will allow up to four asphalt-aggregate combinations to be run in a 24-hour period.

NOTE 2.—This test is designed to be conducted at room temperature (20 to 25°C). Laboratories should conduct this test in a temperature-controlled area. If the tests are to be conducted in an area with poor temperature control, an environmentally controlled shaker bath should be used to control the sample temperature at 25°C.

4.2 Spectrophotometer—Capable of providing a continuous 410 nm wavelength with an accuracy of ± 2 nm, and a precision of better than ± 0.5 nm. The photometric precision should not be greater than $\pm 0.2\%$. The unit shall be capable of receiving standard 10-mm path-length cuvettes and measuring absorbance between 0.000 and 1.999.¹

4.3 Spectrophotometer Cuvettes—Should have a capacity of at least 4.5 mL with a 10-mm path length and suitable optical characteristics for measurements of wavelengths from 375 to 410 nm (generally included with spectrophotometer).

¹Spectronic 20 (VWR 22348-106) has been found to be satisfactory.

4.4 *Erlenmeyer Flasks (500 mL)*—wide-mouthed, with #10 neoprene stoppers.

4.5 *Erlenmeyer Flask (1000 mL)*.

4.6 *Volumetric Flasks (25 mL)*—Class A.

4.7 *Funnel*—75 mm in diameter.

4.8 *Filter Paper*—125 mm in diameter.¹

4.9 *Ring Stand and Clamps*—stand and clamps should be sufficiently large to hold the funnels without danger of tipping over.

4.10 *Graduated Cylinder*—glass, 250 mL capacity.

4.11 *Micropipettor*—capable of being set to any volume from 1 to 10 mL and equipped with disposable tips.²

4.12 *Magnetic Stirrer and Stir Bar*—small magnetic stirrer and appropriately sized stir bar capable of stirring asphalt binder in toluene solution.

4.13 *Analytical Balance*—capacity of 500 g and sensitivity of ± 0.001 g.

4.14 *Aggregate Drying Oven*—capable of maintaining $135^{\circ}\text{C} \pm 1.3^{\circ}\text{C}$.

5. REAGENTS

5.1 *Toluene*—UV or spectroanalyzed grade.

5.2 *Water*—distilled or deionized water. Commercially available bottled water is acceptable.

6. AGGREGATE PREPARATION

6.1 Weigh a 50 ± 0.3 g sample (weighed to the nearest 0.001 g) of the minus 4.75 mm aggregate stockpile and dry, uncovered, in a 135°C oven for a minimum of 15 hours.

6.2 Remove the sample from the oven at least 15 minutes prior to adding to the Erlenmeyer flask and store in a desiccator until needed. Samples not used within 24 hours of

¹Whatman No. 42 (VWR 28480-106) has been found to be satisfactory.

²Eppendorf Maxipettor (VWR 53512-930) has been found to be satisfactory.

drying should be re-dried. **Caution: do not add warm aggregate to the toluene solution. Toluene has a low flash point.**

7. PREPARATION OF 1 g/L STOCK ASPHALT SOLUTION

7.1 Place 500 mL of toluene in a 1,000 mL Erlenmeyer flask. Add approximately 0.5 g of asphalt cement (weighed to the nearest 0.001 g) to the toluene. Record the weight of the asphalt cement on the data sheet (figure 1) and/or laboratory notebook, and calculate the initial concentration of the asphalt cement solution in g/L, recording to two decimal places. Add a magnetic stir bar to the flask. Place the flask on a magnetic stirrer. Agitate the solution for a minimum of 10 minutes or until the asphalt cement is dissolved.

7.2 The appropriate amount of asphalt cement can be obtained by using a sharp knife to cut the sample out of a cooled can of asphalt cement.

7.3 Only asphalt cement-toluene solutions prepared within 24 hours of starting the test should be used. Older solutions should be discarded.

8. TEST PROCEDURE

8.1 All glassware to be used in this procedure must be clean and dry. Use toluene to remove any asphalt cement remaining from previous tests. It is especially important to clean and dry spectrophotometer cuvettes after each use.

8.2 Turn on the spectrophotometer and allow it to warm up in accordance with the manufacturer's recommendations. Once it has completed its internal calibration sequence, set the wavelength to 410 nm and zero the reference point with toluene according to the manufacturer's directions.

8.3 For each asphalt-aggregate combination to be tested, label two 500 mL Erlenmeyer flasks (each sample is run in duplicate). For each aggregate to be tested, also label one Erlenmeyer flask as a "blank."

8.4 Place 50 ± 0.3 g of aggregate (weighed to the nearest 0.001 g) in each of the labeled flasks, including the blank flask. Record the aggregate weight on the data sheet and/or laboratory notebook.

8.5 Using the 250-mL graduated cylinder, add 140 mL of plain toluene to the flask labeled "blank." Add 140 mL of freshly prepared asphalt cement solution to each of the other flasks, *except the blank*.

8.5.1 The blank solution is carried through the entire procedure to insure that there is no material on the aggregate that will interfere with the test. It is expected that most materials will have very low absorbance values for the blank solutions. Some limestones, however, can contain considerable amounts of naturally occurring organic material which

could interfere. If the absorbance values of the blank are greater than 0.010 for any of the readings, this absorbance value must be subtracted from all absorbance readings taken with that aggregate (A_a and A_r).

8.6 Stopper the flasks with a #10 neoprene stopper, and place each flask securely in the holder atop the shaker apparatus.

8.7 Turn on the shaker and adjust the speed to approximately 300 rpm. The rate should be high enough to insure good mixing, but without danger of throwing the flasks off the table. Once the appropriate table speed is determined for the particular shaker, this same speed should be used for all tests run in the laboratory.

8.8 Record the starting time on the data sheet and/or laboratory notebook.

8.9 Using the micropipettor, transfer 4.00 mL of the stock asphalt cement solutions for each asphalt cement being tested into a clean, dry 25 mL volumetric flask, and dilute to the mark with fresh toluene. Holding the stopper on the flask with the fingers, invert the flask at least 6 times to mix the solution.

8.10 Transfer about 4 mL of the diluted stock solution into a spectrophotometer cuvette, and determine the absorbance at 410 nm in the spectrometer. Record this value on the data sheet and/or laboratory notebook as “initial absorbance,” or A_i .

8.11 Using the ring stand and appropriate clamps, set up a funnel for each sample, with a clean, dry spectrophotometer cuvette under each funnel stem. Place a piece of folded filter paper in each funnel.

8.12 After 6.0 hours, stop the shaker table, allow the solution to settle for 10 minutes. Using the adjustable pipettor, transfer 4.00 mL of each solution to an appropriately marked clean, dry 25-mL volumetric flask. Dilute to the mark with clean toluene, stopper, and mix thoroughly by inverting the volumetric flask a minimum of six times while holding the stopper on with the fingers.

8.13 Carefully pour sufficient contents of the 25-mL volumetric flasks into the funnel to filter at least 4 mL of solution into each of the cuvettes.

8.14 Measure the absorbance of each cuvette at 410 nm in the spectrometer. Record this value on the data sheet and/or laboratory notebook under the heading “Abs. @ 6.0 hrs” or A_a .

8.15 Using the adjustable micropipettor, transfer 2.00 mL of water to each of the 500 mL Erlenmeyer flasks on the shaker table, replace the neoprene stoppers, and restart the shaker. Note the time on the data sheet and/or laboratory notebook. The shaker will now be allowed to run overnight while the water desorption step takes place.

8.16 Clean the funnels, volumetric flasks, and cuvettes, dispose of the filter paper, and set up the funnels, as described in section 8.11. Make sure no residual asphalt cement is left on any apparatus. Residual toluene can be removed by gently blowing nitrogen or oil-free compressed air into the glassware inside a laboratory fume hood.

8.17 In the morning, remove the flasks from the shaker table, and repeat steps 8.12, 8.13, and 8.14, recording the absorbance value as the remaining absorbance (A_r) on the data sheet and/or laboratory notebook. Also record the time.

8.18 Clean all glassware, dispose of used toluene in an appropriate waste container, and thoroughly dry all glassware before beginning another test sequence.

9. CALCULATIONS

9.1 Determine the amount of asphalt cement that was initially adsorbed onto the aggregate surface (report to two decimal places):

$$A = \frac{(VC)(A_i - A_a)}{WA_i}$$

where

- A = Initial adsorption, mg/g.
- V = Volume in milliliters of solution in the flask at the time A_a is obtained, (normally 140 mL).
- W = Aggregate weight, in grams (section 8.4).
- C = Initial concentration of asphalt cement in solution, g/L. (section 7.1).
- A_i = Initial absorbance reading (section 8.10).
- A_a = Absorbance reading after 6 hours (section 8.14).

9.2 Determine the net adsorption (report to two decimal places):

$$A_n = \frac{(VC)(A_i - A_r)}{WA_i}$$

where

- A_n = Net adsorption, mg/g.
- V = Volume in milliliters of solution in the flask at the time A_r is obtained, (normally 136 mL).
- W = Aggregate weight, in grams (section 8.4).
- C = Initial concentration of asphalt cement in solution, g/L (section 7.1).
- A_i = Initial absorbance reading (section 8.10).
- A_r = Absorbance reading after water has been added to the column (section 8.17).

9.3 Determine the percentage of asphalt cement remaining on the aggregate after the test:

$$\%NA = \left[\frac{A_n}{A} \right] \times 100$$

where

$\%NA$ = Percent net adsorption.

High values of $\%NA$ indicate increased resistance of the asphalt-aggregate bond to stripping by water.

10. REPORT

10.1 Figure 1 is a sample data sheet prepared to simplify entry of required measurements. It, or a similar form, shall be used to report the following:

10.1 A_i —Initial absorbance readings at 410 nm.

10.2 A_a —Absorbance readings at 410 nm after 6 hours.

10.3 A_r —Absorbance readings at 410 nm after water desorption step.

10.4 A —Initial absorption, mg/g.

10.5 A_n —Net adsorption, mg/g.

10.6 $\%NA$ —Percent net adsorption.

11. NOTES

11.1 Some sedimentary aggregates contain 1 or 2% naturally occurring organic compounds that could potentially interfere with this method. The use of a blank sample (section 8.4.1) will allow correction of this problem if it should occur.

11.2 Highly adsorptive aggregates may not stabilize after the 6-hour adsorption period. If such an aggregate is suspected, the adsorption period should be extended and additional adsorption measurements taken as described in sections 8.12, 8.13, and 8.14. These values can then be calculated using the equation in 9.1, after adjusting the volume V of the sample to reflect the additional amounts of toluene removed from the flask. The proper adsorption time can be determined when the adsorption values stabilize, and no more additional asphalt cement is being adsorbed by the aggregate. A similar caution is also appropriate for the desorption step.

Adsorption/Desorption Testing Data Sheet

Date: _____

Aggregate: _____

Asphalt Cement: _____

Asphalt Sample Weight (g) _____

Stock Solution Concentrate (g/L) _____

Reading	Time	Flask #1	Flask #2	Flask #3
Sample Weight, g				
Initial Abs. (A_i)				
Abs. @ 6.0 hrs. (A_a)				
Blank Abs. @ 6 hrs.				
Abs. after Overnight (A_r)				
Initial Absorption (A)				
Net Adsorption (A_n)				
% Net Adsorption				

Aggregate: _____

Asphalt Cement: _____

Asphalt Sample Weight (g) _____

Stock Solution Concentrate (g/L) _____

Reading	Time	Flask #1	Flask #2	Flask #3
Sample Weight, g				
Initial Abs. (A_i)				
Abs. @ 6.0 hrs. (A_a)				
Blank Abs. @ 6 hrs.				
Abs. after Overnight (A_r)				
Initial Absorption (A)				
Net Adsorption (A_n)				
% Net Adsorption				

Figure 1. Sample Net Adsorption Test Data Sheet

Standard Method of Test for

**Preparation of Compacted Specimens of
Modified and Unmodified Hot Mix Asphalt
by Means of the SHRP Gyratory Compactor**

SHRP Designation: M-002¹

1. SCOPE

1.1 This method covers the compaction of 100- or 150-mm diameter test specimens of modified or unmodified hot mix asphalt (HMA) and the measurement of specimen density during the compaction procedure.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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.*

1.3 The values stated in SI units are to be regarded as standard.

2. REFERENCED DOCUMENTS

2.1 AASHTO Standards:

T67	Standard Practices for Load Verification of Testing Machines
T166	Bulk Specific Gravity of Compacted Bituminous Mixtures
T209	Maximum Specific Gravity of Bituminous Paving Mixtures
T269	Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures

2.2 SHRP Test Methods:

M-007	Short- and Long-Term Aging of Bituminous Mixtures
P-004	Volumetric Analysis of Compacted Hot Mix Asphalt
P-005	Measurement of the Permanent Deformation and Fatigue Cracking Characteristics of Modified and Unmodified Hot Mix Asphalt

¹This standard is based on SHRP Product 1014.

2.3 ASTM Standards:

D 4402 Measurement of Asphalt Viscosity Using a Rotational Viscometer

3. SUMMARY OF TEST METHOD

3.1 The gyratory compactor produces a cylindrical test specimen from a loose modified or unmodified paving mix through a combination of parallel end pressure and gyratory kneading.

3.2 A loose paving mix is prepared in the laboratory; short-term oven aged in accordance with AASHTO M-007; brought to the proper compaction temperature; and placed into a mold. The mold is placed in the compaction device and an end pressure of 600 kPa is applied by means of a vertical ram.

3.3 Alternatively, loose plant mix is obtained; immediately brought to the proper compaction temperature; and placed into a mold. The mold is placed in the compaction device and an end pressure of 600 kPa is applied by means of a vertical ram.

3.4 The mold is set for a 1.25° angle of gyration and the specimen is gyrated at 30 rpm to a predetermined number of gyrations, based on the anticipated traffic for the roadway.

3.5 The height of the specimen is recorded after each revolution and is used to calculate the specimen volume. The weight of the mixture and the specimen volume are used to estimate the specimen density.

3.6 When the compaction is completed, the mold is removed and the test specimen is extruded for density determination using test method AASHTO T166.

3.6.1 The extruded specimen is not a right angle cylinder. If the specimen is to be used for accelerated performance-based tests, the ends must be sawed to conform to the requirements of SHRP P-005.

4. SIGNIFICANCE AND USE

4.1 The specimens are compacted to simulate the density, aggregate orientation, and structural characteristics obtained in the actual road surface when proper construction procedure is used in the placement of the paving mix. The specimens may be used to determine a number of characteristics of bituminous mixtures by specified test methods.

5. APPARATUS

5.1 Oven—Range at least 40 to 150°C, thermostatically controlled to $\pm 3^\circ\text{C}$

5.2 Gyrotory Compactor—Hydraulic compactor with ram and ram heads (see section 5.4) that are restrained from revolving during compaction. The axis of the ram shall be perpendicular to the platen of the compactor. The ram must maintain a pressure of 0.60 ± 0.01 MPa over 100- and 150-mm diameter specimen cross sections.

NOTE 1.—This stress calculates to $4,710 \pm 80$ N and $10,600 \pm 180$ N total force.

The compactor must tilt and gyrate the mold at an angle of 21.8 ± 0.3 mrad ($1.25 \pm 0.02^\circ$) throughout compaction. The mold must be free to revolve on its tilted axis during gyration. Captive inside the mold is a mold bottom (see section 5.4) that is not attached in any way and shall be free to rotate on the lubricated platen of the compactor. Means shall be provided to continuously measure and digitally display the height of the specimen in mm during compaction and to transmit the height via an RS232C serial connection to the computer (see section 5.5) once per gyration. The speed of gyration shall be 30.0 ± 0.5 gyrations per minute.

5.3 Molds—Each mold shall be a minimum of 8.5-mm-thick steel hardened to at least Rockwell C48. Inside finishes shall have a root mean square (rms) of 16 or smoother. The dimension of the molds shall be:

5.3.1 an inside diameter of 99.95 to 100.00 mm and a minimum of 160 mm (6.3 in.) high; 0.05 mm wear allowed;

5.3.2 an inside diameter of 149.95 to 150.00 mm and a minimum of 225 mm high; 0.05 mm wear allowed.

5.4 Ram Heads and Mold Bottoms—All shall be steel hardened to at least Rockwell C48. The ram heads shall have means for staying fixed to the ram and being perpendicular to its axis. The platen side of each mold bottom shall be flat and parallel to its face. All faces (the sides presented to the specimen) shall be ground flat and have one of the following diameters:

5.4.1 99.70 to 99.75 mm; 0.05 mm wear allowed;

5.4.2 149.70 to 149.75 mm; 0.05 mm wear allowed.

5.5 Computer—IBM-compatible, with hard drive, diskette drive and RS232C serial port

5.6 Software—Capable of establishing specimen header information; receiving and recording height of specimen data once per gyration; and subsequently adding and editing header information in each specimen record with the following fields:

5.6.1 Project name;

5.6.2 Date of test;

- 5.6.3** Start time of test;
- 5.6.4** Specimen identification;
- 5.6.5** Percent binder in specimen;
- 5.6.6** Average diameter of mold used, in mm;
- 5.6.7** Mass of specimen, in g;
- 5.6.8** Maximum specific gravity (G_{mm}) of specimen;
- 5.6.9** Bulk specific gravity (G_{mb}) of specimen;
- 5.6.10** Successive heights of specimen, in mm.

NOTE 2.—It is expected that the density of every specimen after gyration number 10 will approach a straight line when plotted versus the base 10 logarithm of the number of gyrations. The line will become asymptotic as it approaches 100% of G_{mm} .

5.7 *Miscellaneous*

- 5.7.1** Items in referenced standards (see section 2.1)
- 5.7.2** *Pan*, metal, with a flat bottom, for heating aggregates
- 5.7.3** *Pans*, metal, round, approximately 4-L (4-qt) capacity, for mixing asphalt and aggregates
- 5.7.4** *Oven and Hot Plate*, electric, for heating aggregates, asphalt, and equipment as required. Oven must also be capable of maintaining temperature for short-term aging.
- 5.7.5** *Scoop*, for batching aggregates
- 5.7.6** *Containers*, gill-type tins, beakers, pouring pots, or sauce pans, for heating asphalt
- 5.7.7** *Thermometers*, armored, glass, or dial-type with metal stem, 10 to 232°C, for determining temperature of aggregates, asphalt and asphalt mixtures.
- 5.7.8** *Balances*, one of 5-kg capacity, sensitive to 1 g, for weighing aggregates and asphalt, and one of 2-kg capacity, sensitive to 0.1 g, for weighing compacted specimens.
- 5.7.9** *Mixing Spoon*, large, or *Trowel*, small
- 5.7.10** *Spatula*, large

5.7.11 Mechanical Mixer, commercial bread dough mixer 4-L capacity or larger, equipped with two metal mixing bowls and two wire stirrers

5.7.12 Gloves, welders', for handling hot equipment.

6. MATERIALS

6.1 Paper disks—100- and 150-mm in diameter.

6.2 Oil—Light lubricant.

7. HAZARDS

7.1 Proper precautions and protective clothing must be used when handling the hot paving mix to prepare test specimens.

8. PREPARATION OF APPARATUS

8.1 Immediately before the paving mix is ready to be placed in the mold, turn on the main power to the gyratory compactor and the LVDT readout.

NOTE 3.—Check to be sure that the ram compaction head is the same size as the mold, and change if necessary.

8.2 Without a specimen in the compaction apparatus, calibrate the vertical pressure to 600 ± 10 kPa.

8.3 Verify that the automatic counter is reset and is set to shut off when the proper number of gyrations has been reached. This is based on the maximum number of gyrations for a specific mix design.

8.4 Verify that the LVDT readout is in the proper units (*mm*), and that the recording device is ready.

8.5 Lightly oil the surface of the rotating base and the surfaces of the four rollers.

8.6 Prepare the computer to record the height data and enter the header information for the specimen.

9. TEST SPECIMENS

9.1 Prepare the paving mix.

9.1.1 Weigh the aggregate fractions for each test specimen in a separate pan. Sufficient aggregate should be used so that the compacted specimen is 50 ± 1 mm high. This normally is 2.1 kg. A trial specimen can be prepared and compacted to determine whether the amount of aggregate should be increased or reduced. Prepare an additional pan for determination of the maximum theoretical specific gravity.

9.1.2 Place the pans in the oven and heat to a temperature approximately 30°C above the required mixing temperature. Charge the mixing bowl with the heated aggregates and dry mix thoroughly.

9.1.3 Form a crater in the dry, blended aggregate and add the required amount of asphalt binder into the mix. Verify that the temperature of the asphalt binder and aggregate is within a range at which the kinematic viscosity of the unaged asphalt binder is 170 ± 20 mm²/s (approximately 0.17 ± 0.02 Pa·s for an asphalt binder density of 1.000 g/cm³) measured in accordance with ASTM D 4402.

NOTE 4.—The SI unit of kinematic viscosity is m²/s; for practical use, the submultiple mm²/s is recommended. The more familiar centistoke is a *cgs* unit of kinematic viscosity; it is equal to 1 mm²/s. The kinematic viscosity is the ratio of the viscosity of the asphalt binder to its density. For an asphalt binder with a density equal to 1.000 g/cm³, a kinematic viscosity of 170 mm²/s is equivalent to a viscosity of 0.17 Pa·s measured with the rotational viscometer by ASTM D 4402.

9.1.4 Mix the aggregate and asphalt binder with the mechanical mixer as quickly and thoroughly as possible to yield a paving mix that has a uniform distribution of asphalt binder.

NOTE 5.—Do not hold the asphalt binder at mixing temperature for more than 1 hour before using.

9.2 After completing the mixture preparation, place the loose mix in a shallow, flat pan and short-term age it in a forced-draft oven in accordance with SHRP M-007.

9.3 Using a companion sample, determine the maximum specific gravity of the loose mix in accordance with AASHTO T209.

9.4 Place the compaction mold in a 135°C oven for 45 to 60 minutes prior to the estimated beginning of the compaction (during which time the mixture is being conditioned in accordance with M-007).

9.5 At the end of the 4-hour conditioning period of SHRP M-007, remove the pan of paving mix from the oven and allow it to achieve the proper compaction temperature.

9.5.1 The compaction temperature range is defined as the range of temperatures where the unaged asphalt binder has a kinematic viscosity of 280 ± 30 mm²/s (approximately 0.28 ± 0.03 Pa·s) measured in accordance with ASTM D 4402.

NOTE 6.—If the compaction temperature is greater than 135°C , the mix is placed in another oven for a brief time (maximum of 30 minutes) to achieve the required temperature.

9.6 Once the compaction temperature is achieved, remove the heated mold, with the base plate, from the oven. Place a paper disk on the bottom of the mold.

9.6.1 The mixture is placed into the mold in three layers. One-third of the mix is placed into the mold and then spaded five times with the mix scoop. This process is repeated for the next third and the final third. After all of the mix is in the mold, the mix is leveled and another paper disk is placed on top.

NOTE 7.—The spading process is used primarily for specimens of a coarse mixture. This process helps minimize segregation of the specimen at the boundaries.

10. COMPACTION PROCEDURE

10.1 Load the specimen into the gyratory compactor.

NOTE 8.—Ensure that the mold is centered under the loading ram.

10.2 Lower the ram until the pressure on the specimen reaches $600 \text{ kPa} \pm 10 \text{ kPa}$.

10.2.1 Apply the $1.25^\circ \pm 0.02^\circ$ tilt to the mold assembly.

10.2.2 Begin the gyratory compaction. Record the specimen height after each revolution. Allow the compaction to proceed until the maximum number of gyrations is reached and the gyratory mechanism shuts off.

10.2.3 Remove the angle from the mold assembly and raise the loading ram.

10.3 Remove the mold from the compactor.

10.3.1 Extrude the specimen from the mold.

NOTE 9.—This can be accomplished immediately for most HMA paving mixes. For lean, rich, or tender mixtures, a cooling period of 5 to 10 minutes may be necessary before extruding the specimen.

NOTE 10.—Specimens produced having a final density less than 93% of maximum theoretical density should be cooled 5 to 10 minutes before extruding the specimens to prevent deformation.

10.3.2 Remove the paper disks from the top and bottom of the specimen.

NOTE 11.—Before reusing the mold, place it in an oven for at least 5 minutes. The use of multiple molds will speed up the compaction process.

10.4 Cool the specimen and determine its mass and bulk specific gravity in accordance with AASHTO T166.

11. CALCULATIONS AND INTERPRETATION OF RESULTS

11.1 Report—Magnetic recording on diskette with one record per specimen as specified in section of 5.6.

11.2 Transmittal—Written and signed acknowledgement of work performed and observations of any unusual conditions and unexpected results.

12. PRECISION AND BIAS

12.1 Precision—The precision of the procedure in test method M-002 for measuring density is being determined.

12.2 Bias—Bias, if any, in test method M-002 for measuring density is being determined.

13. KEY WORDS

Compaction, density, gyratory.

Standard Method of Test for

Determining the Shear and Stiffness Behavior of Modified and Unmodified Hot Mix Asphalt with the SUPERPAVE® Shear Test Device

SHRP Designation: M-003¹

1. SCOPE

1.1 This standard is used to determine the permanent deformation and fatigue cracking characteristics of a bituminous mix. A series of tests are conducted at several temperatures and frequencies in during which the specimen is subjected to repeated axial and shear loads.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems 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. APPLICABLE DOCUMENTS

2.1 AASHTO Standards:

T269 Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixes

2.2 Other documents:

M002 Preparation of Test Specimens by Means of Gyratory Compaction

M008 Preparation of Test Specimens by Means of Rolling Wheel Compaction

The SUPERPAVE® Mix Design Manual for New Construction and Overlays

3. APPARATUS AND MATERIALS

NB: The following instructions relate specifically to the SHRP Shear Test Device. These instructions may be inappropriate for other test equipment.

¹This standard is based on SHRP Product 1017.

3.1 Test System—The test system is capable of applying both vertical and horizontal loads to a specimen. It is also capable of applying static, ramped (increasing or decreasing) and repetitive loads of various waveforms. Loading is provided by two hydraulic actuators (vertical and horizontal) and controlled by closed-loop feedback. Figure 1 illustrates a typical loading condition.

The computer-controlled system is capable of recording load cycles, applied horizontal and vertical loads, and specimen deformation in all directions (axial, horizontal and radial). Provisions have also been made for environmental control and monitoring.

As a minimum, the test system should meet the following requirements.

Load Measurement and Control

Range: 0 to 32 kN
Resolution: 0.02 kN
Accuracy: ± 0.04 kN

Confining Pressure Measurement and Control

Range: 0 to 700 kPa
Resolution: 0.7 kPa
Accuracy: ± 1.4 kPa

Deformation Measurement and Control

Horizontal (Repetitive Shear)

Range: 5 mm
Resolution: 0.0025 mm
Accuracy: ± 0.005 mm

Horizontal (Frequency Sweep)
Vertical (Constant Height, Frequency Sweep)

Range: ± 0.05 mm
Resolution: 0.0013 mm
Accuracy: ± 0.0025 mm

Radial

Range: ± 1.02 mm
Resolution: 0.005 mm
Accuracy: ± 0.01 mm

Temperature Measurement and Control

Range: −10°C to 80°C
Resolution: 0.25°C
Accuracy: ± 0.5°C

3.2 Platen-Specimen Assembly Device (figure 2)—This device is used to facilitate bonding of the specimen to loading platens. The device maintains the platens in a parallel position (relative to each other) when the specimen is glued to them. The platens must be parallel so that stresses do not develop in the specimen when the specimen-platen assembly is clamped in the test system.

3.3 *Miscellaneous Apparatus and Materials:*

3.3.1 calipers for measuring specimen height and diameter;

3.3.2 aluminum loading platens;

3.3.3 quick-set adhesive with a minimum hardened stiffness modulus of 2,070 MPa for bonding platens to specimen ends;

3.3.4 rubber membrane for uniform application of confining pressure;

3.3.5 silicone sealant to seal membrane against platens;

3.3.6 O-rings to secure ends of rubber membrane on platens;

3.3.7 6-mm diameter plastic tube to be inserted between membrane and specimen so as to relieve any internal air pressure;

3.3.8 device(s) for mounting LVDTs.

4. TEST SPECIMENS

4.1 *Compact Asphalt Concrete Specimens*—Specimens should be compacted in accordance with procedures outlined in section 2.2. Specimen dimensions should be 150 mm in diameter and 50 to 65 mm in height for mixes containing a maximum aggregate size of 19 mm or less.¹

4.2 *Measure Specimen Size*—Measure the height and diameter of the specimen at three different points around its perimeter and report to the nearest 0.025 mm. Average the three measurements and report to the nearest 0.25 mm.

¹It is recommended that specimen dimensions be 200 mm in diameter by 75 mm in height for mixes containing a maximum aggregate size greater than 38 mm.

4.3 Determine Air Void Content—Determine the air void content in accordance with AASHTO T-269-80.

4.4 Bonding Specimen to Platens (Required for all tests except volumetric)—Place platens in the platen-specimen assembly device. Spread thin layer of adhesive (≈ 1.5 mm) on the top and bottom of specimen and the matching face of platen. Lower the top platen onto the specimen and rotate the specimen one full revolution to ensure an even distribution of adhesive between specimen and platens. (Do not block pressure-relief port on the platen with adhesive during the gluing process.) Insert a plastic pressure-relief tube into the port provided in the bottom platen. Follow the adhesive manufacturer's instructions for the time and temperature required to achieve full strength in the adhesive. Leave the specimen in the assembly device until the adhesive has set.

4.5 Application of Elastic Membrane (Required for volumetric and uniaxial tests)—Spread a very thin layer of silicone sealant around the perimeter of each platen where the elastic membrane will be in contact with the platen. Stretch the membrane over the top platen and slide it down over the specimen, the pressure-relief tube and the bottom platen. Place the rubber O-rings around the top and bottom of the membrane in the grooves provided around the perimeter of each platen (figure 3).

4.6 Stabilize Specimen to Test Temperature—Place the specimen in an oven or other environmentally controlled unit for a minimum of two hours prior to testing to ensure that specimen is at the specified test temperature.

5. TEST PROCEDURES

5.1 Volumetric/Hydrostatic Test

5.1.1 Specimen Setup—Attach 2 vertical and 1 radial LVDTs to the specimen as shown in figure 4. The vertical LVDTs are used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The radial LVDT, which measures changes in the specimen perimeter, should be mounted around the specimen at mid-height and move freely. Completely lower the environmental chamber to seal off the specimen from the outside temperature influences. Testing is conducted at temperatures of 4°C, 20°C, and 40°C \pm 0.5°C.

5.1.2 Testing—Precondition specimen by applying a confining pressure of 70 kPa for 1 second and then immediately reduce the confining pressure to about 7 kPa. After preconditioning, apply the confining pressure at a rate of 70 kPa per second until reaching the desired level: 550, 690, or 830 kPa at 40, 20, or 4°C, respectively (figure 5). The confining pressure is applied for a total of 10 seconds, after which the confining pressure is relieved at a rate of about 23 kPa per second until reaching a residual confining pressure of about 7 kPa. Continue recording deformation for an additional 30 seconds during this recovery period. Axial and radial deformation, as well as axial load and confining pressure, should be recorded at appropriate intervals during the test, i.e., approximately 10 data points per second.

The following test parameters should be recorded.

- $\sigma_{11} = \sigma_{22} = \sigma_{33}$; confining pressure
- δ_v = vertical displacement of the specimen
- δ_h = radial displacement of the specimen

The following engineering quantities should be calculated.

- $\epsilon_{11} = \epsilon_{22} = \epsilon_{33} = \delta_v/h$; uniaxial strain where h is the height of the specimen

5.2 Uniaxial Test

5.2.1 Specimen Setup—The test setup is essentially identical to that for the volumetric/hydrostatic test with one exception: a 75-mm circular loading unit is placed between the load cell and top cap to create a more nearly uniform stress distribution. Attach 2 vertical and 1 radial LVDTs to the specimen as shown in figure 4. The vertical LVDTs are used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The radial LVDT, which measures changes in the specimen perimeter, should be mounted around the specimen at mid-height and move freely. Completely lower the environmental chamber to seal off the specimen from the outside temperature influences. Testing is conducted at temperatures of 4°C, 20°C, and 40°C \pm 0.5°C.

Position the vertical test system head to allow the specimen-platen assembly to slide between the bottom horizontal and top vertical heads. Position the horizontal test head such that the top and bottom test heads are aligned vertically. Slide the specimen between the heads so that it is centered between the heads. Secure the platens to the heads by activating the hydraulic clamps.

5.2.2 Testing—Precondition the specimen by applying an axial load corresponding to an axial stress of 70 kPa in 1 second, then immediately reduce the load such that the axial stress is about 7kPa. After preconditioning the specimen, apply an axial load to induce an axial stress at a rate of 70 kPa per second until reaching the desired level: 345, 415 and 655 kPa at 40, 20 and 4°C, respectively (figure 6). The axial load is applied for a total of 10 seconds, after which the axial load is relieved to achieve the release of the axial stress at rate of about 23 kPa per second until reaching a residual stress of about 7 kPa. (The confining pressure is adjusted by closed loop feedback control from the radial LVDT measuring the change in perimeter.) Continue recording data for an additional 30 seconds during this recovery period. Axial and radial deformations, as well as axial load and confining pressure should be recorded at appropriate intervals during the test, i.e., approximately 10 data points per second.

The following test parameters should be recorded.

- axial load (P);
- confining pressure ($\sigma_{22} = \sigma_{33}$);

- vertical displacement of the specimen (δ_v);
- radial displacement of the specimen (δ_h);

The following engineering quantities should be calculated.

- $\sigma_{11} = P/A + \text{confining stress } (\sigma_{22} = \sigma_{33})$; axial stress where A is the cross-sectional area of the specimen
- $\epsilon_{11} = \delta_v/h$; uniaxial strain where h is the height of the specimen

5.3 Frequency Sweep Test

5.3.1 Specimen Setup—Attach vertical and horizontal LVDTs to the specimen as shown in figure 4. The vertical LVDT is used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The horizontal LVDTs measure the difference in horizontal displacement between two points on the specimen separated by 37.5 mm. The horizontal LVDTs should be mounted such that they contact the specimen at approximately 19 mm on either side of the specimen at mid-height.

Position the vertical test system head to allow the specimen-platen assembly to slide between the bottom horizontal and top vertical heads. Position the horizontal test head such that the top and bottom test heads are aligned vertically. Slide the specimen between the heads so that it is centered between the heads. Secure the platens to the heads by activating the hydraulic clamps.

Completely lower the environmental chamber to seal off the specimen from the outside temperature influences. Testing is conducted at temperatures of 4°C, 20°C, and 40°C.

5.3.2 Testing—The test is conducted at constant height requiring the vertical actuator servovalve to be controlled by the vertical LVDT. Furthermore, this is a *strain-controlled* test with the maximum shear strain limited to 0.0001 mm/mm. Precondition the specimen by applying a sinusoidal horizontal shear strain of amplitude ≈ 0.0001 mm/mm at a frequency of 10 Hz for 100 cycles. After preconditioning, a series of 10 tests are conducted in *descending* order of frequency at each temperature level beginning with the lowest temperature. (The shear strain is applied at the following frequencies at each test temperature: 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, 0.02 and 0.01 Hz.) Recording 50 data points per load cycle is sufficient. Since the test is conducted at a constant height, the axial actuator is under closed loop feedback control from the LVDT measuring the relative displacement between the specimen caps.

The following test parameters should be recorded.

- axial load (P);
- shear load (V);
- δ_v = vertical displacement of the specimen
- δ_h = horizontal displacement of the specimen

The following engineering quantities should be calculated.

- $\sigma_{11} = P/A$; axial stress where A is the cross-sectional area of the specimen
- $\tau_{12} = V/A$; shear stress
- $\epsilon_{12} = \delta_v/2h$; shear strain where h is the height of the specimen
- $G = \tau_{12}/\epsilon_{12}$; complex shear modulus;
- ψ = phase angle in degrees

5.4 Simple Shear Test (Constant Height)

5.4.1 Specimen Setup—Attach vertical and horizontal LVDTs to the specimen as shown in figure 4. The vertical LVDT is used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The horizontal LVDTs measure the difference in horizontal displacement between two points on the specimen separated by 37.5 mm. The horizontal LVDTs should be mounted such that they contact the specimen at approximately .19 mm on either side of the specimen at mid-height.

Position the vertical test system head to allow the specimen-platen assembly to slide between the bottom (horizontal) and top (vertical) heads. Position the horizontal test head such that the top and bottom test heads are aligned vertically. Slide the specimen between the heads so that it is centered between the heads. Secure the platens to the heads by activating the hydraulic clamps.

Completely lower the environmental chamber to seal off the specimen from the outside temperature influences. Testing is conducted at a temperatures of 4°C, 20°C, and 40°C.

5.4.2 Testing—This is a *stress-controlled* test with the feedback to the horizontal actuator servovalve from the magnitude of the shear load. The test is conducted at constant height, requiring the vertical actuator servovalve to be controlled by the vertical LVDT. (i.e., the axial actuator is under closed loop feedback control from the LVDT to measure the relative displacement between the specimen caps.) Precondition the specimen by applying a 7 kPa shear stress for 100 cycles. After preconditioning the specimen, increase the shear stress at a rate of 70 kPa/s and hold for 10 seconds in accordance with figure 7 (35, 105, and 350 kPa at 40, 20 and 4°C, respectively). After 10 seconds, reduce the shear stress to zero at a rate of about 21 kPa/s. Continue to record data for an additional 30 seconds during this recovery period. Axial and shear deformations, as well as axial and shear loads, should be recorded at appropriate intervals during the test, i.e., approximately 10 data points per second.

The following test parameters should be recorded.

- axial load (P);
- shear load (V);
- δ_v = vertical displacement of the specimen
- δ_h = horizontal displacement of the specimen

The following engineering quantities should be calculated.

- $\sigma_{11} = P/A$; axial stress where A is the cross-sectional area of the specimen
- $\tau_{12} = V/A$; shear stress
- $\epsilon_{12} = \delta_v/h$; shear strain where h is the height of the specimen

5.5 Repetitive Shear Test (Constant Stress Ratio)

5.5.1 Specimen Setup—Attach vertical and horizontal LVDTs to the specimen as shown in figure 4. The vertical LVDT is used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The horizontal LVDTs measure the difference in horizontal displacement between two points on the specimen separated by 37.5 mm. The horizontal LVDTs should be mounted such that they contact the specimen at approximately 19 mm on either side of the specimen at mid-height.

Position the vertical test system head to allow the specimen/platen assembly to slide between the bottom (horizontal) and top (vertical) heads. Position the horizontal test head such that the top and bottom test heads are aligned vertically. Slide the specimen between the heads so that it is centered between the heads. Secure the platens to the heads by activating the hydraulic clamps.

Completely lower the environmental chamber to seal off the specimen from the outside temperature. This stress-controlled test is usually performed at an *effective temperature for permanent deformation* (see The SUPERPAVE® Mix Design Manual for New Construction and Overlays, chapter 4), calculated from weather data for the site of the paving project.

5.5.2 Testing—This is a constant stress ratio test. The vertical actuator servovalve is controlled by the magnitude of axial load as feedback. The horizontal actuator servovalve is controlled by the magnitude of shear load as feedback. Both axial and shear loads are haversine in shape and are applied such that, at every moment in time during the loading phase, the ratio of axial load to shear load remains constant. Precondition the specimen by applying 100 cycles of **synchronized** haversine axial and shear load pulses (0.1 second on and 0.6 seconds off). The axial stress for preconditioning should not exceed 7 kPa with the ratio of axial to shear stress held constant at a value of 1.2 to 1.5. After preconditioning, the synchronized haversine axial and shear stress pulses should be applied for a total of 5000 repetitions or until 5% shear strain is reached. During testing the ratio of axial to shear stress should be held constant at a value of 1.2 to 1.5. The maximum shear stress level should be determined in accordance with the guidelines in table 1. Axial and shear deformations, as well as axial and shear loads, should be recorded at appropriate intervals. Collecting 60 data points per load cycle is sufficient.

The following test parameters should be recorded.

- axial load (P)
- shear load (V)
- ratio of axial to shear load

Table 1. Guidelines for Shear and Compressive Stress

Base Condition	Maximum Shear (τ) and Compressive (σ_v) Stress Levels (kPa) at Asphalt Binder Content					
	Above Design		At Design		Below Design	
	τ	σ_v	τ	σ_v	τ	σ_v
Weak	84	119	63	98	49	56
Strong	98	175	84	105	56	91

Note: A weak base is defined as an unbound granular or crushed stone material (i.e., new construction), whereas a strong base is defined as an existing asphalt concrete or portland cement concrete pavement, a cement-stabilized or asphalt-stabilized base, or a strong crushed stone base material (i.e., a resilient modulus of 560,000 kPa or greater).

- δ_v = vertical displacement of the specimen
- δ_h = horizontal displacement of the specimen

The following engineering quantities should be calculated.

- $\sigma_{11} = P/A$; axial stress where A is the cross-sectional area of the specimen
- $\tau_{12} = V/A$; shear stress
- $\epsilon_{12} = \delta_v/h$; shear strain where h is the height of the specimen

5.6 Repetitive Shear Test (Constant Height)

5.6.1 Specimen Setup—Attach vertical and horizontal LVDTs to the specimen as shown in figure 4. The vertical LVDT is used to measure changes in specimen height as represented by changes in the distance between the top and bottom platens. The horizontal LVDTs measure the difference in horizontal displacement between two points on the specimen separated by 37.5 mm. The horizontal LVDTs should be mounted such that they contact the specimen at approximately 19 mm on either side of the specimen at mid-height.

Position the vertical test system head to allow the specimen-platen assembly to slide between the bottom horizontal and top vertical heads. Position the horizontal test head such that the top and bottom test heads are aligned vertically. Slide the specimen between the heads so that it is centered between the heads. Secure the platens to the heads by activating the hydraulic clamps.

Completely lower the environmental chamber to seal off the specimen from the outside temperature influences. Testing is conducted at the seven-day maximum pavement temperature occurring at 50 mm depth.

5.6.2 Testing—This is a *stress-controlled* test with the feedback to the horizontal actuator servovalve from the magnitude of the shear load. The test is conducted at constant height requiring the vertical actuator servovalve to be controlled by the vertical LVDT (i.e.,

the axial actuator is under closed loop feedback control from the LVDT measuring the relative displacement between the specimen caps). Precondition the specimen by applying a haversine load corresponding to a 7 kPa shear stress for 100 cycles (0.1 s on, 0.6 s off). After preconditioning the specimen, apply a 70 kPa haversine shear pulse (0.1 s on and 0.6 s off) for 5000 cycles or until 5% shear strain is reached. Axial and shear deformations, as well as axial and shear loads, should be recorded at appropriate intervals. Collecting 60 data points per load cycle is sufficient.

The following test parameters should be recorded.

- axial load (P)
- shear load (V)
- δ_v = vertical displacement of the specimen
- δ_h = horizontal displacement of the specimen

The following engineering quantities should be calculated.

- $\sigma_{11} = P/A$; axial stress where A is the cross-sectional area of the specimen
- $\tau_{12} = V/A$; shear stress
- $\epsilon_{12} = \delta_v/h$; shear strain where h is the height of the specimen

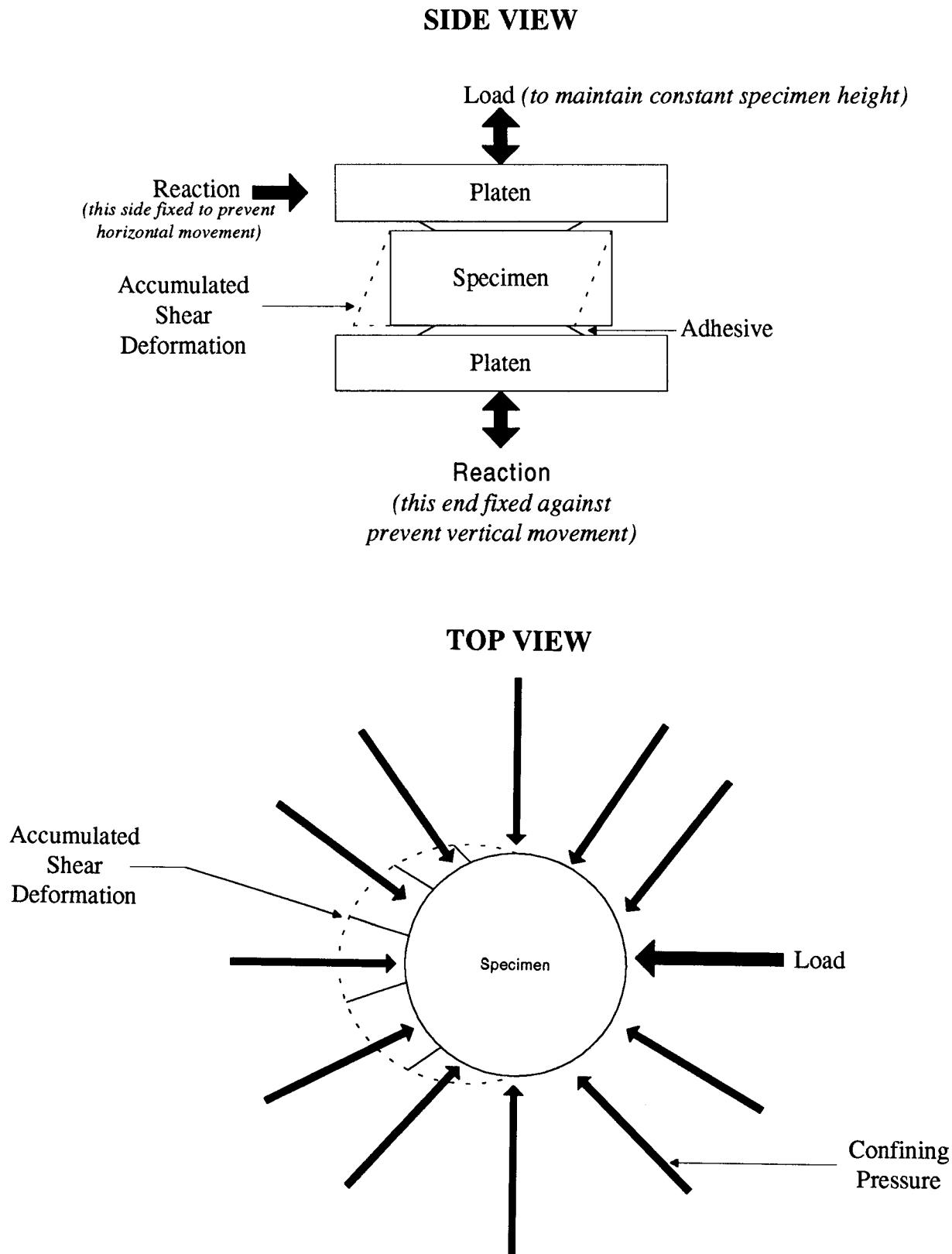


Figure 1. Specimen Loading Conditions

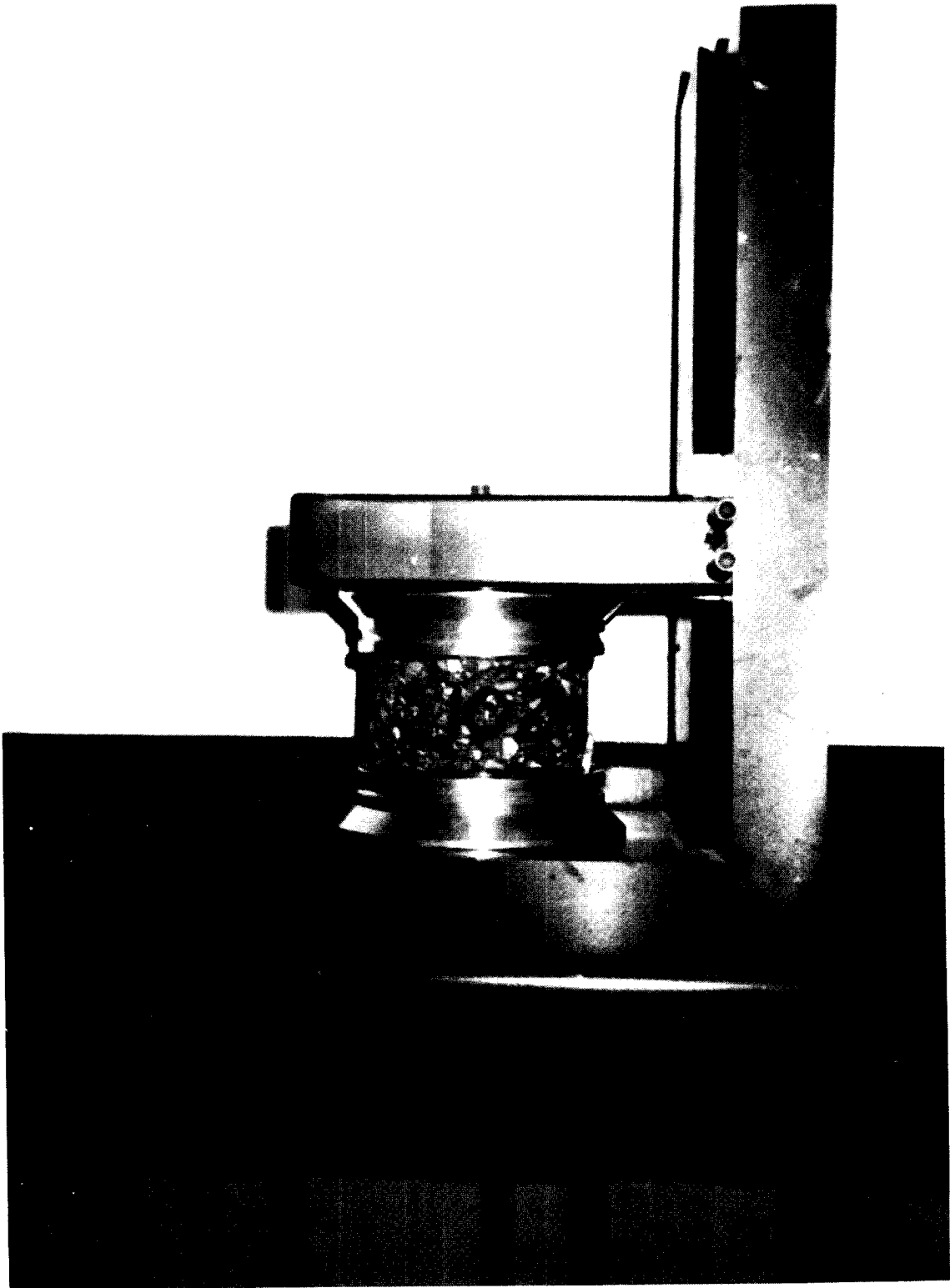


Figure 2. Platen-Specimen Assembly Device

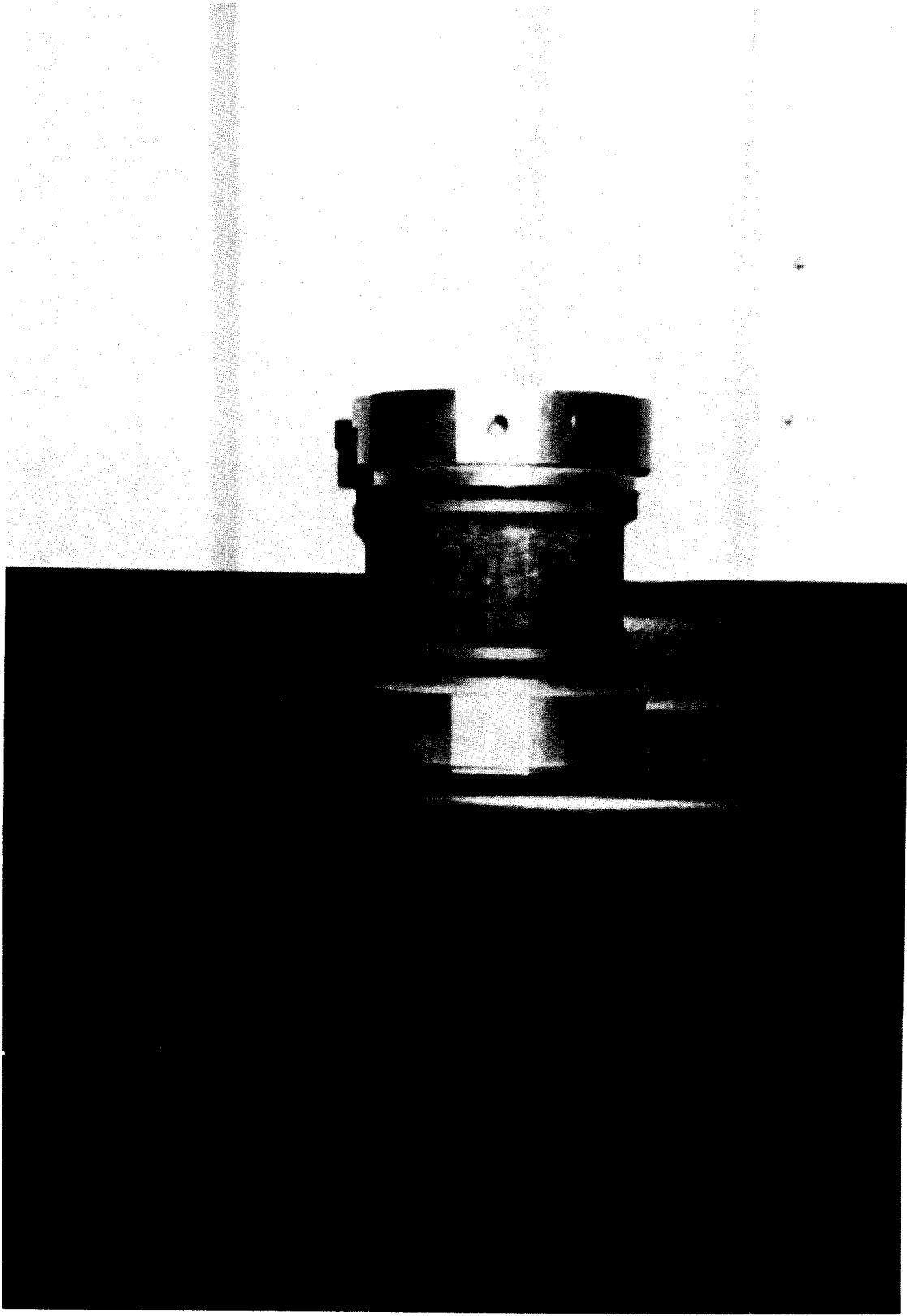


Figure 3. Application of Elastic Membrane and O-rings



Figure 4. Positioning of Vertical and Horizontal LVDTs (Radial LVDT not shown)

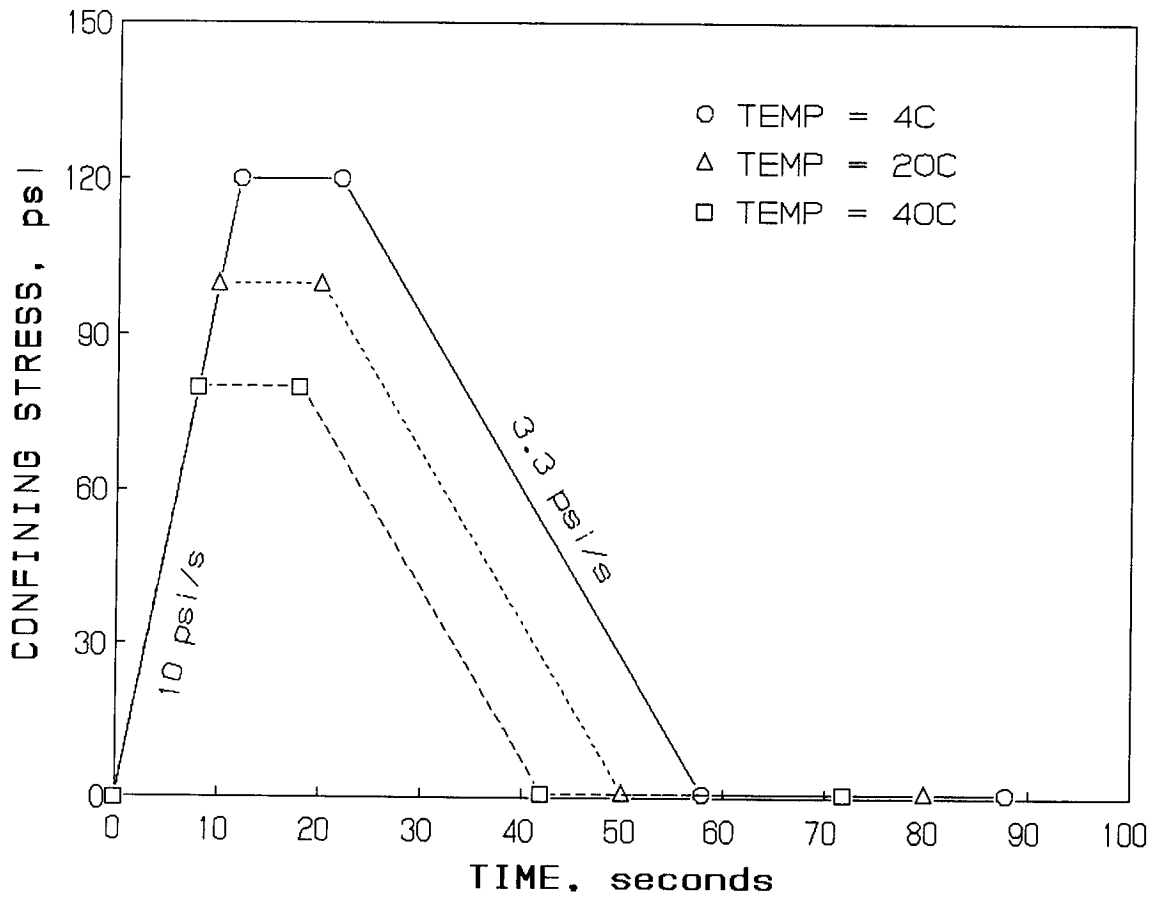


Figure 5. Loading for Volumetric/Hydrostatic Test

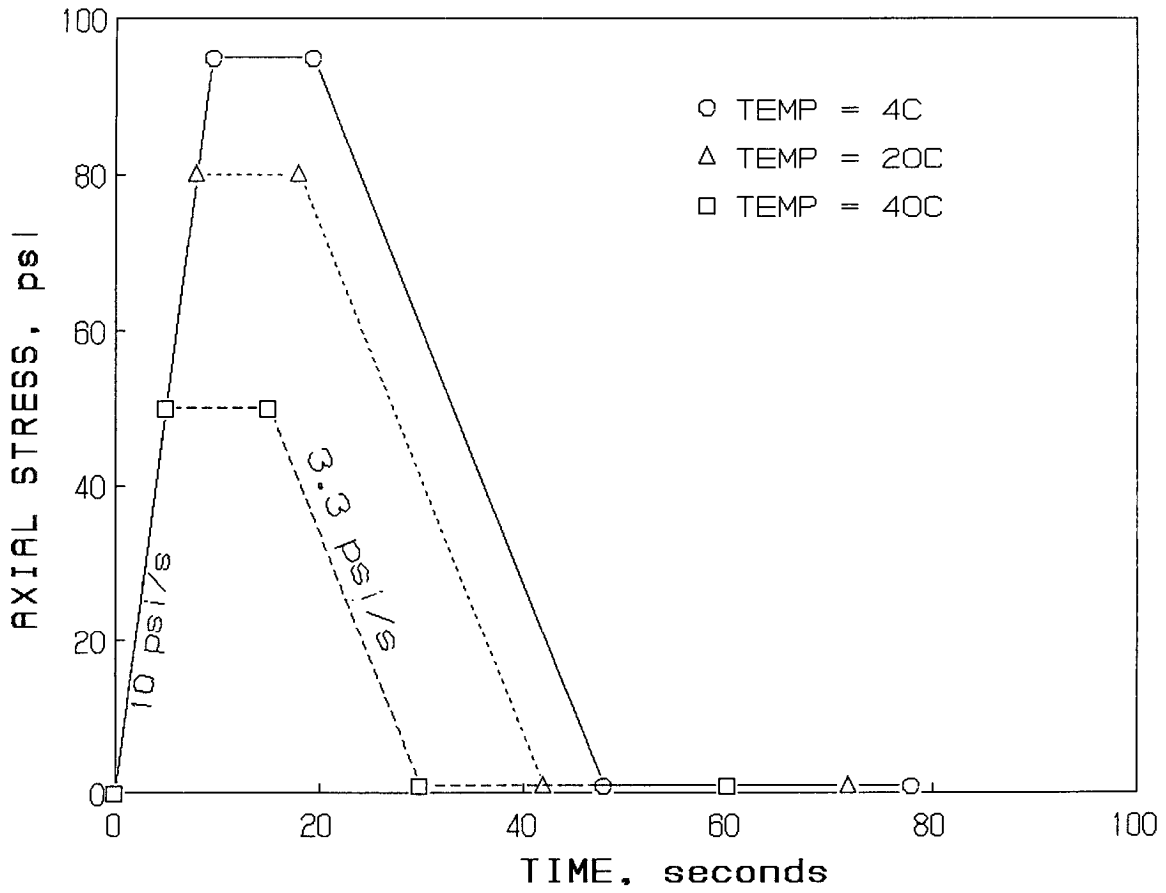


Figure 6. Loading for Uniaxial Strain Test

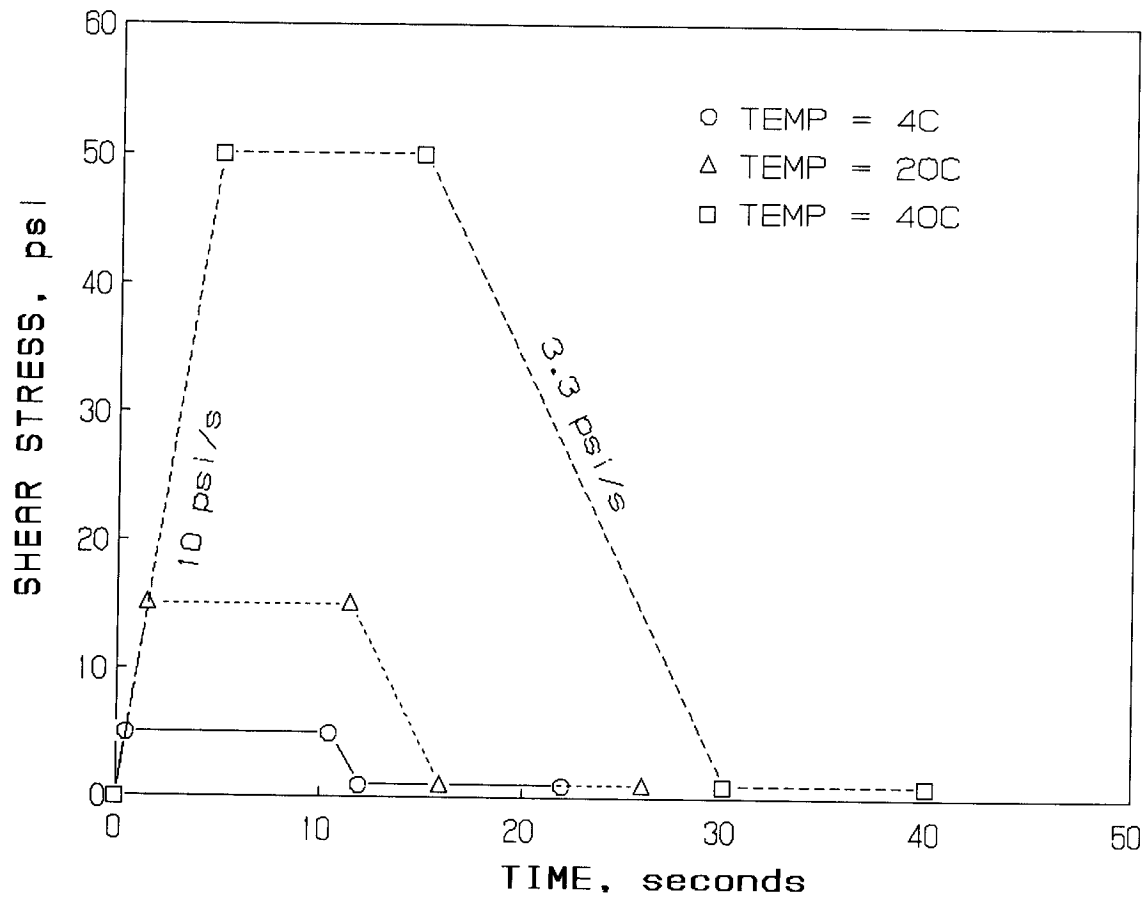


Figure 7. Loading for Simple Shear (Constant Height Test)

Standard Method of Test for

**Determining the Creep Compliance and Strength
of Modified and Unmodified Hot Mix Asphalt Using
Indirect Tensile Loading Techniques**

SHRP Designation: M-005¹

1. SCOPE

1.1 This method covers the determination of creep compliance and strength at different loading times using diametral loadings (commonly referred to as indirect tensile testing) for compacted, dense-graded, hot-mixed, hot-laid bituminous mixtures. Indirect tensile testing is used to characterize asphalt concrete mixtures in tension for thermal and fatigue cracking analyses.

1.2 The indirect tensile creep and failure tests are intended for low-temperature characterization (0°C and below) of cylindrical laboratory compacted and/or field-cored asphalt concrete specimens. The primary goal of the test method is to determine the master compliance curve and failure limits (strength, strain or energy) as a function of temperature, which are required inputs into a mechanistic-based low temperature cracking performance prediction model.

1.3 The test method also provides strength information and data required at temperatures less than 20°C to estimate the number of loading cycles to propagate a crack through an asphalt concrete layer in fatigue cracking predictions that use fracture mechanics.

1.4 This method is applicable to dense-graded, hot-mixed, hot-laid asphalt concrete mixtures, as defined by ASTM D 3515 (Bituminous Paving Mixtures, Hot-Mix, Hot-Laid), and may be used on cores recovered from roadways or cylindrical specimens compacted in the laboratory.

1.5 The values of creep compliance and tensile strength determined with this method can be used in linear-elastic and non-linear elastic layered system theories to calculate the low temperature and fatigue cracking potential of asphalt concrete layers subjected to thermal and wheel loadings.

1.6 The values stated in SI units are to be regarded as the standard.

¹This standard is based on SHRP Product 1022.

1.7 *This test may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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. APPLICABLE DOCUMENTS

2.1 SHRP Documents

M-002 Preparation of Compacted Specimens of Modified and Unmodified Hot Mix Asphalt by Means of the SHRP Gyratory Compactor

2.2 AASHTO Documents

T166 Bulk Specific Gravity of Compacted Bituminous Mixtures

T209 Maximum Specific Gravity of Bituminous Paving Mixtures

T245 Test Method for Resistance to Plastic Flow of a Bituminous Mixture Using the Marshall Apparatus

T247 Method for Preparation of Test Specimens of a Bituminous Mixture by Means of the California Kneading Compactor

T269 Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures

T275 Standard Method of Test for Bulk Specific Gravity of Compacted Bituminous Mixes Using Paraffin-Coated Specimens

2.3 ASTM Documents

D3202 Preparation of Bituminous Mixture Beam Specimens by Means of the California Kneading Compactor

D3387 Test for Compaction and Shear Properties of Bituminous Mixtures by Means of the U.S. Corps of Engineers Gyratory Testing Machine (GTM)

D3515 Specifications for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures

D4013 Preparation of Test Specimens of Bituminous Mixtures by Means of Gyratory Shear Compactor

3. SUMMARY OF METHOD

3.1 This test method consists of two types of tests: a tensile creep test and a tensile strength test. The tensile strength test can be performed separately (for fatigue cracking analyses) or in concert with the creep test (for thermal cracking analyses).

3.2 A static load of fixed magnitude is applied along the diametral axis of a preconditioned specimen for a fixed duration of time, 1,000 seconds. The horizontal and vertical deformations measured near the center of the specimen are used to calculate a tensile compliance at a particular duration of time. Loads are selected to keep strains in the linear viscoelastic range (typically below 300 microstrains). By measuring both horizontal and vertical strains in regions where the stresses are relatively constant and away from the localized non-linear effects induced by the steel loading strips, the Poisson's ratio can be more accurately determined. The Poisson's ratio is then used to better predict three-dimensional stresses and strains.

3.3 The failure portion of the test immediately follows the creep portion. Without releasing the creep load, a constant rate of vertical deformation (or ram movement) is applied to the specimen to failure. The failure limits determined can be input into mechanistic-based models for thermal cracking or used to compare relative qualities of mixtures. The failure portion of the test method can be performed separately when only the tensile strength properties are needed.

4. DEFINITIONS

4.1 *Creep Compliance*—The slow movement of asphalt concrete mixtures under a sustained load per unit of the applied stress; time-dependent strain (continuing strain) with a sustained stress level.

5. SIGNIFICANCE AND USE

5.1 The values of creep compliance can be used to evaluate the relative quality of materials, as well as to generate input for pavement design and evaluation models. From creep testing, these values include the intercept and straight line slope of log creep-compliance versus log loading time, or the entire master-compliance curve. The test can be used to study effects of temperature, load magnitude, binder content, and loading time.

5.2 When used in conjunction with other mixture physical properties, the creep compliance may contribute to the overall mixture characterization. It is one factor for determining a mixture's suitability for use as a highway paving material under given traffic and environmental conditions.

5.3 Reheated, recompacted mixtures may be used in this method, but the resulting creep compliance values will be higher than for newly prepared mixtures because of changes

in binder viscosity, an important factor of creep strains, as measured under these specific loading conditions and temperatures.

6. APPARATUS

6.1 Axial Loading Machine—Any loading machine capable of providing a fixed or constant load and constant rate of ram displacement with a resolution of ± 4.5 N shall be used. Typically, a closed-looped electrohydraulic system, or a combination of a screw-type machine with a cam and switch or timer control of solenoid valves that operates a pneumatic air piston can be used.

6.2 Temperature/Control System—The temperature control system shall be capable of control over a temperature range from -20 to $20^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$ of the specified temperature within the range (see note 1). The system can be a room, chamber or cabinet that shall be large enough to hold at least three specimens for a period of 12 hours prior to testing. If the testing machine is located in a room without the specified temperature control systems, a controlled temperature cabinet shall be used during the entire test.

NOTE 1.—Use of the indirect tensile test to characterize mixtures in tension at relatively high temperatures (above room temperature) has been a problem, at long loading times (i.e., creep testing). As most asphalt concrete mixes are far from elastic at high temperatures, these equations must be used with caution. The indirect tensile equations used to calculate the tensile strains and moduli values were developed using the theory of elasticity. Thus, the test temperature of the IDT creep test should be 0°C or less, and the test temperature of the IDT strength test should be less than 20°C .

6.3 Specimen Deformation Measurement Devices—The creep compliance test requires deformation transducers with a high resolution and small range during the creep portion of the test and less resolution but a larger range during the strength portion of the test. The linear variable differential transducer (LVDT) is considered to be the most suitable deformation transducer for the test. A range of ± 0.25 mm is required, while simultaneously maintaining a minimum resolution of 2.5×10^{-4} mm.

6.4 Specimen Load Measurement Device—The load measuring device is to be an electronic load cell. The load is to be measured by placing the load cell between the loading platen and piston. The total load capacity of the load transducer (load cell) shall be of the proper order of magnitude with respect to the maximum total load to be applied to the test specimen. Generally, its capacity should be no greater than 5 times the total maximum load applied to the test specimen to ensure that the necessary measurement accuracy is achieved. The load-measuring device shall be capable of measuring the load to an accuracy of $\pm 1\%$ of the applied load.

6.5 Recording Device—Specimen behavior in the creep compliance test is evaluated from time records of applied load and specimen deformation. Commonly, these parameters are recorded on a multichannel strip-chart recorder. Analog-to-digital data acquisition systems may be used if the data can be converted into a convenient form for analysis and interpretation.

6.5.1 For analog strip-chart recording equipment, the deformation recorder trace must be of sufficient magnitude and time resolution to enable accurate data reduction. Resolution of each variable should be better than 2% of the maximum value being measured. The trace shall have sufficient contrast to the background so that it may be reproduced in reports. At all times, the minimum resolution of the trace must be maintained at 2% of the maximum value of the recorded parameter.

6.5.2 For digital data acquisition systems, the minimum sampling frequencies for the 1,000-second creep test are as follows:

- 100 Hz for the first 10 seconds
- 1 Hz for the next 5 minutes (up to 300 seconds)
- 0.2 Hz through the remainder of the test (remaining 700 seconds)

For the indirect tensile strength test, which is performed immediately after the creep test and uses a stroke rate of 13 mm per minute, a sampling frequency of 20 Hz is used through the entire test (see note 2).

NOTE 2.—Experience has shown that a 16-bit A/D board is required to obtain both the resolution needed in the creep test and the range for the strength portion.

6.5.3 When a digital data acquisition system is used, a special conditioner is required. This special conditioner shall have the following characteristics.

- An excitation frequency of 2.9 to 20 kHz
- An excitation voltage of 1 V
- A load independence of 30 ohms
- An output ± 10 V
- A noise level less than 2.5×10^{-4} mm measured at output of the conditioner when ± 10 V equals ± 2.5 mm
- A filter cut-off greater than 5 Hz

6.6 *Oven*—The oven for the preparation of hot mixtures shall be capable of being set to maintain any desired temperature from room temperature to 163°C.

6.7 *Mounting Template*—A mounting template, as shown in figure 1, is used to place and mount the eight brass gauge points to each side of the test specimen (four per side).

6.8 *Specimen Loading Frame*—The specimen load frame shall be capable of delivering test loads in good alignment and with minimal friction (less than 2.27 kg resistance) in guides or bearings even when eccentric loads occur (caused by slightly uneven specimens, temperature changes, etc.) (see note 3). Loading platens shall have a width equal to $D/8$, where D is the standard diameter of the test specimens, and a radius of $r = D/2$.

NOTE 3.—Often a smaller guide frame with special alignment capabilities is used in conjunction with the larger loading frame to accomplish this, as portrayed in figure 2.

7. PREPARATION OF TEST SPECIMENS

7.1 *Laboratory Molded Specimens*

7.1.1 Prepare three replicate laboratory-molded specimens, as a minimum for each test temperature, in accordance with SHRP test method M-002 or other acceptable procedures, such as AASHTO T247 or ASTM D3387 and D4013 (see notes 4 and 5). Other procedures include cores cut from laboratory-prepared beams or slabs. If only strength measurements are required, the number of specimens can be reduced to two per temperature.

NOTE 4.—The type of compaction device will influence the test results or creep compliance values. SHRP M-002 is the preferred technique, but AASHTO T247 produces specimens that are reasonable. AASHTO T245 (Marshall hammer) is not permitted for preparing specimens for creep compliance testing.

NOTE 5.—Test specimens normally are compacted using a standard compactive effort. A specific compactive effort, however, may not reproduce the air voids measured on field cores. If specimens are to be compacted to a target air void content, the compactive effort needs to be varied. For SHRP M-002, the number of gyrations can be varied; for AASHTO T247 (kneading compactor) the number of tamps, the foot pressure and/or the leveling load can be altered. The actual compactive effort to be used should be determined experimentally.

7.1.2 Saw at least 6 mm from both sides of each test specimen to provide smooth, parallel (saw-cut) surfaces for mounting of measurement gauges (see note 6). The final height and diameter of the sawed laboratory molded specimens are given under section 7.3.

NOTE 6.—Measurements taken on cut faces yield more consistent results, and gauge points can be epoxied with much greater bonding strength.

7.2 *Core Specimens*

7.2.1 Cores shall have smooth and parallel surfaces and conform to the height and diameter requirements specified for specimens under section 7.3. Three replicate cores shall be prepared for each test temperature. If only strength measurements are required, the number of cores can be reduced to two per temperature. If rough or uneven surfaces exist, cores shall be sawn to provide required smoothness and conformity, as required in section 7.1.2 (see note 6).

7.3 *Specimen Size*

7.3.1 Indirect tensile specimens to be tested shall have a height (or thickness) of at least 30 mm and a minimum diameter of 100 mm for mixtures that contain a maximum aggregate size of 25 mm or less. Mixtures that contain maximum size aggregates up to 38 mm in diameter shall have a height of at least 50 mm and a minimum diameter of 150 mm. The specimen height-to-diameter ratio shall exceed 0.33 (see note 7).

NOTE 7.—The size of test specimens has an influence on results from the tensile creep compliance test. If at all possible, the ratio of the sample diameter to the maximum aggregate size diameter should be greater than 4.

8. PROCEDURE

8.1 Measure the bulk specific gravity of each test specimen in accordance with AASHTO T166 or T275, whichever applies (note 8).

NOTE 8.—If the bulk specific gravity of the test specimens is measured in accordance with AASHTO T166, the specimens must be allowed to dry prior to testing and preconditioning. Moisture or water trapped in the permeable voids can have an effect on the test results. Retaining the specimens in the temperature cabinet for 12 hours should be sufficient to allow the moisture to evaporate from the permeable voids.

8.2 After the specimens become dry, place the test specimen in a controlled temperature cabinet and bring it to the specified test temperature. Unless the temperature is monitored and the actual temperature known, the specimen shall remain in the cabinet at the specified test temperature for at least 12 hours prior to testing.

8.3 Measure the height and diameter of the specimen to the nearest 2.5 mm. Height or thickness and diameter measurements shall be made at 1/3 points and the values averaged for use in any calculations.

8.4 *Mounting LVDTs on the Specimen's Surface*

8.4.1 Transducers shall be mounted about the center of flat faces of diametral specimens, with a gauge length equal to one-fourth the specimen's diameter. They should be mounted so that the transducer's centerline is no more than 6 mm above the specimen's surface. Measurements shall be taken in both horizontal and vertical directions on both sides of the specimen.

8.4.2 One such system that has been used successfully is shown in figure 3. The displayed system uses a brass mounting apparatus clamped onto brass gauge points. The gauge points are 8 mm in diameter by 3 mm thick and are placed on the specimen with epoxy and a specially designed gauge point template (see figure 3 and note 9). One piece of the mounting apparatus holds the LVDT's transformer securely, while the other piece suspends the core of the LVDT. Both pieces clamp securely to the gauge points with set screws.

NOTE 9.—The two-piece mounting apparatus shown in figure 3 was designed to be used with sub-miniature LVDTs and is machined from a 12-mm diameter brass rod.

8.5 Precondition the room-temperature specimens by one of the following procedures for different equipment.

8.5.1 *For a closed-looped electrohydraulic system.* Apply 100 cycles of haversine load with amplitude equivalent to 70 kPa tension. One load cycle shall consist of 0.1 seconds of haversine loading and 0.9 seconds of zero-load condition. The amplitude of the load may be calculated by

$$P = 11 \times 10^4 tD$$

where

- t = specimen thickness, m (see section 8.3)
 D = specimen diameter, m (see section 8.3)

8.5.2 *For a combination of a screw-type machine with a cam and switch operating a pneumatic air piston.* Apply a constant load equivalent to 70 kPa in tension for 10 seconds. After 10 seconds, release the entire preconditioning load.

8.6 Following the preconditioning procedure, the temperature of the environmental chamber or room is lowered to the test temperature, and the specimens shall be held at the test temperature for 12 hours prior to testing, unless the temperature is monitored within a similar specimen. The remainder of the test procedure is divided into two parts. The first is for the creep-strength test procedure required for thermal cracking evaluations, and the second is for only the strength test procedure required for obtaining data for fatigue cracking analyses.

8.7 Creep-Strength Testing Procedures, Thermal Cracking

8.7.1 The test temperatures for the creep-strength test to evaluate an asphalt concrete mixture's resistance to thermal cracks are 0°C and less. Three test temperatures are typically required for calculating a master compliance curve: 0, -10, and -20°C. As a minimum, however, at least two test temperatures are required for use. Typical values that have been used and proven to produce acceptable results are -5 and -15°C.

8.7.2 After maintaining a constant test temperature in the test specimens for the proper amount of time, zero or rebalance the electronic measuring system and apply a static load of fixed magnitude ($\pm 2\%$) without impact to the specimen.

8.7.3 The fixed load to be used for tensile creep portion of the test must produce between 50 and 200 microstrains of horizontal strain in the first 60 seconds of testing. If either limit is violated, the test shall be stopped and the load adjusted accordingly. A minimum recovery time of 3 minutes is required before restarting the test. Strict compliance to these limits will prevent both non-linear response characterized by exceeding the upper limit and minimize problems associated with noise and drift inherent in sensors when violating the lower strain limit.

8.7.4 Monitor both of the vertical and horizontal deformations on both sides of the specimen during the entire loading time. The load shall be applied for a period of 1,000 seconds ± 15 seconds.

NOTE 10.—Shorter loading times and rest periods (section 8.7.4) can be used to determine the creep properties of asphalt concrete mixtures. It is important that the slope of the log of time versus log of creep compliance be constant or in the steady state range.

8.7.5 After the fixed load has been applied over a period of 1,000 seconds, additional load shall be applied to the specimen at a rate of 12.5 mm of ram or vertical

movement per minute. Both the horizontal and vertical movements and load shall be monitored, until the load begins to decrease (10% reduction from the peak value).

8.8 *Strength Testing Procedure, Fatigue Cracking*

8.8.1 The test temperature to be used for fatigue cracking analyses shall not exceed 20°C.

8.8.2 After maintaining a constant temperature in the test specimens for the proper amount of time, zero or rebalance the electronic measuring system.

8.8.3 Apply a load to the specimen at a rate of 50 mm of ram or vertical movement per minute. Both the horizontal and vertical movements and load shall be monitored, until the load begins to decrease. The test should be stopped as soon as the load begins to decrease to prevent damage to the LVDT equipment from a sudden failure within the specimen.

8.9 After testing has been completed, the specimens shall be broken down and the maximum specific gravity measured in accordance with AASHTO T209.

9. CALCULATIONS

9.1 Calculate the air voids for each test specimen in accordance with AASHTO T269.

9.2 *Compliance Calculations*

9.2.1 Normalize all vertical and horizontal deformation measurements to account for differences caused by variations between specimens in thickness, diameter and applied load. These normalized deformations are calculated by:

$$\Delta_n = \Delta_{m,i} \frac{t_i}{t_{avg}} \frac{P_{avg}}{P_i} \frac{D_i}{D_{avg}}$$

where

Δ_n = Normalized deformation in the horizontal or vertical direction

$\Delta_{m,i}$ = Actual measured deformation in the horizontal or vertical direction for specimen i .

t_i, D_i, P_i = Average thickness, diameter, and load, respectively, for specimen i at a specific temperature.

$t_{avg}, D_{avg}, P_{avg}$ = Average thickness, diameter, and applied load, respectively, for all specimens tested at a specific temperature.

9.2.2 Calculate the average vertical and horizontal displacements with time using the trimmed mean approach. In other words, the highest and lowest normalized deformation readings in the vertical and horizontal directions are excluded from calculating the average values. The highest and lowest readings are identified by comparing the deformations between 460 and 540 seconds of loading time. For each of these specimens at one temperature, a normalized vertical and horizontal displacement with time is calculated.

9.2.3 Calculate the average ratio between the horizontal and vertical readings with time, which is related to Poisson's ratio, ν .

$$\nu = \left(\frac{\Delta_y}{\Delta_x} \right)_{\text{avg}}$$

9.2.4 Calculate the corrected tensile and compressive stresses in the center of the specimen.

$$\sigma_x = \left[\frac{2 P_{\text{avg}}}{\pi t_{\text{avg}} D_{\text{avg}}} \right] C_{\sigma x}$$

$$\sigma_y = \left[\frac{6 P_{\text{avg}}}{\pi t_{\text{avg}} D_{\text{avg}}} \right] C_{\sigma y}$$

where

$C_{\sigma x}$, $C_{\sigma y}$ = Correction factors for the horizontal and vertical stresses, respectively, from table 1.

9.2.5 Calculate the revised Poisson's ratio, ν^*

$$\nu^* = \left[\frac{\sigma_x - \left(\frac{1.093 C_{BX}}{C_{BY} (Y/X)_{\text{avg}}} \right) \sigma_y}{\sigma_y - \left(\frac{1.093 C_{BX}}{C_{BY} (Y/X)_{\text{avg}}} \right) \sigma_x} \right]$$

where

C_{BY} , C_{BX} = Correction factors for bulging in the vertical and horizontal directions, respectively, from table 2

9.2.6 Subtract the initial ν from the revised ν^*

$$E = \nu^* - \nu$$

If E is greater than 0.01, substitute ν^* for ν and repeat steps 10.1.4 through 10.1.6. If E is less than or equal to 0.01, proceed with the following steps.

9.2.7 Calculate the tensile strain in the center of the specimen.

$$\epsilon_x = \left[\frac{\Delta_x}{l} \right] C_{BX}$$

where:

l = gauge length (25.4 or 38.1 mm)

9.2.8 Calculate the compliance at any time, $D(t)$.

$$D(t) = \frac{\epsilon_x}{\sigma_x - \nu^* \sigma_y}$$

9.3 Tensile Strength Calculations

9.3.1 Plot the normalized vertical displacement minus the normalized horizontal displacement as a function of time.

$$\Delta^* = \Delta_y - \Delta_x$$

9.3.2 Define the time at which Δ^* peaks on one of the specimen's faces. Calculate the tensile stress at that time. This tensile stress is the strength of the mix.

$$\sigma_t = \sigma_x @ t_{\text{fail}}$$

10. REPORT

10.1 The report shall include the following information as a minimum.

10.1.1 The bulk specific gravity of each specimen tested.

10.1.2 The maximum specific gravity of the asphalt concrete mixture.

10.1.3 The height and diameter of all test specimens.

10.1.4 The test temperature and load levels (for creep testing) used during the test.

10.1.5 The creep compliance values for the times specified, as a minimum.

10.1.6 The slope of the creep-compliance curve at each test temperature.

10.1.7 The indirect tensile strength and failure strain of the mixture.

Table 1. Correction Factors for Horizontal and Vertical Stress

		Diameter to Thickness Ratio, (t/D)				
$D = 100 \text{ mm or } 150 \text{ mm}$	ν	0.167	0.333	0.500	0.625	0.750
C_{ax}	0.20	0.9471	0.9773	1.0251	1.0696	1.1040
	0.35	0.9561	1.0007	1.0871	1.1682	1.2321
	0.45	0.9597	1.0087	1.1213	1.2307	1.3171
C_{ay}	0.20	-0.9648	-0.9754	-0.9743	-0.9693	-0.9611
	0.35	-0.9732	-0.9888	-0.9844	-0.9710	-0.9538
	0.45	-0.9788	-0.9971	-0.9864	-0.9646	-0.9395

Table 2. Bulging Correction Factors

		Diameter to Thickness Ratio, (t/D)				
$D = 100 \text{ mm or } 150 \text{ mm}$	ν	0.167	0.333	0.500	0.625	0.750
C_{Bx}	0.20	0.9816	0.9638	0.9461	0.9358	0.9294
	0.35	0.9751	0.9518	0.9299	0.9179	0.9108
	0.45	0.9722	0.9466	0.9234	0.9111	0.9040
C_{By}	0.20	0.9886	0.9748	0.9677	0.9674	0.9688
	0.35	0.9808	0.9588	0.9479	0.9473	0.9493
	0.45	0.9759	0.9492	0.9364	0.9358	0.9380

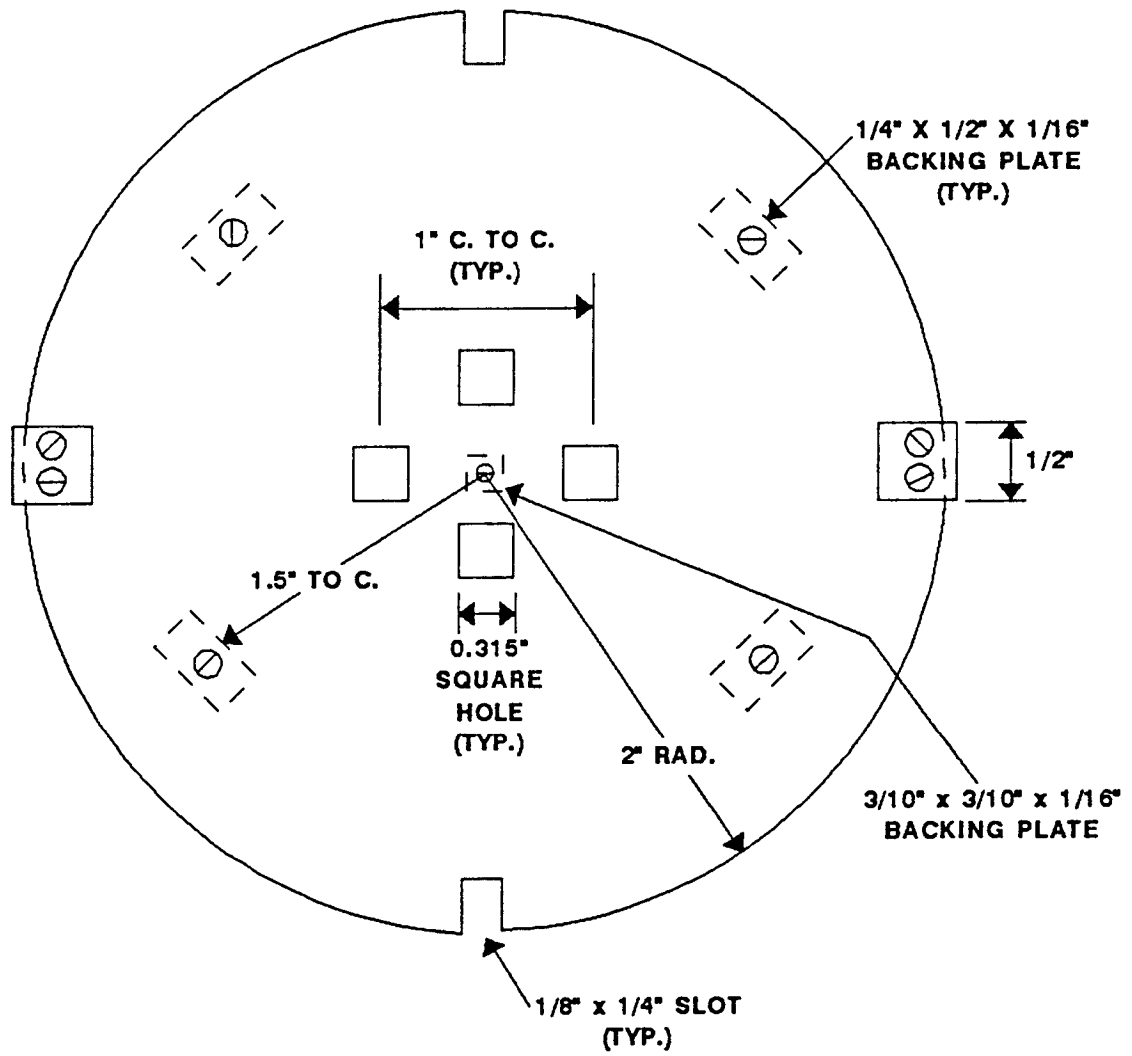


Figure 1. Four-Inch Gauge Point Template (Top View)

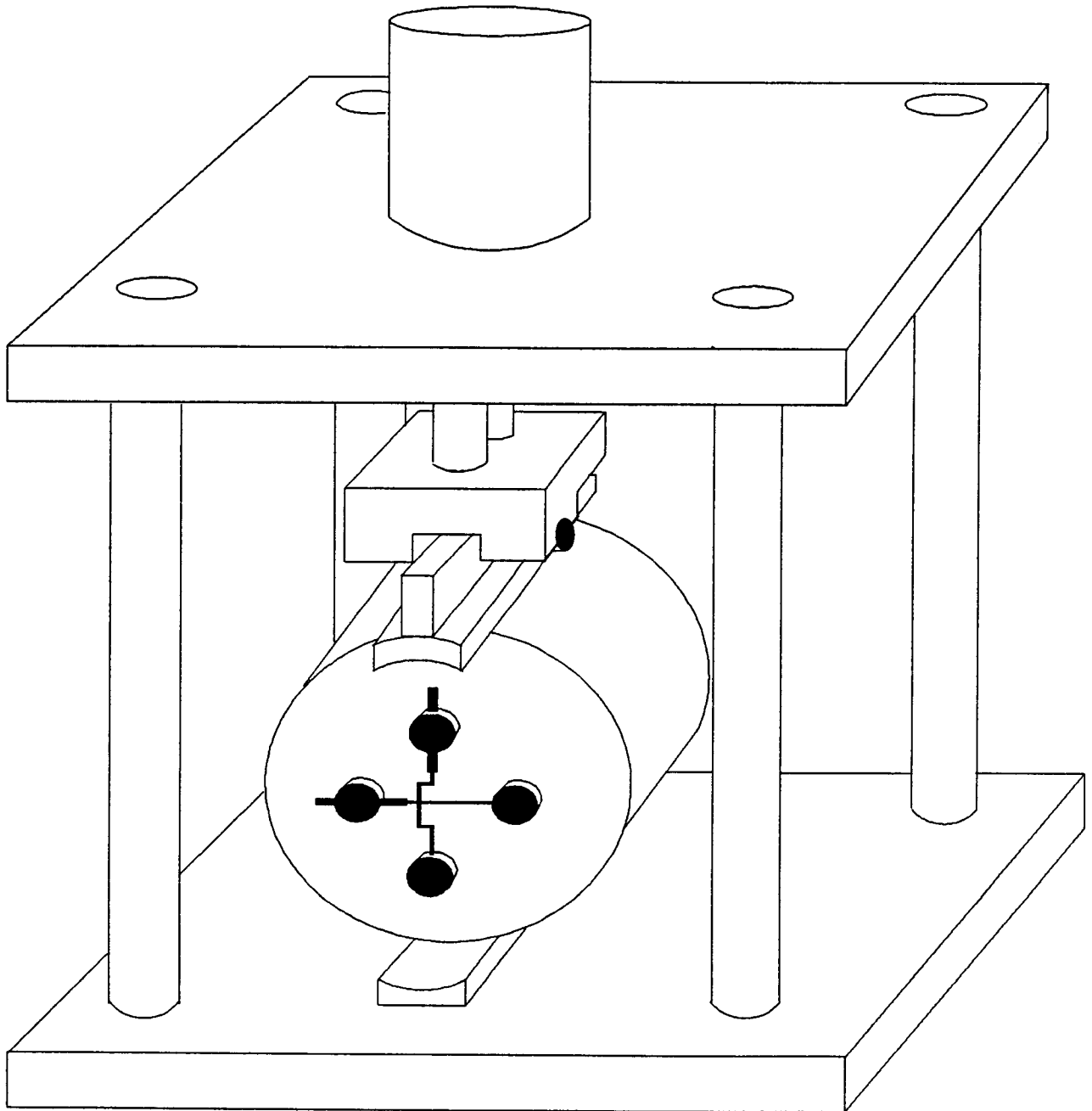


Figure 2. Specimen Loading Frame with Smaller Guide Frame

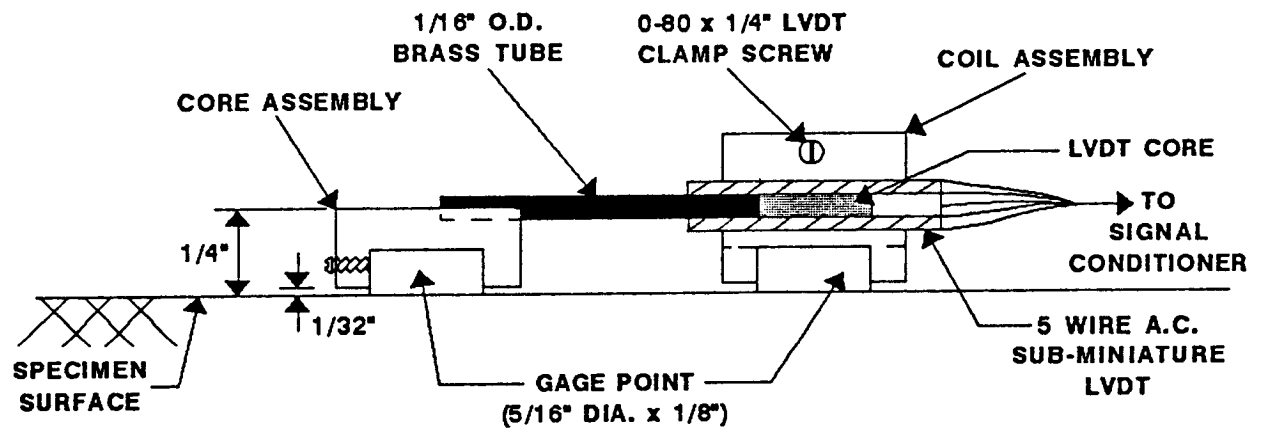


Figure 3. Cross Section of LVDT Mounting

Standard Method of Test for

**Determining Moisture Sensitivity Characteristics
of Compacted Bituminous Mixtures Subjected
to Hot and Cold Climate Conditions**

SHRP Designation: M-006¹

1. SCOPE

1.1 This method determines the water sensitivity or stripping characteristics of compacted asphalt concrete mixtures under warm and cold climatic conditions.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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.*

1.3 The values stated in SI units are to be regarded as the standard. The values in parentheses are for information only.

2. REFERENCED DOCUMENTS

2.1 *AASHTO Documents*

MP1	Method of Test for Performance-Graded Asphalt Binder
R 11	Practice for Indicating Which Places of Figures are to be Considered Significant in Specifying Limiting Values
T2	Method for Sampling Aggregates
T27	Method for Sieve Analysis of Fine and Coarse Aggregates
T40	Method for Sampling Bituminous Materials
T164	Method for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
T167	Method for Compressive Strength of Bituminous Mixtures
T168	Method of Sampling Bituminous Paving Mixtures
T247	Method for Preparation of Test Specimens of a Bituminous Mixture by Means of the California Kneading Compactor
T269	Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures

¹This standard is based on SHRP Product 1024.

- M-002 Preparation of Compacted Concrete Specimens of Modified and Unmodified Hot Mix Asphalt by Means of the SHRP Gyrotory Compactor
- M-008 Preparation of Test Specimens of Bituminous Mixtures by Means of Rolling Wheel Compaction
- M-007 Short- and Long-Term Aging of Asphalt Concrete Mixtures

2.2 ASTM Documents

- D 8 Standard Definitions of Terms Relating to Materials for Roads and Pavements
- D 3497 Standard Test Methods for Dynamic Modulus of Asphalt Mixtures
- D 3549 Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
- E 1 Specification for Thermometers

3. TERMINOLOGY

3.1 Definitions for many terms to asphalt are found in the following documents:

3.1.1 ASTM D8 Standard Definitions

3.1.2 AASHTO MP1 Performance-Graded Asphalt Binder

4. SUMMARY OF PRACTICE

4.1 Compacted asphalt concrete test specimens are subjected to a water and temperature conditioning process. The water sensitivity characteristics of the compacted mixtures are determined based upon measurements of percent stripping, the environmental conditioning system (ECS) modulus, and the coefficients of permeability for air and water flow.

5. SIGNIFICANCE AND USE

5.1 The measured water sensitivity characteristics may be used to evaluate or characterize asphalt concrete mixtures.

5.2 The water sensitivity characteristics of asphalt concrete mixtures can be used to determine their suitability for use as highway paving materials. This information may also be used to compare and select binders, modifiers, mixtures, additives, and aggregates for asphalt concrete.

6. APPARATUS

6.1 Environmental Condition System (ECS)—Any closed-loop computer-controlled test system that meets the minimum requirements outlined in table 1. The ECS must be capable of within an asphalt concrete specimen increasing the temperature to 100°C and decreasing it to -20°C within 2 hours. It must be able to "pull" distilled water through a specimen at specified vacuum levels. The ECS must be able to apply axial load pulses (220 ± 5 N static and 6700 ± 25 N dynamic) in a haversine wave form with a load duration of 0.1 s and a rest period of 0.9 s between load pulses. The system must also be capable of measuring axial deformations and be equipped with computer software which can compute axial compressive stress and recoverable axial deformation strain at various load cycles. In addition, the ECS must be capable of applying loads sufficient to obtain deformations between 50 to 100 μ strain. The ECS is illustrated in figures 1, 2, and 3.

Table 1. Minimum Test System Requirements

Measurement and Control Parameters	Range	Resolution	Accuracy
Load (compression)	0 to 6700 N	≤ 2.5 N	± 5 N
Axial Deformation	0 to 6.5 mm	≤ 0.0001	± 0.0001
Chamber Temperature	-20 to 100°C	$\leq 0.5^\circ\text{C}$	$\pm 0.5^\circ\text{C}$
Vacuum Pressure	0 to 635 mm Hg	≤ 25 mm Hg	± 25 mm Hg
Air Flow	20 to 20,000 cm ³ /min	≤ 20 cm ³ /min	± 10 cm ³ /min
Water Flow	0 to 2525 cm ³ /min	≤ 2 cm ³ /min	± 1 cm ³ /min
Water Reserve Temperature	$25 \pm 3^\circ\text{C}$	$\leq 0.5^\circ\text{C}$	$\pm 0.5^\circ\text{C}$

6.2 Testing Machine—a pneumatic or hydraulic testing machine that meets the requirements outlined in section 4.3 of T167.

6.3 Specimen End Platens—Two aluminum end platens are shown in figure 4. The end platens shall be 102 ± 2 mm diameter by 51 ± 2 mm thick. Each end platen will have a drainage hole at its center that is 4.76 ± 0.5 mm in diameter and one side of each end platen will be patterned with grooves as shown in figure 4. In addition, the platen must have a groove around its perimeter at mid height which is of sufficient width and depth to hold the O-rings described in section 6.5.2.

6.4 Perforated Teflon Disks—As shown in figure 4. The perforations must coincide with the grooving pattern in the specimen end platens.

6.5 *Miscellaneous Apparatus:*

6.5.1 150 mm of 100 mm diameter rubber membrane capable of covering the cylindrical surface area of the specimen.

6.5.2 Two 102 mm O-rings

6.5.3 Caulking gun

6.5.4 Calipers

6.5.5 Spatula

6.5.6 Vacuum source

7. MATERIALS

7.1 The following materials are required:

7.1.1 Clear silicone sealant (e.g., general household sealant, silicon rubber)

7.1.2 Compressed air

7.1.3 40 L of distilled water

8. SAMPLING

8.1 Asphalt binder shall be sampled in accordance with AASHTO T40.

8.2 Aggregate shall be sampled in accordance with AASHTO T2.

8.3 Asphalt concrete mixtures shall be sampled in accordance with AASHTO T168.

9. SPECIMEN PREPARATION

9.1 Prepare an asphalt concrete mixture sample in accordance with sections 9.1, 9.2, and 9.3 of T247. Prepare a sufficient amount of material to ensure that the final compacted test specimen is 102 ± 4 mm in diameter by 102 ± 4 mm in height.

9.2 Subject the asphalt concrete mixture prepared in section 9.1 to short-term aging in accordance with sections 10.1, 10.2, and 10.3 of T247.

NOTE 1.—Plant mixed asphalt concrete samples are not to be subjected to short-term aging as described in T247.

9.3 Heat or cool the asphalt concrete mixture to the described compaction temperature.

9.4 Compact the asphalt concrete mixture in accordance with T247. Compact a sufficient amount of material to ensure that the final compacted test specimen is 102 ± 4 mm in height.

9.5 Determine the air void of the specimen.

NOTE 2.—It is *not* recommended that the Marshall method of compaction (AASHTO T245-82 or ASTM D 1559-89) be used. If specimens are cored from the field or from a slab, the top and bottom of the specimen must *not* sustain a cut surface.

9.6 Measure the diameter and height or thickness of the specimen at three locations, at approximately one-third points and record the average measurement as the diameter and thickness of the specimen ± 1.0 mm in accordance with D 3549.

9.7 Place the specimen inside the 150-mm long rubber membrane, centering the specimen within the membrane so that there is a 25-mm overlap at each end. Inject a continuous line of silicone cement between the membrane and the specimen with a caulking gun. Use a spatula to smooth the silicone to a thick, uniform layer between the rubber membrane and the specimen. Allow the specimen to stand at room temperature, overnight or longer, until the silicone is dry.

10. PROCEDURE

10.1 Specimen Setup

10.1.1 Place a perforated Teflon disk on top of the grooved surface of the bottom end platen inside the load frame.

10.1.2 Place the specimen vertically on top of the Teflon disk and bottom end platen.

NOTE 3.—For cores removed from field pavements, it is important that the specimen be placed such that the top of the specimen corresponds to the top of the pavement.

10.1.3 Place a perforated Teflon disk on top of the specimen and place the top end platen on top of the disk, with the grooved surface facing the disk and specimen.

10.1.4 Seal the rubber membrane around the specimen platen assembly by placing an O-ring in each groove of the end platens, over the rubber membrane.

10.1.5 To ensure that the system is airtight, select vacuum with the water-vacuum-air valve. This closes the system to air and water. Open the vacuum valve until the inlet and outlet pressure reads 510 mm of Hg. Adjust the vacuum level with the vacuum regulator. Close the vacuum valve. Close the bypass valve so that the vacuum is drawn through the

specimen. Wait for 5 minutes. If both gauge readings remain constant, the system is airtight and testing may continue. If the readings decrease, the system is not airtight and adjustments must be made to the system prior to continuing testing.

10.1.6 Attach the yoke with the spacers and the LVDTs to the specimen.

10.2 *Coefficient of Permeability for Air Flow*

10.2.1 Set and establish the temperature of the environmental control chamber to $25 \pm 0.5^\circ\text{C}$.

10.2.2 Open the vacuum valve and select air flow from the water-vacuum-air valve. Apply the lowest differential pressure possible (typically 50 mm of Hg) by adjusting the vacuum regulator. Record the air flow through the test specimen. Record the pressure differential reading.

10.2.3 Repeat 10.2.2 for four different pressures. The pressures selected will vary depending on the void content of the specimen being tested. They may range from 50 to 400 mm of Hg. It is important that a range be selected that is consistent with the air void content. A constant interval between the pressures must be selected e.g., 20, 30, 40, and 50 kPa.

10.2.4 Calculate the coefficient of permeability for air flow of the test specimen as described in 11.2.1 for each of the pressures. Report the average of the four results.

NOTE 4.—Air flow measurements should be within 10% of each other.

10.2.5 Close the vacuum valve.

10.3 *ECS Modulus Test*

10.3.1 Maintain the temperature of the environmental chamber at $25 \pm 0.5^\circ\text{C}$. Remove the spacers from the yoke.

10.3.2 Apply a static load of 130 ± 25 N and an axial compressive repeated load of 2200 ± 25 N to the test specimen. The repeated load should be in a haversine wave form with a load duration of 0.1 s and a rest period of 0.9 s between load pulses.

10.3.3 Adjust the specimen until the readings from the two LVDTs are within 15% of each other.

10.3.4 If the strain is less than $50 \mu\text{strain}$, *increase* the repeated load until a strain level between 50 and $100 \mu\text{strain}$ is reached. If the strain is more than $100 \mu\text{strain}$, *decrease* the repeated load until a strain level between 50 and $100 \mu\text{strain}$ is reached.

10.3.5 If using the ECS software, the load and deformation data for the last five cycles are collected and the ECS modulus automatically calculated when the [ESC] key is

pressed. Otherwise, measure and record the peak axial load and recoverable vertical deformation for the load interval from the last five cycles. Then calculate the ECS modulus as outlined in section 11.3.3.

NOTE 5.—Typically, to achieve a strain level of $100 \pm 5 \mu\text{strain}$, a dynamic load approximately 4000 N is required. Once the load has been adjusted, use the same loads for subsequent measurements for the *same* specimen after the conditioning cycles.

NOTE 6.—Do *not* exceed 250 load cycles when performing the ECS modulus test. This will damage the specimen.

10.3.6 Remove the load from the specimen after the last load cycle. Check that the inlet and outlet gauges are closed.

10.4 *Vacuum*

10.4.1 Check that the bypass valve is open. Select vacuum with the vacuum-water-air valve.

10.4.2 Open the vacuum valve and close the bypass valve. Apply a vacuum of 510 mm of Hg for 10 min.

10.4.3 Open the bypass valve.

10.5 *Wetting*

10.5.1 Maintain the temperature of the environment chamber at $25 \pm 0.5^\circ\text{C}$. Establish the temperature of the distilled water source at $25 \pm 3^\circ\text{C}$ (room temperature). Open the bypass valve.

10.5.2 Select water flow from the vacuum-water-air valve. Turn on the vacuum and adjust using the vacuum regulator until a level of 510 ± 25 mm of Hg (as measured by the outlet gauge) has been reached.

10.5.3 Wait for one minute or until distilled water has been drawn into the tubing and the system. Close the bypass valve so that the distilled water is pulled through the test specimen for 30 ± 1 min.

10.6 *Coefficient of Permeability of Water Flow*

10.6.1 Decrease the vacuum level to approximately 40 kPa (5.8 psi) differential pressure by adjusting the vacuum regulator. Record the water flow through the test specimen. Record the pressure differential reading.

10.6.2 Repeat the procedure described in section 10.6.1 for four different pressures. The pressures selected will vary depending on the void content of the specimen being tested.

They may range from 20 to 40 kPa differential pressure. It is important that a range be selected that is consistent with the air void content.

10.6.3 Calculate the coefficient of permeability for water flow as described in section 11.5.1 for each pressure. Report the average result.

NOTE 7.—Water flow measurements should be within 10% of each other.

10.7 Water Conditioning

10.7.1 Conduct water conditioning for either the warm or cold climate conditions as described in sections 10.7.2 or 10.7.3, respectively. Table 2 summarizes the procedures described in sections 10.7.2 and 10.7.3.

Table 2. Conditioning Cycles for Warm and Hot Climates

Conditioning Factor	Conditioning Stage				
	Wetting*	Cycle-1	Cycle-2	Cycle-3	Cycle-4
Vacuum Level (mm Hg)	510	250	250	250	250
Repeated Loading	NO	YES	YES	YES	NO
Ambient Temperature (°C)**	25	60	60	60	-18
Duration (hrs)	0.5	6	6	6	6

The diagram below the table shows two horizontal arrows indicating the scope of conditioning procedures. The top arrow, labeled 'Conditioning Procedure for Warm Climates', spans from the 'Wetting*' column to the end of the 'Cycle-3' column. The bottom arrow, labeled 'Conditioning Procedure for Cold Climate', spans from the 'Wetting*' column to the end of the 'Cycle-4' column. Vertical dashed lines mark the boundaries of these procedures.

*Wetting the specimen prior to the conditioning cycles

**inside the environmental cabinet

Notes:

1. The conditioning procedure for a warm climate is wet, then 3 hot cycles.
2. The conditioning procedure for a cold climate is wet, then 3 hot cycles plus one cold cycle.

10.7.2 Warm Climate Conditioning

10.7.2.1 Reduce the vacuum pressure to 254 ± 25 mm Hg at the outlet gauge and reduce the water flow to 4 ± 1 cm³/min.

10.7.2.2 Set the temperature of the environmental cabinet to $60 \pm 0.5^\circ\text{C}$ for 6 hours ± 5 min, followed by a temperature of $25 \pm 0.5^\circ\text{C}$ for at least 2 hours.

10.7.2.3 Apply a repeated axial compressive load of 90 ± 5 N static and 900 ± 25 N dynamic to the test specimen, in a haversine wave form with a load duration of 0.1 s and a rest period of 0.9 s between load pulses. Continuous application of the load is to occur throughout the hot conditioning cycle (i.e., 6 hours at 60°C).

NOTE 8.—For open-graded mixes, the loads may need to be reduced.

10.7.2.4 At the end of 8 hours, close the vacuum valve, open the bypass valve and open the system to atmospheric pressure. Continue to maintain the temperature setting of the environmental chamber at $25 \pm 0.5^\circ\text{C}$. Determine the ECS modulus as described in section 10.3.

NOTE 9.—For the modulus test, use the same loads that were initially established in section 10.3.

10.7.2.5 Continue to maintain temperature setting of the environmental chamber at $25 \pm 0.5^\circ\text{C}$ and determine the coefficient of permeability of water flow as described in section 10.6.

NOTE 10.—If excessive deformation (5 to 10%) of the specimen is experienced after the first hot cycle, terminate the conditioning.

10.7.2.6 Begin a second hot conditioning cycle by repeating the procedure in sections 10.7.2.1 to 10.7.2.5.

10.7.2.7 Begin a third hot conditioning cycle by repeating the procedure in sections 10.7.2.1 to 10.7.2.5.

10.7.3 *Cold Climate Conditioning*

10.7.3.1 Complete the three hot conditioning cycles as described in sections 10.7.1. to 10.7.2.7.

10.7.3.2 Reduce the vacuum pressure to 250 ± 25 mm Hg at the outlet gauge and reduce the water flow to 4 ± 1 cm³/min. Turn off the load.

10.7.3.3 Set the temperature of the environmental chamber to $-18 \pm 0.5^\circ\text{C}$ for 6 hours ± 5 min followed by a temperature of $25 \pm 0.5^\circ\text{C}$ for at least 2 hours.

10.7.3.4 At the end of the 8 hours, close the vacuum valve, open the bypass valve and open the system to atmospheric pressure. Continue to maintain the temperature setting of the environmental chamber at $25 \pm 0.5^\circ\text{C}$. Determine the ECS resilient modulus as described in section 10.3.

10.7.3.5 Continue to maintain the temperature setting of the environmental chamber at $25 \pm 0.5^\circ\text{C}$ and determine the coefficient of permeability of water flow as described in section 10.6.

10.8 Stripping Evaluation

10.8.1 At the conclusion of the last conditioning cycle, remove the specimen from the environmental chamber. Remove the membrane from the specimen and place it in a diametral position between two bearing plates of a loading jack on a mechanical or hydraulic testing machine.

10.8.2 Apply a load sufficient to induce a vertical crack in the specimen.

10.8.3 Remove the test specimen and pull the two halves apart. Estimate the percentage of stripping that has occurred by making a relative comparison to the standard patterns of stripping shown in figure 6.

11. CALCULATIONS

11.1 Calculate the following:

11.1.1 *Cross Sectional Area (m^2):*

$$A = \frac{\pi d^2}{40,000} \quad (1)$$

where

d = Average diameter of the test specimen, in cm
 π = 3.14159

11.2 After conducting the air permeability testing outlined in section 10.2, calculate the following:

11.2.1 *Coefficient of Permeability of Air Flow (cm/s):*

$$k_a = \frac{1.7937 \times 10^{-8} qL}{\Delta P} \quad (2)$$

where

k_a = Coefficient of permeability for air flow, in cm/s
 q = Flow rate of air at mean pressure across specimen, in cm^3/min
 L = Average height of the test specimen, in mm
 ΔP = Pressure difference across the specimen, mm Hg

11.3 For the last five load cycles applied as specified in section section 10.3, calculate the following:

NOTE 11.—The ECS software should automatically make the computations described in sections 11.3, 11.4, and 11.6.1.

11.3.1 Peak Stress (kPa) per load cycle:

$$\sigma_{i-n} = \left[\frac{V_{i-n}}{A} \right] \quad (3)$$

where

V_{i-n} = Peak load applied by the vertical actuator over a load cycle, in N

i = Number of conditioning cycles applied (i.e., 0, 1...4)

n = Number of load cycles applied (i.e., 1, 2, 3, 4, 5)

11.3.2 Recoverable Axial Strain (mm/mm) per load cycle:

$$\epsilon_{i-n} = \frac{\delta_{ri-n}}{2h} \quad (4)$$

where

δ_{ri-n} = Peak recoverable vertical deformation over a load cycle, in mm

h = Gauge length, the distance over which deformations are measured (i.e., distance between yoke rings), in mm

NOTE 12.—The recoverable deformation is the position of the total deformation that disappears (or is recovered) upon unloading the specimen as shown in figure 7.

11.3.3 ECS Modulus (kPa) per load cycle:

$$M_{Ri-n} = \left[\frac{\sigma_{i-n}}{\epsilon_{i-n}} \right] \quad (5)$$

11.4 After calculating ECS modulus for the last five load cycles, calculate the following:

11.4.1 Average ECS Modulus (kPa) per conditioning cycle:

$$M_{Ri} = \frac{\sum_{n=1}^5 (M_{Ri-n})}{\Delta n} \quad (6)$$

where

Δn = the number of load cycle included in M_{Ri} calculation (for last five load cycles, $\Delta n = 5$)

11.5 After conducting the water permeability testing outlined in section 10.6, calculate the following:

11.5.1 *Coefficient of Permeability for Water Flow (cm/s):*

$$k_w = \frac{7.4075 \times 10^{-6} qL}{\Delta P} \quad (7)$$

where

k_w	=	Coefficient of permeability for water flow, in cm/s
q	=	Flow rate of water at mean pressure across specimen, in cm ³ /min
L	=	Average height of the test specimen, in mm
ΔP	=	Pressure difference across the specimen, in kPa

11.6 After completing each conditioning cycle (*i*), compute the following:

11.6.1 *ECS Modulus Ratio:*

$$M_R R_i = \left[\frac{M_{Ri}}{M_{R0}} \right] \quad (8)$$

where

M_{R0} = Initial ECS resilient modulus, in kPa

11.6.2 *Water Permeability Ratio:*

$$k_{Rwi} = \left[\frac{k_{wi}}{k_{w0}} \right] \quad (9)$$

where

k_{w0} = Initial water permeability, in cm/s

12. REPORT

12.1 Report the following information:

12.1.1 *Asphalt Binder Grade*

12.1.2 *Asphalt Binder Content*—in percent to the nearest 0.1%

12.1.3 *Aggregate Type and Gradation*

12.1.4 *Mixing and Compaction Conditions*—the following information is applicable:

12.1.4.1 *Plant Mixing Temperature*—in degrees Celsius to the nearest 1°C

12.1.4.2 *Laboratory Mixing Temperature*—in degrees Celsius to the nearest 1°C

12.1.4.3 *Laboratory Compaction Temperature*—in degrees Celsius to the nearest 1°C

12.1.4.4 *Laboratory Compaction Method*

12.1.4.5 *Compacted Specimen Height*—in centimeters to the nearest 0.15 cm

12.1.4.6 *Compacted Specimen Diameter*—in centimeters to the nearest 0.15 cm

12.1.4.7 *Compacted Specimen Area*—in square centimeters to the nearest 0.02 cm²

12.1.4.8 *Compacted Specimen Density*—in kilograms per square meter to the nearest 0.02 cm²

12.1.4.9 *Compacted Specimen Air Voids*—in percent to the nearest 0.1%

12.1.5 *Coefficient of Permeability for Air Flow*—a table listing of the following results for each different pressure applied:

12.1.5.1 *Chamber Testing Temperature*—in degrees Celsius to the nearest 0.5°C

12.1.5.2 *Differential Pressure*—in mm of Hg

12.1.5.3 *Air Flow*—in cubic centimeters per second to the nearest 2 cm³/s

12.1.5.4 *Coefficient of Permeability for Air Flow*—in cm/s to the nearest 2 cm/s

12.1.6 *ECS Modulus Results*—a table listing the following results for each load cycle (last five cycles) prior to any conditioning cycles and after each conditioning cycle:

12.1.6.1 *Chamber of Testing Temperature*—in degrees Celsius to the nearest 0.5°C

12.1.6.2 *Static Load Applied*—in newtons to the nearest 5 N

12.1.6.3 *Dynamic Load Applied*—in newtons to the nearest 5 N

12.1.6.4 *Peak Stress*—in kilopascals to the nearest 0.1 kPa

12.1.6.5 Recoverable Axial Strain—in millimeters per millimeter to the nearest 10^{-6} mm/mm

12.1.6.6 ECS Modulus—in kilopascals to the nearest 5 kPa

12.1.7 Initial ECS Modulus—in kilopascals to the nearest 5 kPa

12.1.8 Coefficient of Permeability for Water Flow—a table listing the following results for each differential pressure applied after each conditioning cycle:

12.1.8.1 Chamber Testing Temperature—in degrees Celsius to the nearest 0.5°C

12.1.8.2 Water Temperature—in degrees Celsius to the nearest 0.5°C

12.1.8.3 Differential Pressure—in kPa to the nearest 5 kPa

12.1.8.4 Water Flow—in cubic centimeters per minute to the nearest $2\text{ cm}^3/\text{min}$

12.1.8.5 Coefficient of Permeability of Water Flow—in centimeters per second to the nearest 10^{-4} cm/s

12.1.9 Water Conditioning Results—a table listing the following results for each conditioning cycle:

12.1.9.1 Average ECS Modulus—in kPa to the nearest 5 kPa

12.1.9.2 ECS Modulus Ratio

12.1.9.3 Water Permeability Ratio

12.1.10 Stripping Rate—in percent to the nearest 5%

13. PRECISION

13.1 Data to support a precision statement for this test method are not available.

13.2 Since there is no accepted reference value, the bias for this test method cannot be determined.

14. KEYWORDS

14.1 Asphalt concrete, asphalt concrete permeability, bituminous mixtures, bituminous paving mixtures, moisture sensitivity, resilient modulus, stripping potential, water sensitivity.

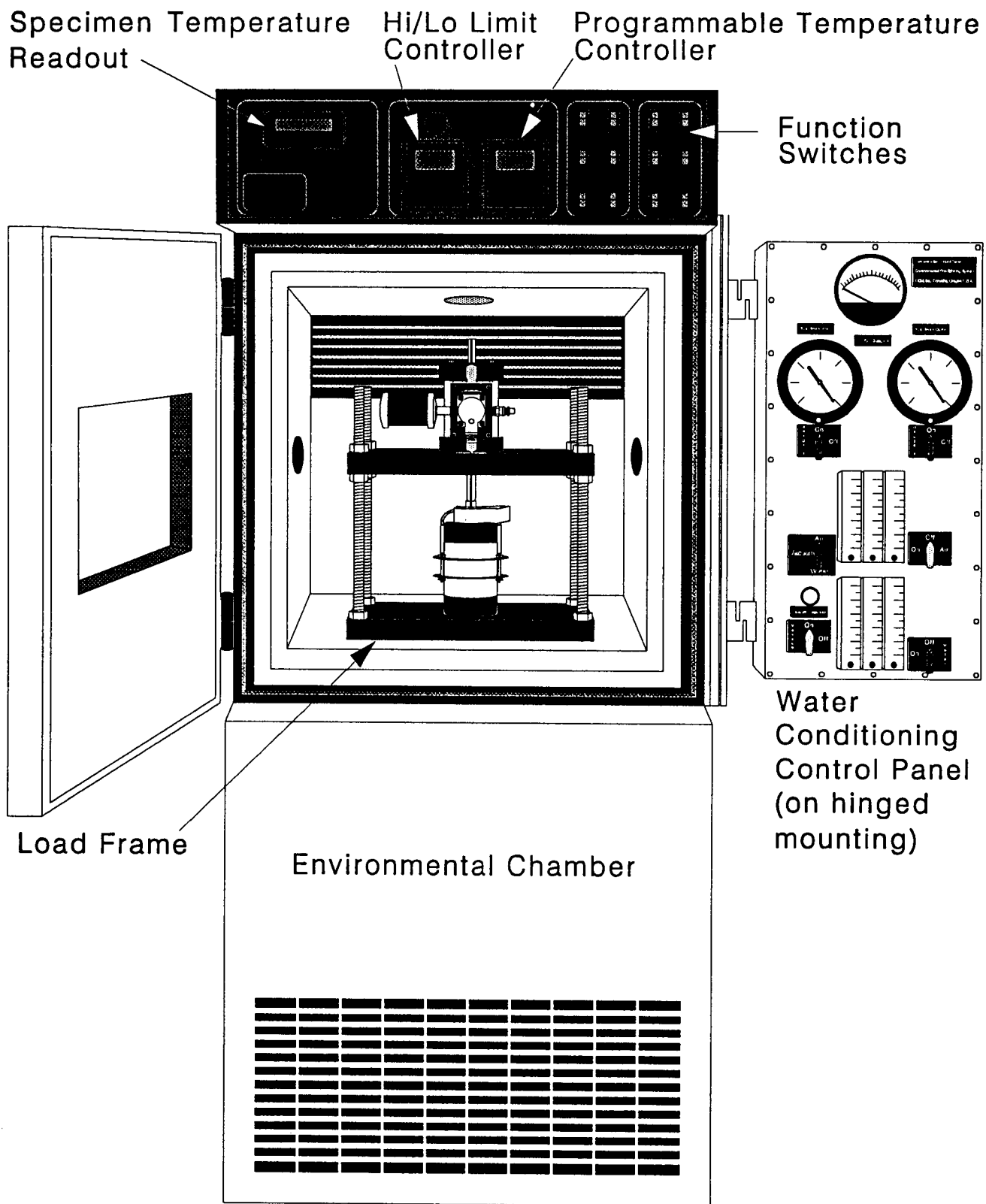


Figure 1. Environmental Conditioning System (Front View)

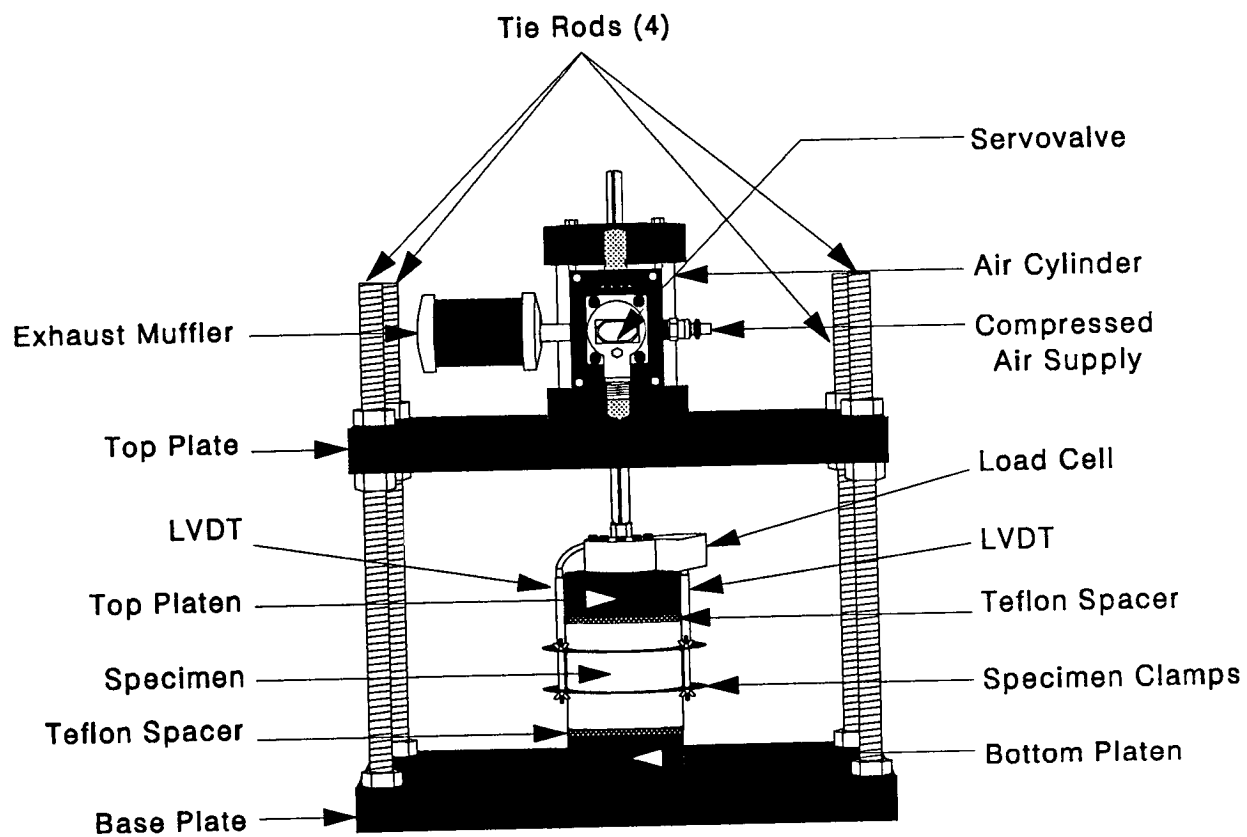


Figure 2. Load Frame with Specimen

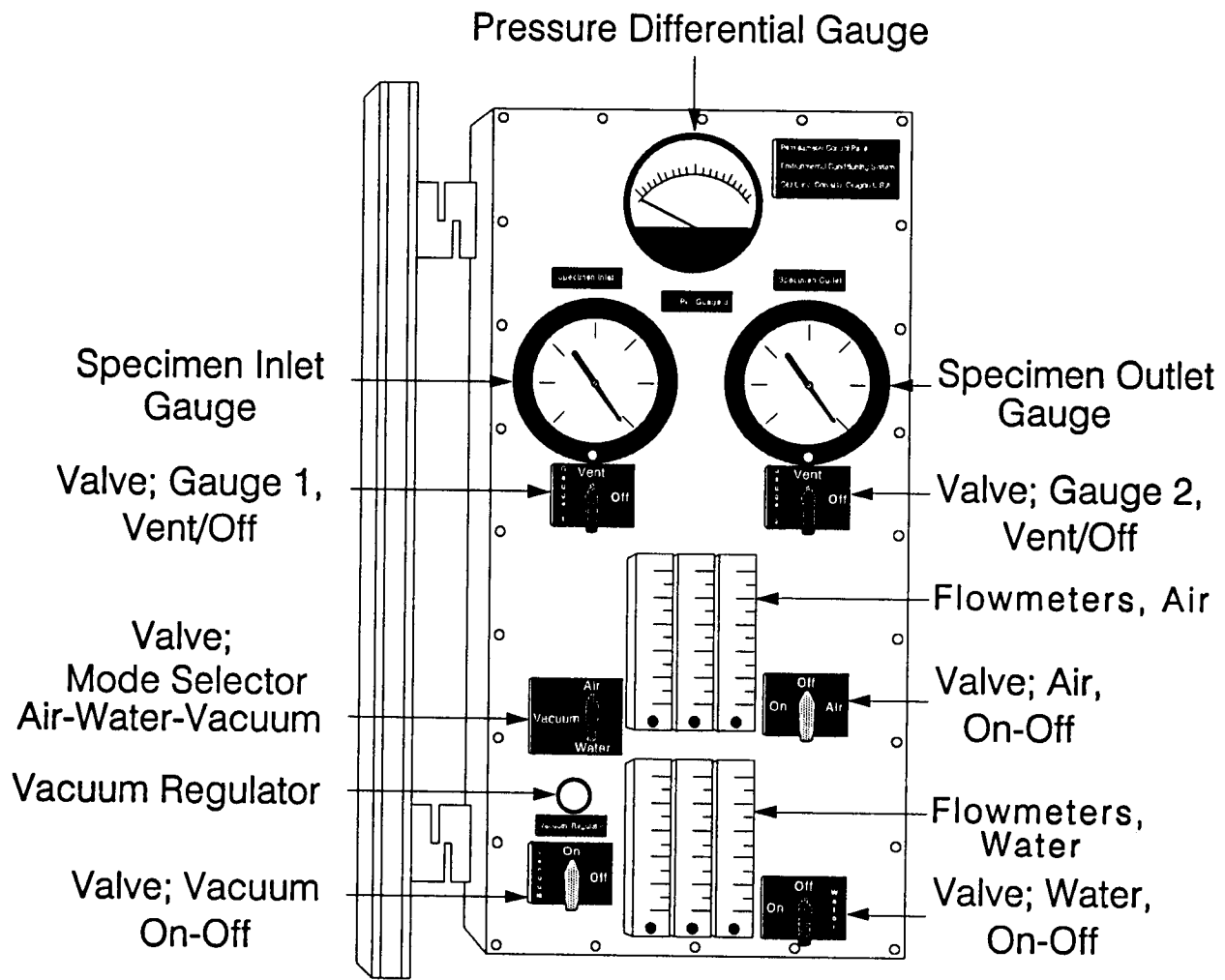


Figure 3. Control Panel

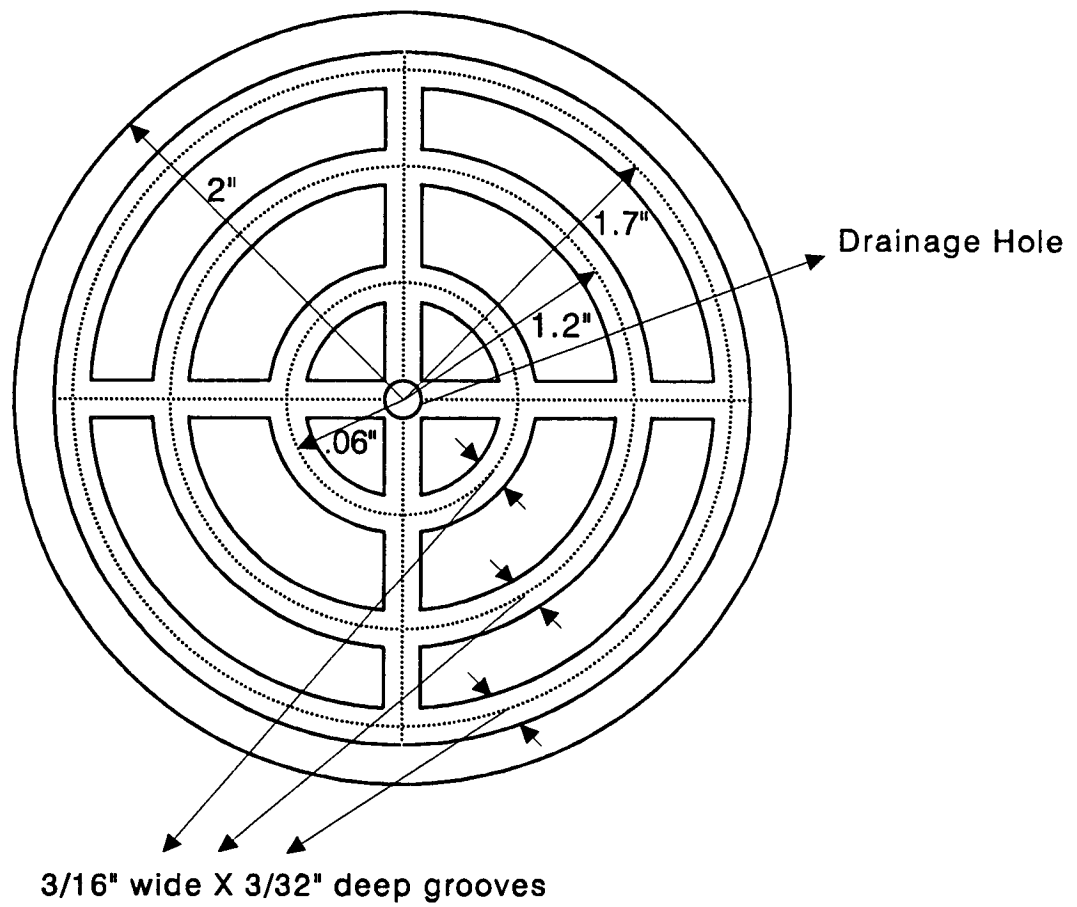


Figure 4. Groove Pattern for End Platens

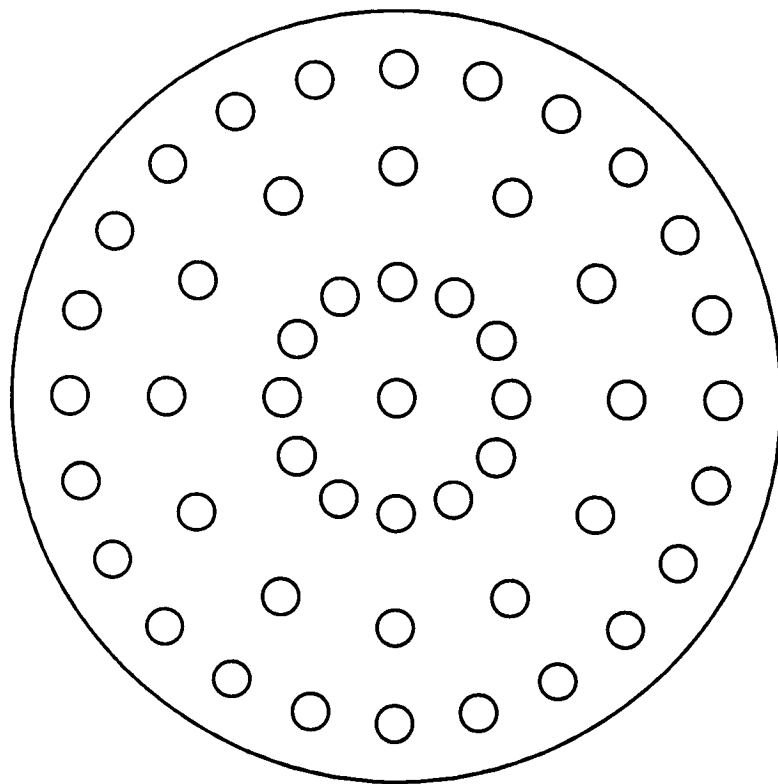


Figure 5. Perforated Teflon Spacers

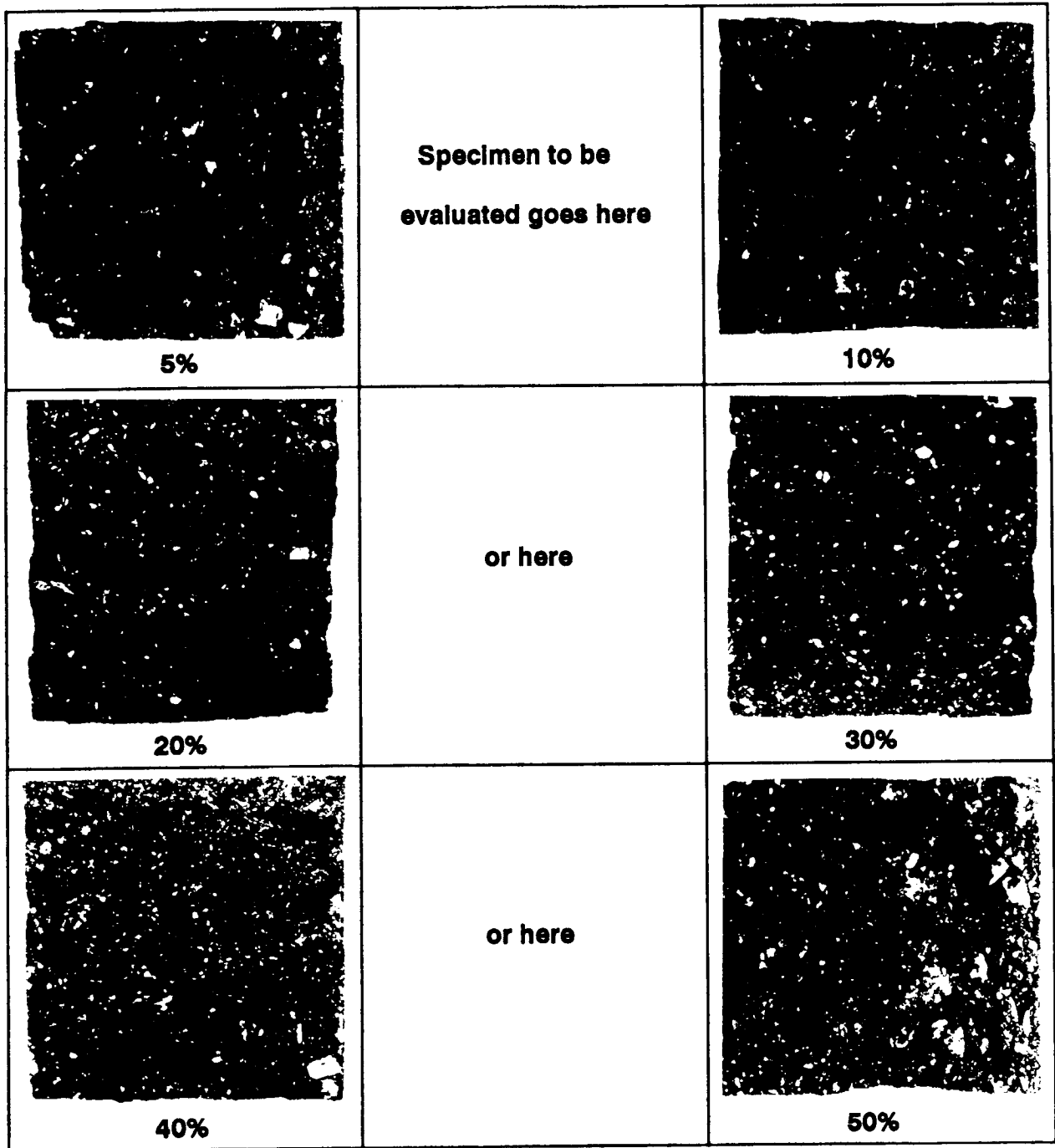


Figure 6. Stripping Rate Standards

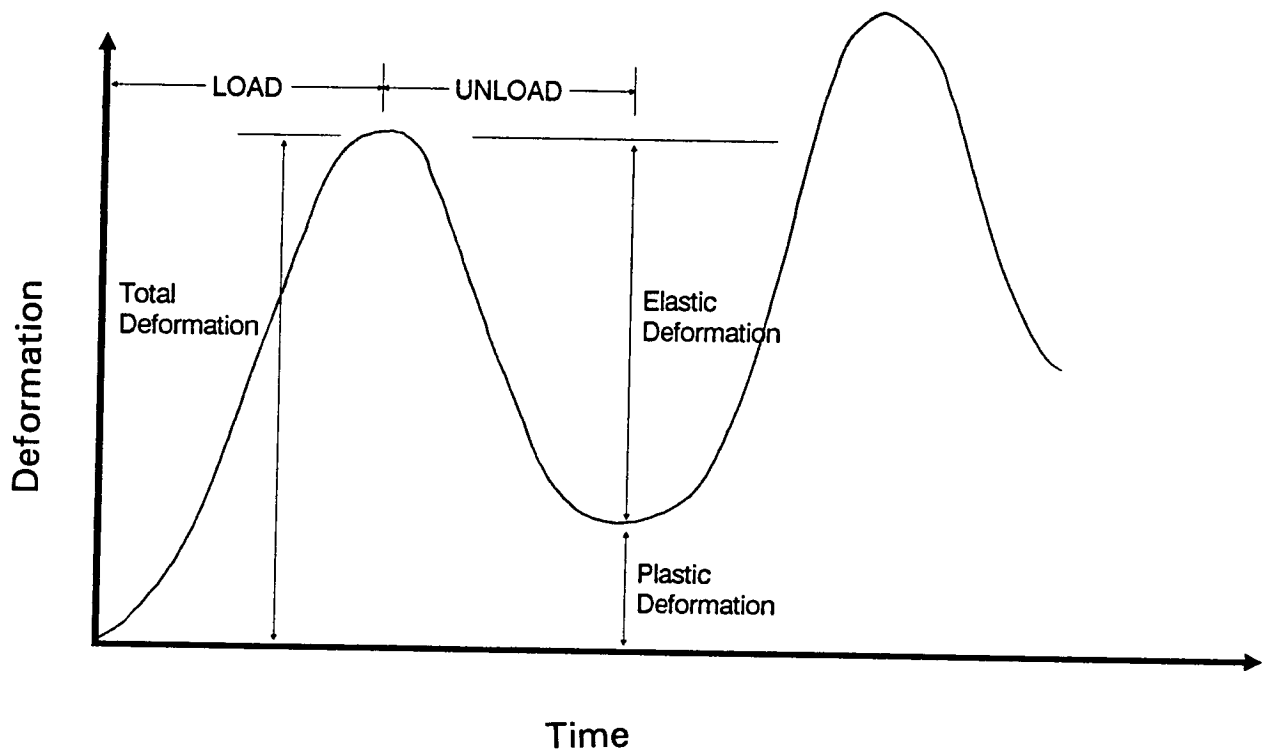


Figure 7. Illustration of Specimen Deformation Resulting from Application of Load Cycles

Standard Method of Test for
Short- and Long-Term Aging of Bituminous Mixes

SHRP Designation: M-007¹

1. SCOPE

1.1 This method describes the short- and long-term aging procedures for compacted and uncompacted bituminous mixtures. Two types of aging are described: 1) short-term aging of uncompacted mixtures to simulate the precompaction phase of the construction phase, and 2) long-term aging of compacted mixtures to simulate the aging that occurs over the service life of a pavement. The long-term aging procedures should be preceded by the short-term aging procedure. Evaluation of the extent of aging should be performed using a resilient modulus test (ASTM D 4123-82), dynamic modulus test (ASTM D 3497-79) or other approved test.

1.2 *This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems 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.*

1.3 The values stated in SI units are to be regarded as the standard. The values in parentheses are for information only.

2. REFERENCED DOCUMENTS

2.1 AASHTO Documents:

MP1	Test Method for Performance-Graded Asphalt Binder
R 11	Practice for Indicating Which Places of Figures are to be Considered Significant in Specifying Limiting Values
T2	Methods of Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials
T27	Method for Sieve Analysis of Fine and Coarse Aggregates
T40	Method of Sampling Bituminous Materials
T164	Methods of Test for Quantitative Extraction of Bitumen from Bituminous Paving Material
T168	Methods of Sampling Bituminous Paving Mixtures

¹This standard is based on SHRP Products 1025 and 1030.

- T201 Method of Test for Kinematic Viscosity of Asphalts
- T269 Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures
- M-002 Preparation of Compacted Specimens of Modified and Unmodified Hot Mix Asphalt by Means of the SHRP Gyrotory Compactor
- M-008 Preparation of Test Specimens of Bituminous Mixtures by Means of Rolling Wheel Compaction

2.2 ASTM Documents:

- D 8 Standard Definitions of Terms Relating to Materials for Roads and Pavements
- D 3497 Standard Test Methods for Dynamic Modulus of Asphalt Mixtures
- D 3549 Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens
- D 4123 Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixes
- E 1 Specification for Thermometers

3. TERMINOLOGY

3.1 Desired Mixing Temperature—the target temperature for mixing asphalt binder and aggregate in the laboratory. The desired mixing selected should be equivalent to the anticipated field plant mixing temperature. If field mixing temperatures are unknown, select a temperature which corresponds to a kinematic viscosity of 170 ± 20 mm²/s for the asphalt binder.

3.2 Desired Mixing Temperature—the target temperature for mixing asphalt binder and aggregate in the laboratory. The desired mixing temperature should be equivalent to the anticipated field plant mixing temperature. If field mixing temperatures are unknown, select a temperature which corresponds to a kinematic viscosity of 170 ± 20 mm²/s for the asphalt binder which is used.

3.3 Definitions for many terms common to asphalt are found in the following documents:

3.3.1 ASTM D 8 Standard Definitions

3.3.2 AASHTO MP1 Performance-Graded Asphalt Binder

3.3.3 AASHTO T201 Kinematic Viscosity of Asphalts

4. SUMMARY OF PRACTICE

4.1 For short-term aging, a mixture of aggregate and asphalt binder is aged in a forced draft oven for 4 hours at 135°C. The oven aging is designed to simulate the aging the mixture would undergo during plant mixing and construction.

4.2 For long-term aging, a compacted mixture of aggregate and asphalt binder is aged in a forced draft oven for 5 days at 85°C. The oven aging is designed to simulate the total aging that the compacted mixture will undergo during 7 to 10 years of service.

5. SIGNIFICANCE AND USE

5.1 The short-term aging practice simulates the aging that asphalt concrete mixtures undergo during field plant mixing operations. The long-term aging practice simulates the in-service aging of asphalt concrete mixtures after field placement and compaction.

5.2 The properties and performance of asphalt concrete mixtures may be more accurately predicted by using aged test samples.

6. APPARATUS

6.1 *Aging Test System*—A system that consists of a forced draft oven which possesses the requirements specified in table 1.

Table 1. Minimum Aging Test System Requirements

	Range (°C)	Resolution (°C)	Accuracy (°C)
Temperature Measurement	10-260	<1	±1
Temperature Control	25-250	<0.1	±0.1

6.2 *Oven*—Any oven which is thermostatically controlled and capable of being set to maintain any desired temperature from room temperature to 160°C. The oven shall be used for heating aggregates, asphalt binders, or laboratory equipment.

6.3 *Mixing Apparatus*—Any type of mechanical mixer that: 1) can be maintained at the required mixing temperatures; 2) will provide a well-coated, homogenous mixture of the required amount of asphalt concrete in the allowable time; and 3) allows essentially all of the mixture to be recovered.

6.4 *Miscellaneous Apparatus*

6.4.1 One metal oven pan for heating aggregates

6.4.2 One shallow metal oven pan for heating uncompacted asphalt concrete mixtures

6.4.3 Thermometers that have a range of 50 to 260°C and conform to the requirements prescribed in ASTM Document E 1

6.4.4 One metal spatula or spoon

6.4.5 Oven gloves

7. HAZARDS

7.1 This test method involves the handling of hot asphalt binder, aggregate, and asphalt concrete mixtures. These materials can cause severe burns if allowed to contact skin. Proper precautions must be taken to avoid burns.

8. SAMPLING

8.1 The asphalt binder shall be sampled in accordance with T40.

8.2 The aggregate shall be sampled and tested in accordance with T2 and T27, respectively.

9. SPECIMEN PREPARATION

9.1 Preheat the aggregate for a minimum of 2 h at the desired mixing temperature. The amount of aggregate preheated shall be of sufficient size to obtain a mixture specimen of the desired size.

9.2 Preheat the asphalt binder to the desired mixing temperature. The amount of asphalt binder preheated shall be of sufficient size to obtain the desired asphalt binder content to be tested.

NOTE 1.—Asphalt binders held for more than 2 h at the desired mixing temperature should be discarded.

9.3 Mix the heated aggregate and asphalt binder at the desired asphalt content.

10. PROCEDURE

10.1 Place the mixture on the baking pan and spread it to an even thickness of approximately 21 to 22 kg/m². Place the mixture and pan in the forced draft oven for 4 h ± 5 min at a temperature of 135°C ± 1°C.

10.2 Stir the mixture every hour to maintain uniform aging.

10.3 After 4 h, remove the mixture from the forced draft oven. The aged mixture is now ready for further conditioning or testing as required. Proceed to section 11 if the specimens are *not* conditioned for the effects of *long-term* aging.

10.4 Sampling

10.4.1 Plant-mixed asphalt concrete mixtures shall be sampled in accordance with T164.

10.4.2 Laboratory-mixed asphalt concrete mixtures shall be sampled, prepared and aged in accordance with T164.

10.4.3 Compacted roadway samples shall have a cut test specimen size that is 102 ± 6 mm in diameter by 152 ± 6 mm in height.

10.5 Heat the asphalt concrete to the desired compaction temperature.

10.6 Compact the sample in accordance with M-002 or M-008.

NOTE 2.—Compact a sufficient amount of material to ensure that the final test specimen size is 102 ± 6 mm in diameter by 152 ± 6 mm in height.

10.7 Cool the compacted test specimen to $60^{\circ}\text{C} \pm 1^{\circ}\text{C}$ in an oven set at 60°C .

NOTE 3.—Cooling to 60°C will take approximately 2 h for the test specimen size stated in note 2.

10.8 After cooling the test specimen to 60°C , level the specimen ends by applying a static load to the specimen at a rate of $72.00 \pm .05$ kN/min. Release the load at the same rate when the specimen ends are level or when the load applied reaches a maximum of 56 kN.

10.9 After cooling the test specimen at room temperature overnight, extrude the specimen from the compaction mold.

10.10 Place the compacted test specimen on a rack in the forced draft oven for 120 ± 0.5 h at a temperature of $85^{\circ}\text{C} \pm 1^{\circ}\text{C}$.

10.11 After 120 h, turn the oven off, open the doors, and allow the test specimen to cool to room temperature. Do not touch or remove the specimen until it has cooled to room temperature.

NOTE 4.—Cooling to room temperature will take approximately overnight for the test specimen size stated in note 21.

10.12 After cooling to room temperature, remove the test specimen from the oven. The aged specimen is now ready for testing as required.

11. REPORT

11.1 Report the following information:

11.1.1 *Asphalt Binder Grade*

11.1.2 *Asphalt Binder Content*—in percent to the nearest 0.1%

11.1.3 *Aggregate Type and Gradation*

11.1.4 *Short-Term Aging Conditions*—the following information as applicable:

11.1.4.1 *Plant-Mixing Temperature*—in degrees Celsius to the nearest 1°C

11.1.4.2 *Laboratory-Mixing Temperature*—in degrees Celsius to the nearest 1°C

11.1.4.3 *Short-Term Aging Temperature in Laboratory*—in degrees Celsius to the nearest 1°C

11.1.4.4 *Short-Term Aging Duration in Laboratory*—in minutes to the nearest 1 min

11.1.5 *Long-Term Aging Conditions*

11.1.5.1 *Compaction Temperature*—in degrees Celsius to the nearest 1°C

11.1.5.2 *Compacted Specimen Height*—in millimeters to the nearest 1 mm

11.1.5.3 *Compacted Specimen Diameter*—in millimeters to the nearest 1 mm

11.1.5.4 *Compacted Specimen Density*—in kilograms per square meter to the nearest 1 kg/m²

11.1.5.5 *Compacted Specimen Air Voids*—in percent to the nearest 0.1%

11.1.5.6 *Long-Term Aging Temperature*—in degrees Celsius to the nearest 1°C

11.1.5.7 *Long-Term Aging Duration*—in minutes to the nearest 1 min

12. KEY WORDS

12.1 Aging, asphalt concrete, asphalt concrete aging, bituminous mixtures, bituminous paving mixtures, short-term aging.

Standard Practice for

**Preparation of Test Specimens of Bituminous Mixtures
by Means of Rolling Wheel Compaction**

SHRP Designation: M-008¹

1. SCOPE

1.1 This method describes the mixing and compaction procedures to produce large slab specimens (approximately 101.6 mm × 762 mm × 762 mm) of bituminous concrete in the laboratory by means of a mechanical rolling wheel compactor. It also describes the procedure for determining the air void content of the specimens obtained.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems 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. APPLICABLE DOCUMENTS

2.1 AASHTO Test Methods:

T11-85 Amount of Material Finer than 75- μ m Sieve in Aggregate

T27-84 Sieve Analysis of Fine and Coarse Aggregates

T246-81 Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus

2.2 ASTM Test Methods:

C 117-90 Materials Finer than 75- μ m (No. 200) Sieve in Mineral Aggregates by Washing

C 136-84a Sieve Analysis of Fine and Coarse Aggregates

¹This standard is based on SHRP Product 1015.

- D 1561-81a Preparation of Bituminous Mix Test Specimens by Means of California Kneading Compactor
- D 2041-78 Test Method for Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures
- D 2493-91 Standard Viscosity Temperature Chart for Asphalts

3. APPARATUS

3.1 Rolling Wheel Compactor—A mechanical, self-propelled rolling wheel compactor with forward/reverse control such as that shown in figure 1 for compaction of asphalt concrete mixtures. It must weigh a minimum of 1,000 kg and possess the capability of increasing the weight to 1,500 kg. The load applied must be in the static mode.

3.2 Mold—A mold to hold the bituminous mix as shown in figure 2. The mold is composed of one lift 101.6 mm thick.

3.3 Ovens—Forced-draft electric ovens of sufficient size, capable of maintaining a uniform temperature between $100 \pm 3^\circ\text{C}$ and $200 \pm 3^\circ\text{C}$. It is preferable to have ovens with a capacity of $2.8 \times 10^{-2} \text{ m}^3$ to $4.2 \times 10^{-2} \text{ m}^3$ for asphalts and 0.7 m^3 to 0.85 m^3 for aggregates.

3.4 Specimen Mixing Apparatus—Suitable mechanized mixing equipment is required for mixing the aggregate and the bituminous material. It must be capable of maintaining the bituminous mixture at the selected mixing temperature, and allow the aggregate to be uniformly and completely coated with asphalt during the mixing period (approximately 4 min). It is preferable to have a mixer with a capacity of $7 \times 10^{-2} \text{ m}^3$ to $8.5 \times 10^{-2} \text{ m}^3$. A conventional concrete mixer fitted with infrared propane heaters has been found to be suitable.

3.5 Coring and Saw Cutting Equipment—Mechanized coring and saw cutting equipment capable of coring specimens 101.6 mm to 203.2 mm in diameter and beams of different sizes from an asphalt concrete slab. It is preferable to dry-cut the cores and beams.

3.6 Balance—Two balances are required: one with a capacity of 5 kg or more and sensitive to 1.0 g or less, and the other with a capacity between 45 and 120 kg, and sensitive to 0.5 kg or less.

3.7 Miscellaneous Apparatus:

3.7.1 Digital thermometers with thermocouple probe

3.7.2 Spatulas, trowels, scoops, spades, rakes

3.7.3 Heat-resistant gloves

3.7.4 Metal pans

3.7.5 Socket wrench, sockets, screw drivers, crescent wrench

3.7.6 Lubricant for mold (e.g., PAM[®] cooking oil or equivalent)

3.7.7 Tape measure

3.7.8 Parafilm (manufactured by American National Can Co., Greenwich, CT)

3.7.9 Pallet jack

4. MATERIAL PREPARATION

4.1 Aggregate—Aggregate to be used for specimen preparation should be prepared in accordance with AASHTO T11-85 and T27-84. After the aggregate has dried to a constant weight, remove the aggregate from the oven, and cool to room temperature. Then sieve into the separate size fractions necessary to accurately recombine into test mixtures that conform to specified grading requirements.

4.2 Determine material quantities—Calculate the quantity of material required to achieve the desired air void content. These calculations are shown in section 7.

4.3 Mixing Temperature—Set the oven to the mixing temperature. For mixes employing unmodified asphalt cements, the temperature of the aggregate and the asphalt at the time mixing begins shall be in accordance with the temperatures specified in AASHTO T246-82 or ASTM D 1561-81a. The temperature selected should correspond to a viscosity of $170 \pm 20 \text{ mm}^2/\text{s}$ (based on the original asphalt properties).

4.4 Heating the asphalt—Asphalts supplied in 19-L epoxy-coated containers must first be heated to 135°C in a forced draft oven. The container should be loosely covered with a metal lid. This first heating is to subdivide the 19-L sample into smaller containers for subsequent use. After approximately 1.5 h, remove the sample from the oven, and stir with a large spatula or metal rod. The sample should be stirred every half hour to ensure uniform heating. Typically, a 19-L sample will require approximately 5 h for the entire heating cycle.

NOTE 1.—Watch for signs of blue smoke from the asphalt. This would indicate overheating. If a noticeable quantity of smoke is observed, then the oven temperature should be reduced by 5 to 10°C.

Place paper or newsprint on the floor in a well-ventilated area. Place empty and clean 1-L containers on the paper in a sequence convenient for pouring the hot asphalt. Different-sized containers may also be used. It is important that the containers be properly labelled with self-adhesive labels or a diamond-tipped pencil prior to pouring.

Remove the 19-L container from the oven and stir the asphalt for approximately 1 minute. Fill the containers, taking care that the labels on the containers are not obliterated.

After filling, close all containers tightly, and allow to cool to room temperature. Store at a temperature of 10°C. Closing the containers prior to cooling will produce a vacuum seal.

4.5 Prior to mixing, set the oven to the mixing temperature as determined in section 4.3. Place a sufficient number of 1-L cans (with a total weight greater than that calculated in section 7.8) of asphalt in the oven at least 2 h prior to mixing. Monitor the temperature of the asphalt periodically. When the temperature approaches the mixing temperature, transfer the asphalt into a large pot (e.g., an 11-L stock pot) and at the same time weigh the amount of asphalt added to the pot. Transfer enough asphalt to equal the amount calculated in section 7.8 plus an extra 80 g (to account for the quantity retained in the pot after asphalt has been added to the aggregate). Then place the pot in the oven and continue to monitor the temperature periodically.

NOTE 2.—This constitutes the second heating of the asphalt. Any asphalts that have been heated more than twice must be discarded.

4.6 *Mixing*—Preheat the mixer approximately 1 h prior to mixing. Place coarse aggregate in the mixer, followed by the fine aggregate, and then the asphalt. Mix for approximately 4 min to ensure uniform coating of the aggregate.

4.7 *Short Term Aging*—After mixing, remove the mixture from the mixer and place it in metal pans. Place the mixture in an oven set at a temperature of $135^{\circ} \pm 1^{\circ}\text{C}$ for $4 \text{ h} \pm 1 \text{ min}$. Stir the mixture once an hour.

5. COMPACTION

5.1 Assemble the mold as shown in the schematic illustrated in figure 2. Preheat the mold with a "tent" equipped with infrared heat lamps (see figure 3).

5.2 Check the oil and fuel levels in the rolling wheel compactor and refill if necessary. Start the compactor and allow it to warm up. Spray a mild soapy solution on the rollers.

5.3 Sparingly apply a light oil (e.g., PAM[®] cooking oil) to the base and sides of the mold.

5.4 Remove a pan of mixture from the oven and place it in the center of the mold. Level the mixture using a rake while at the same time avoiding any segregation of the mixture (i.e., avoid any tumbling of the coarse aggregate). Repeat this process until the mold is filled with the required quantity of material to achieve the target air void content. This should be all of the pre-weighed material. Tamp the mixture to achieve as level a surface as possible.

5.5 Monitor the temperature of the mixture at the surface, at mid-depth, and at the bottom in various locations. Allow the mixture to cool until the coolest temperature corresponds to the pre-established compaction temperature (see notes 3 and 4).

NOTE 3.—The field compaction temperature should be used. As general guide, the compaction temperature to be used for most typical asphalt cements (AC-5 to AC-30) should correspond to an equivalent temperature of 280 ± 30 mm²/s (based on original binder properties) as described in section 4.3. If necessary, the mixture should be placed in an oven until it reaches a uniform temperature.

NOTE 4.—Lower compaction temperatures in the range between 115°C and 138°C may be necessary depending on the compactibility of the mixtures used under the rolling wheel compactor.

5.6 Compact the mixture until the rollers bear down on the compaction stops (steel channels with depths equal to slab thickness inserted in the mold as shown in figure 2). When compacting, each pass of the roller must extend from the ramp to the platform in a continuous motion, with no stops on the mixture. After the first few passes, it may be necessary to scrape bituminous mixture off the rollers and reshape the mixture.

5.7 When compaction is complete, let the slab cool overnight (typically 15 to 16 h) before removing the mold. If the slab is still warm to the touch, do not remove the mold. Do *not* place any weights on top of the slab.

5.8 After the slab is completely cooled, remove the slab from the mold together with the removable base of the mold (constructed of particle board) before placing on a pallet jack.

5.9 The slab should be dry cored and sawn into the desired specimen shapes as soon as possible. Note that the specimens should not be taken within 5 to 6.3 cm of the outside edges of the slab. This is approximately 2 to 2.5 times the nominal top size of the aggregate used. Store approximately 3 kg of the wasted mix for the determination of the theoretical maximum specific gravity as described in section 6.

6. CALCULATE THE AIR VOID CONTENT

6.1 Weigh the dry, unwrapped, room-temperature–stabilized specimen. Record this as *Mass in Air, A*.

6.2 Wrap the specimen in Parafilm so that it is completely watertight with no air bubbles between the Parafilm and the specimen. Use the minimum amount of Parafilm necessary. Weigh the specimen in air and record this as *Mass in Air with Parafilm, B*.

6.3 Weigh the wrapped specimen suspended in water at 25°C (77°F), taking the reading as soon as the balance stabilizes. Record this as the *Mass in Water with Parafilm, C*.

6.4 Determine the specific gravity of Parafilm at 25°C, or assume a value of 0.9. Record this as *D*.

6.5 Calculate the bulk specific gravity of the specimen as follows:

$$G_{mb} = \left[\frac{A}{B - C - \left(\frac{B - A}{D} \right)} \right] \quad (1)$$

where

A	=	Mass of dry uncoated specimen in air, g
B	=	Mass of Parafilm-coated specimen in air, g
C	=	Mass of Parafilm-coated specimen in water, g
D	=	Specific gravity of Parafilm at 25°C (77°F)
G_{mb}	=	bulk specific gravity

6.6 Determine the theoretical maximum specific gravity, G_{mm} , in accordance with ASTM D 2041-78.

6.7 Calculate the air void content as follows:

$$\text{Air Voids} = \left[1 - \left(\frac{G_{mb}}{G_{mm}} \right) \right] \cdot 100\% \quad (2)$$

7. CALCULATE THE QUANTITY OF BITUMINOUS MIX REQUIRED

7.1 Measure the dimensions (height, length and width) of the compaction mold that will contain the compacted slab. Record this as H, L and W in dm.

7.2 Determine the volume (V) of the mold in units of cm^3 .

7.3 Determine the maximum specific gravity of the bituminous mix at the desired asphalt content in accordance with ASTM D 2041. Record this as G_{mm} .

7.4 Determine the target bulk specific gravity for the compacted slab based on the target air void content:

$$G_{mb} = G_{mm} \left[1 - \frac{\%AV}{100} \right] \quad (3)$$

where

G_{mb}	=	target bulk specific gravity of the compacted slab
$\%AV$	=	target air voids of the compacted slab (percent)

7.5 Determine the unit mass (density) of the compacted slab:

$$\rho = G_{mb} \rho_w \quad (4)$$

where

$$\begin{aligned} \rho &= \text{unit mass of the compacted slab, kg/m}^3 \\ \rho_w &= \text{unit mass of water, kg/m}^3 \end{aligned}$$

7.6 Determine the mass, M (in kilograms) of the compacted slab:

$$M = \rho V$$

7.7 Determine the mass of the aggregate required for compaction as shown below in equations 5 and 6. Equation 5 uses the asphalt content based on the dry mass of the aggregate, whereas equation 6 uses the asphalt content based on total mass of the mixture.

$$M_{\text{aggr}} = \left[\frac{M}{\left(1 + \frac{\%AC}{100}\right)} \right] \quad (5)$$

$$M_{\text{aggr}} = M \left[1 - \frac{\%AC}{100} \right] \quad (6)$$

where

$$\begin{aligned} M_{\text{aggr}} &= \text{total mass of aggregate, kg} \\ \%AC &= \text{asphalt content} \end{aligned}$$

7.8 Determine the mass of asphalt binder required for compaction as shown in equations 7 and 8 below. Equation 7 uses the asphalt content based on the dry mass of the aggregate, whereas equation 8 uses the asphalt content based on total mass of the mixture.

$$M_{AC} = M_{\text{aggr}} \left[\frac{\%AC}{100} \right] \quad (7)$$

$$M_{AC} = M \left[\frac{\%AC}{100} \right] \quad (8)$$

where

$$M_{AC} = \text{mass of asphalt binder, kg}$$

8. REPORT

8.1 The report shall include the following information:

8.1.1 *Bituminous Mixture Description*—bitumen type, bitumen content, aggregate type, aggregate gradation, and air void percentage.

8.1.2 Mix and compaction temperatures, °C.

8.1.3 Mass of specimen in air, g (*A*)

8.1.4 Mass of specimen in air with Parafilm, g (*B*)

8.1.5 Mass of specimen in water with Parafilm, g (*C*)

8.1.6 Specific gravity of Parafilm (*D*)

8.1.7 Bulk specific gravity, G_{mb}

8.1.8 Maximum specific gravity, G_{mm}

8.1.9 Air void content of specimen, percent

8.1.10 Dimensions of mold, cm

8.1.11 Volume of mold, cm³

8.1.12 Unit mass of compacted slab, kg/cm³

8.1.13 Mass of mix required for compaction, kg

8.1.14 Mass of aggregate required for compaction, M_{aggr} (kg)

8.1.15 Weight of asphalt required for compaction, M_{AC} (kg)

8.1.16 Time of mixing, minutes

8.1.17 Time of compaction, minutes

9. PRECISION

9.1 A precision statement has not yet been developed for this test method.

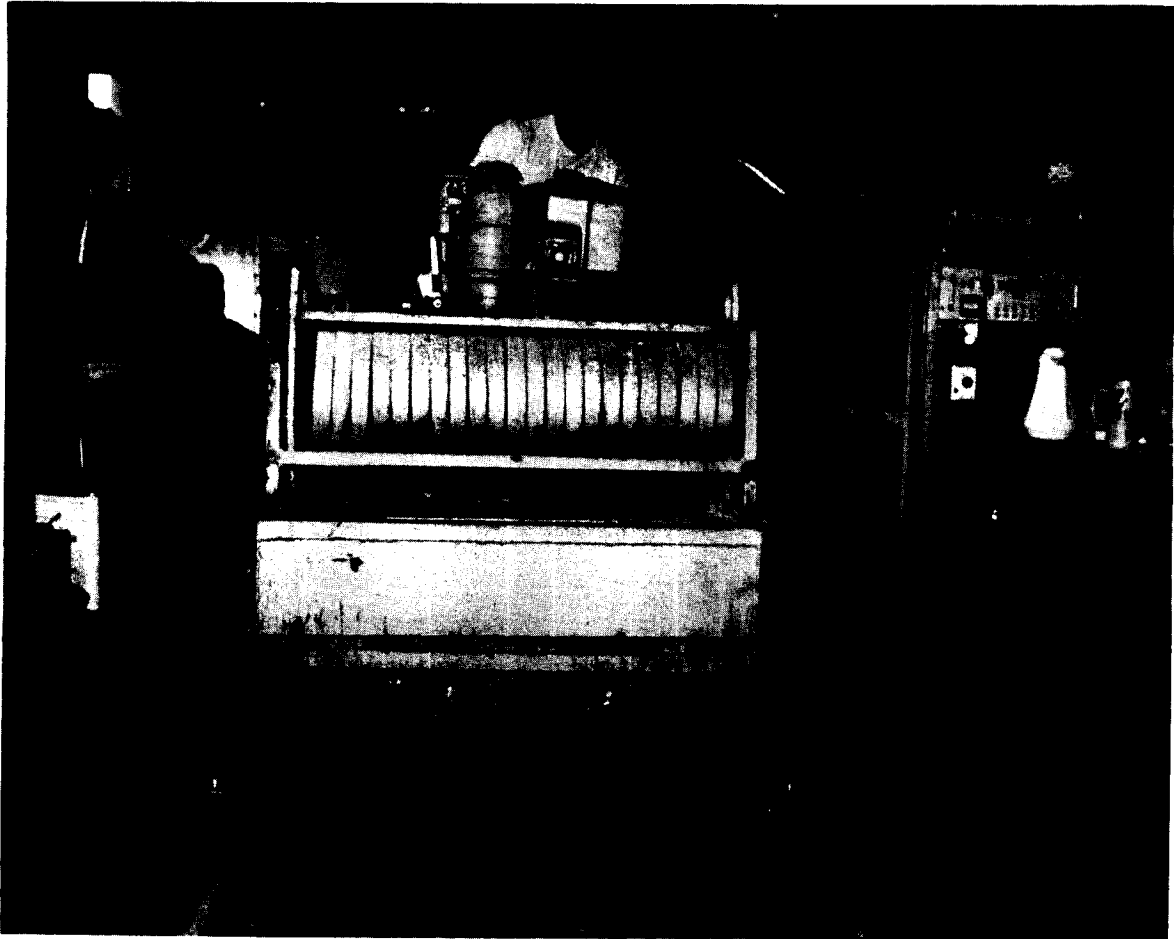


Figure 1. Rolling Wheel Compactor

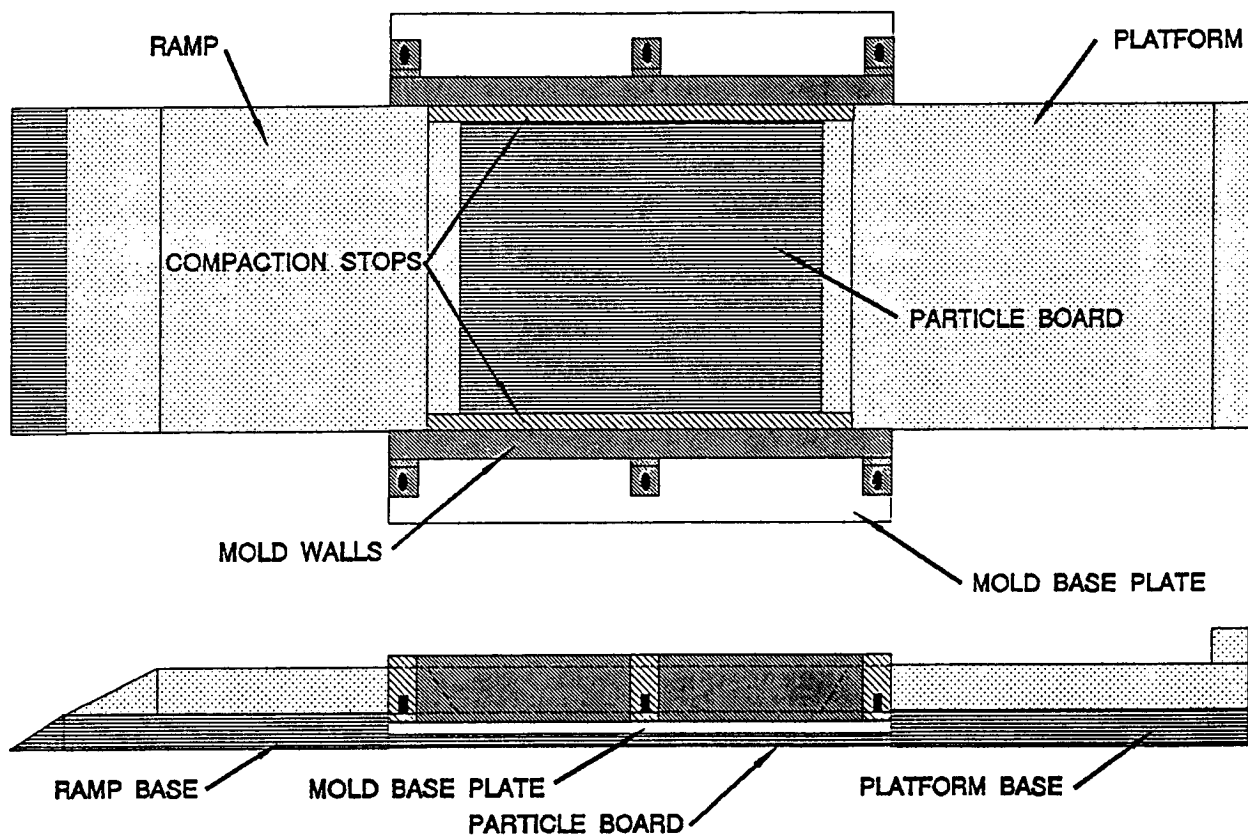


Figure 2. Schematic of Mold for Slab

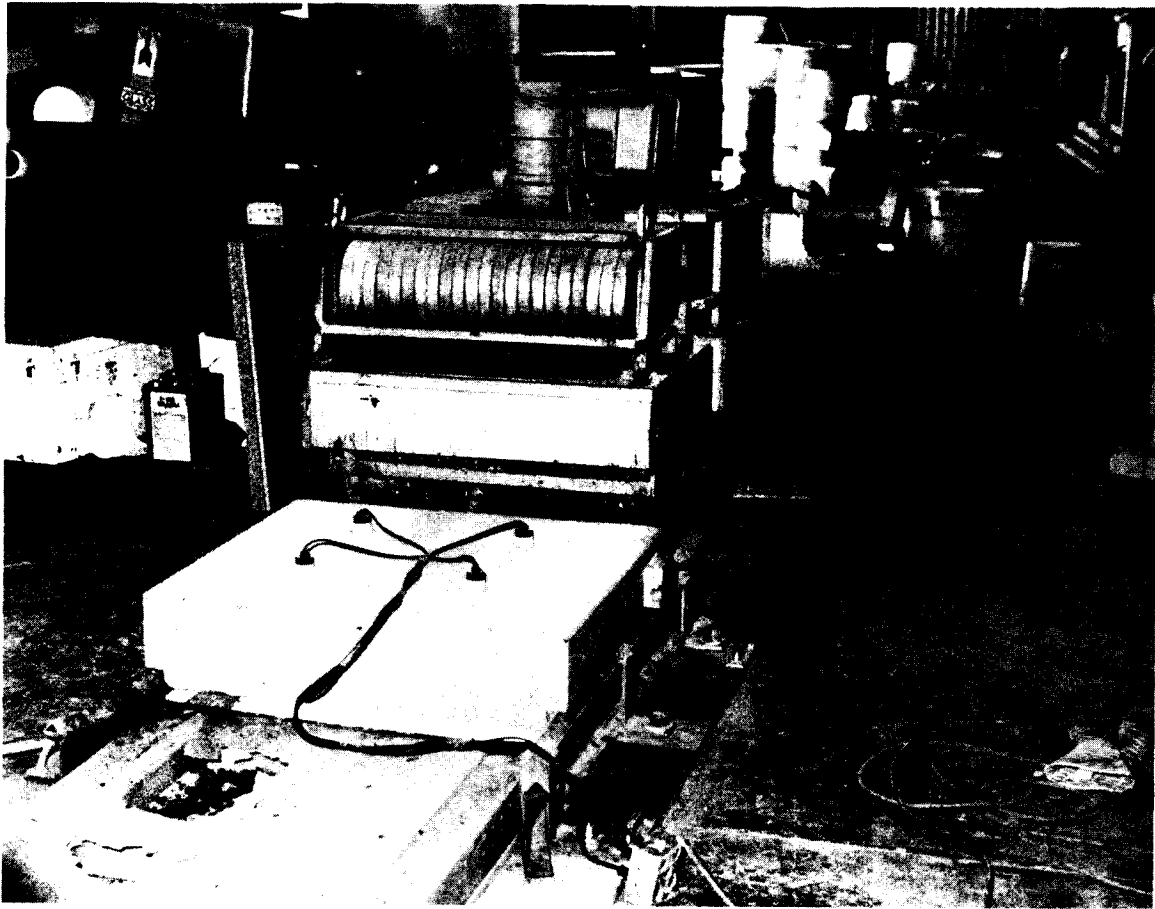


Figure 3. Preheating the Mold

Standard Method of Test for

**Determining the Fatigue Life
of Compacted Bituminous Mixtures Subjected
to Repeated Flexural Bending**

SHRP Designation: M-009¹

1. SCOPE

1.1 This method determines the fatigue life and fatigue energy of a bituminous mixture beam specimen subjected to repeated flexural bending until failure. The failure point is defined as the load cycle at which the specimen exhibits a 50% reduction in stiffness relative to the initial stiffness.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems 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. APPARATUS

2.1 *Test System*—The test system shall be capable of providing repeated sinusoidal loading at a frequency of between 5 and 10 Hz. The specimen shall be subjected to 4-point bending with free rotation and horizontal translation at all load and reaction points. Figure 1 illustrates the loading conditions. The specimen shall be forced back to its original position (i.e., zero deflection) at the end of each load pulse. The test system or surrounding environment shall maintain the specimen at 20°C during testing.

The test system shall be a closed-loop, computer-controlled system that, during each load cycle, measures the deflection of the beam specimen, computes the strain in the specimen, and adjusts the load such that the specimen experiences a constant level of strain on each load cycle. The test system should record load cycles, the applied load and beam deflection, and compute the maximum tensile stress, maximum tensile strain, phase angle, stiffness, dissipated energy, and cumulative dissipated energy at load cycle intervals specified by the user.

¹This standard is based on SHRP Product 1019.

As a minimum, the test system should meet the following requirements:

Load Measurement and Control

Range: ± 4.5 kN
Resolution: 0.002 kN
Accuracy: ± 0.004 kN

Displacement Measurement and Control

Range: ± 5.0 mm
Resolution: 0.00254 mm
Accuracy: ± 0.005 mm

Frequency Measurement and Control

Range: 5 to 10 Hz
Resolution: 0.005 Hz
Accuracy: 0.01 Hz

Temperature Measurement and Control

Resolution: 0.25°C
Accuracy: ± 0.5 °C

2.2 Miscellaneous Apparatus:

- epoxy for attaching nut to specimen
- screw, nut, block assembly for referencing LVDT to neutral axis of specimen
- jig for setting proper clamp spacing

3. TEST SPECIMENS

3.1 Compacted Bituminous Concrete Specimens—Specimens shall be sawn on all sides with a diamond blade from a slab or beam of bituminous mixture prepared by kneading compaction or rolling wheel compaction. Specimens shall be 381 ± 6.35 mm in length, 50.8 ± 6.35 mm in height and 63.5 ± 6.35 mm in width.

3.2 Measurement of Specimen Size—Measure the height and width of the specimen at three different points along the middle 90 mm of the specimen length. Report measurements to the nearest 0.025 mm. Average the three measurements for each dimension and report the averages to the nearest 0.25 mm.

3.3 Epoxy Nut to Neutral Axis of Specimen—Figure 2 illustrates a nut epoxied to the neutral axis of the specimen. Locate the center of a specimen side. Apply epoxy in a circle around this center point and place the nut on the epoxy such that the center of the nut is over the center point. Avoid applying epoxy such that it fills the center of the nut. Allow the epoxy to harden before moving the specimen.

4. TEST PROCEDURE

4.1 Stabilize Specimen to Test Temperature—If the ambient temperature is not 20°C, place the specimen in an environment which is at $20 \pm 1^\circ\text{C}$ for 2 hours to ensure the specimen is at the test temperature prior to beginning the test.

4.2 Specimen Setup—Refer to figures 3 and 4.

The clamps should be open to allow the specimen to be slid into position. The jig is used to ensure proper horizontal spacing of the clamps: 119 mm center-to-center. Once the specimen and clamps are in the proper positions, close the outside clamps by applying sufficient pressure to hold the specimen in place. Next, close the inside clamps by applying sufficient pressure to hold the specimen in place.

Figure 4 illustrates the connection of the screw/nut/block assembly and the LVDT such that beam deflections at the neutral axis will be measured. Attach the LVDT block to the specimen by screwing the screw into the nut epoxied to the specimen. The LVDT probe should rest on top of the block and the LVDT should be positioned and secured within its clamp so its reading is as close to zero as possible.

4.3 Test Parameter Selection—The operator selects the following test parameters and enters them into the automated test program: deflection level, loading frequency and load cycle intervals at which test results are recorded and computed by the computer. The deflection level depends on the strain level desired. The loading frequency should be between 5 and 10 Hz. The selection of load cycle intervals at which test results are computed and recorded is limited by the amount of memory available for storing data.

4.4 Estimation of Initial Stiffness—Apply 50 load cycles at a constant strain of 100–300 micro-in/in. Determine the specimen stiffness at the 50th load cycle. This stiffness is an estimate of the initial stiffness which will be used as a reference for determining specimen failure.

4.5 Selection of Strain Level—The selected deflection level should correspond to a strain level such that the specimen will undergo a minimum of 10,000 load cycles before its stiffness is reduced to 50% or less of the initial stiffness. A stiffness reduction of 50% or more represents specimen failure. A minimum of 10,000 load cycles ensures the specimen does not decrease in stiffness too rapidly.

4.6 Testing—After selecting the appropriate test parameters, begin the test. Monitor and record (*if not automated*) the test results at the selected load cycle intervals to ensure the

system is operating properly. When the specimen has experienced greater than 50% reduction in stiffness, stop the test.

5. CALCULATIONS

5.1 The following calculations shall be performed at the operator-specified load cycle intervals:

5.1.1 Maximum Tensile Stress (kN)

$$\sigma_t = \frac{300aP}{wh^2} \quad (1)$$

where

- a = $L/3$
- L = the beam span, typically 356 mm
- P = the load in kilonewtons
- w = the beam width in millimeters
- h = the beam height in millimeters

5.1.2 Maximum Tensile Strain (mm/mm)

$$\epsilon_t = (12\delta h)/(3L^2 - 4a^2) \quad (2)$$

where

- δ = maximum deflection at center of beam, in mm
- L = length of beam between outside clamps, 356 mm

5.1.3 Flexural Stiffness (kPa)

$$S = \sigma_t/\epsilon_t \quad (3)$$

5.1.4 Phase Angle (deg)

$$\phi = 360fs \quad (4)$$

where

- f = load frequency, in Hz
- s = time lag between P_{\max} and δ_{\max} , in seconds

5.1.5 Dissipated Energy (kPa) per cycle

$$D = \pi\sigma_t\epsilon_t\sin(\phi) \quad (5)$$

5.1.6 Cumulative Dissipated Energy (kPa)

$$\sum_{i=1}^{i=n} D_i \quad (6)$$

where

$$D_i = D \text{ for the } i^{\text{th}} \text{ load cycle}$$

NOTE 1.—If data acquisition is automated, dissipated energy (D) cannot be calculated for *every* load cycle, due to memory limitations of the computer system. Therefore, dissipated energy must be plotted against load cycles for the particular load cycles at which data was collected (i.e., the load cycles selected by the operator) up to the load cycle of interest. The area under the curve represents the cumulative dissipated energy. See figure 5 for a typical dissipated energy versus load cycle plot.

5.1.7 Initial Stiffness (kPa)—The initial stiffness is determined by plotting stiffness (S) against load cycles (N) and best-fitting the data to an exponential function of the form

$$S = Ae^{bN} \quad (7)$$

where

$$\begin{aligned} e &= \text{natural logarithm to the base } e \\ A &= \text{constant} \\ b &= \text{constant} \end{aligned}$$

Figure 6 presents a typical plot of stiffness versus load cycles. The constant A represents the initial stiffness.

5.1.8 Cycles to Failure—Failure is defined as the point at which the specimen stiffness is reduced to 50% of the initial stiffness. The load cycle at which failure occurs is computed by solving for N from equation 7, or simply

$$N_{f,50} = [\ln(S_{f,50}/A)]/b \quad (8)$$

where

$$\begin{aligned} S_{f,50} &= \text{stiffness, 50\% of initial stiffness, in kPa} \\ S_{f,50}/A &= 0.5, \text{ by definition} \end{aligned}$$

5.1.9 Cumulative Dissipated Energy to Failure (kPa)

$$\sum_{i=1}^{i=N_{f,50}} D_i$$

(9)

NOTE 2.—It is not necessary to measure the dissipated energy for *every* load cycle; the computer program used to control the fatigue test will systematically determine the dissipated energy at specified load cycles during the test. The total dissipated energy to failure will be summarized as part of the computer output.

6. REPORT

6.1 The test report shall include the following information:

6.1.1 *Bituminous Mixture Description*—bitumen type, bitumen content, aggregate gradation, and air void percentage.

6.1.2 *Specimen Length*—millimeters, to four significant figures

6.1.3 *Specimen Height*—millimeters, average as per section 3.2, to three significant figures

6.1.4 *Specimen Width*—millimeters, average as per section 3.2, to three significant figures

6.1.5 *Test Temperature*—average during test, to the nearest 1.0°C

6.1.6 *Test Results*—table listing the following results (to three significant figures) for each load cycle interval selected by the operator:

Load Cycle	Applied Load	Beam Deflection	Tensile Stress	Tensile Strain	Flexural Stiffness	Phase Angle	Cumulative Dissipated Energy	Dissipated Energy
	kN	mm	kPa	mm/mm	kPa	deg	kPa	kPa

6.1.7 *Plot of Stiffness versus Load Cycles*—refer to figure 6 for typical plot

6.1.8 *Initial Flexural Stiffness*—kPa, to three significant figures

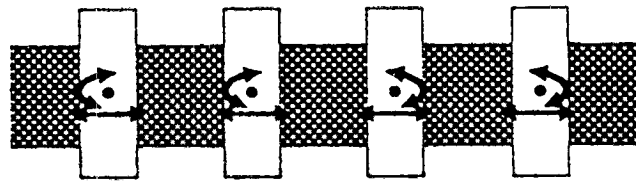
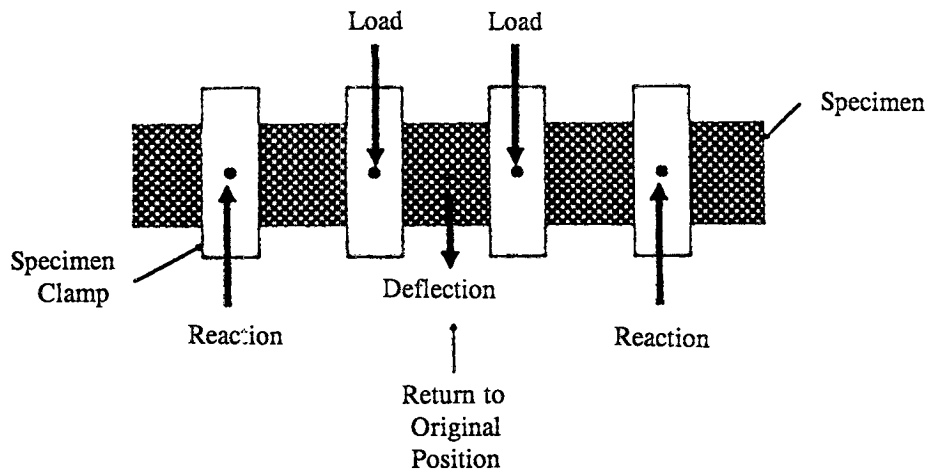
6.1.9 *Cycles to Failure*

6.1.10 *Cumulative Dissipated Energy to Failure*—kPa, to three significant figures

6.1.11 *Plot of Dissipated Energy versus Load Cycles*—refer to figure 5 for typical plot

7. PRECISION

7.1 A precision statement has not yet been developed for this test method.



Free Translation and Rotation

Figure 1. Load and Freedom Characteristics of Fatigue Test Apparatus

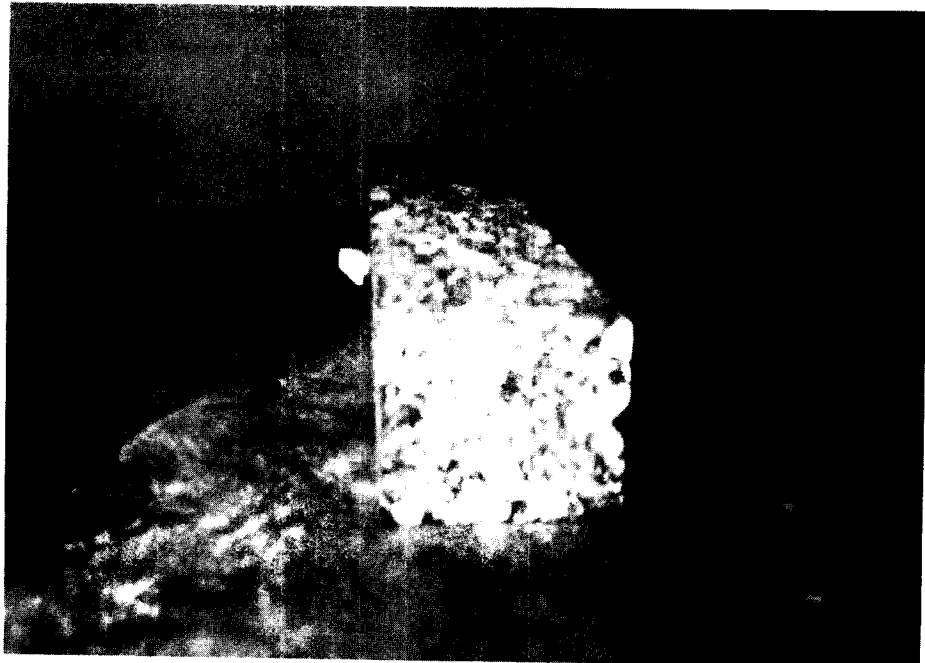


Figure 2. Nut Epoxied to Neutral Axis of Specimen and LVDT Block Attached

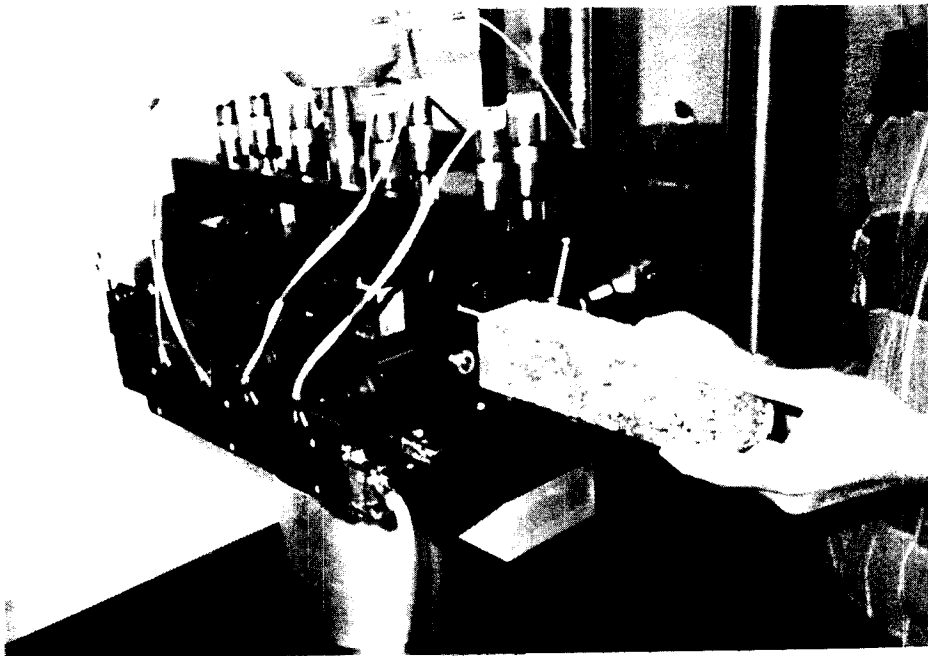
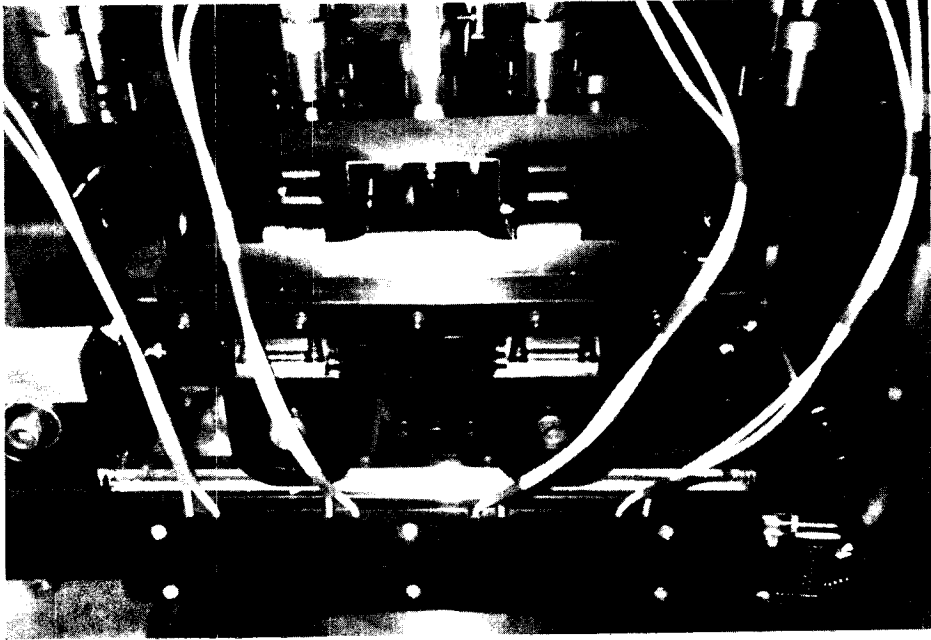


Figure 3. Inserting Specimen into Device

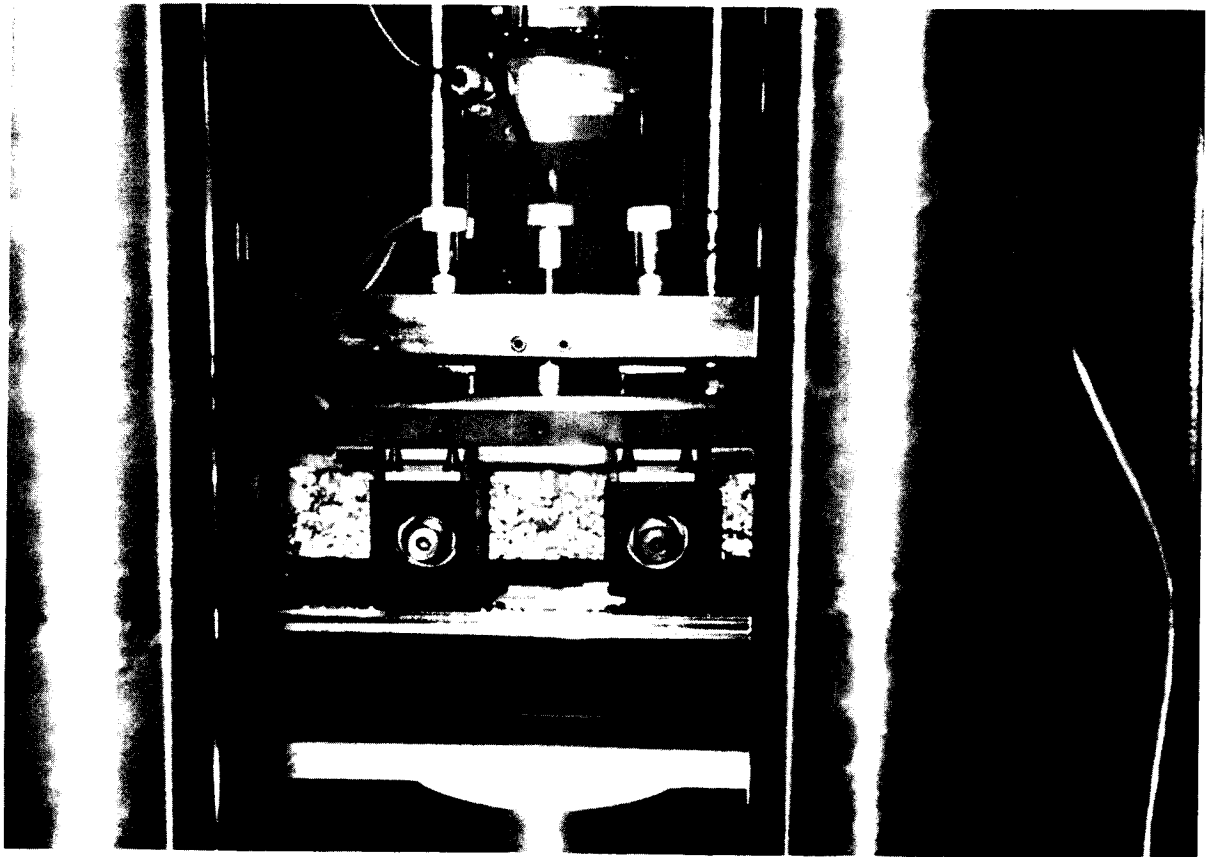


Figure 4. Nut/Block/Screw/LVDT Connection

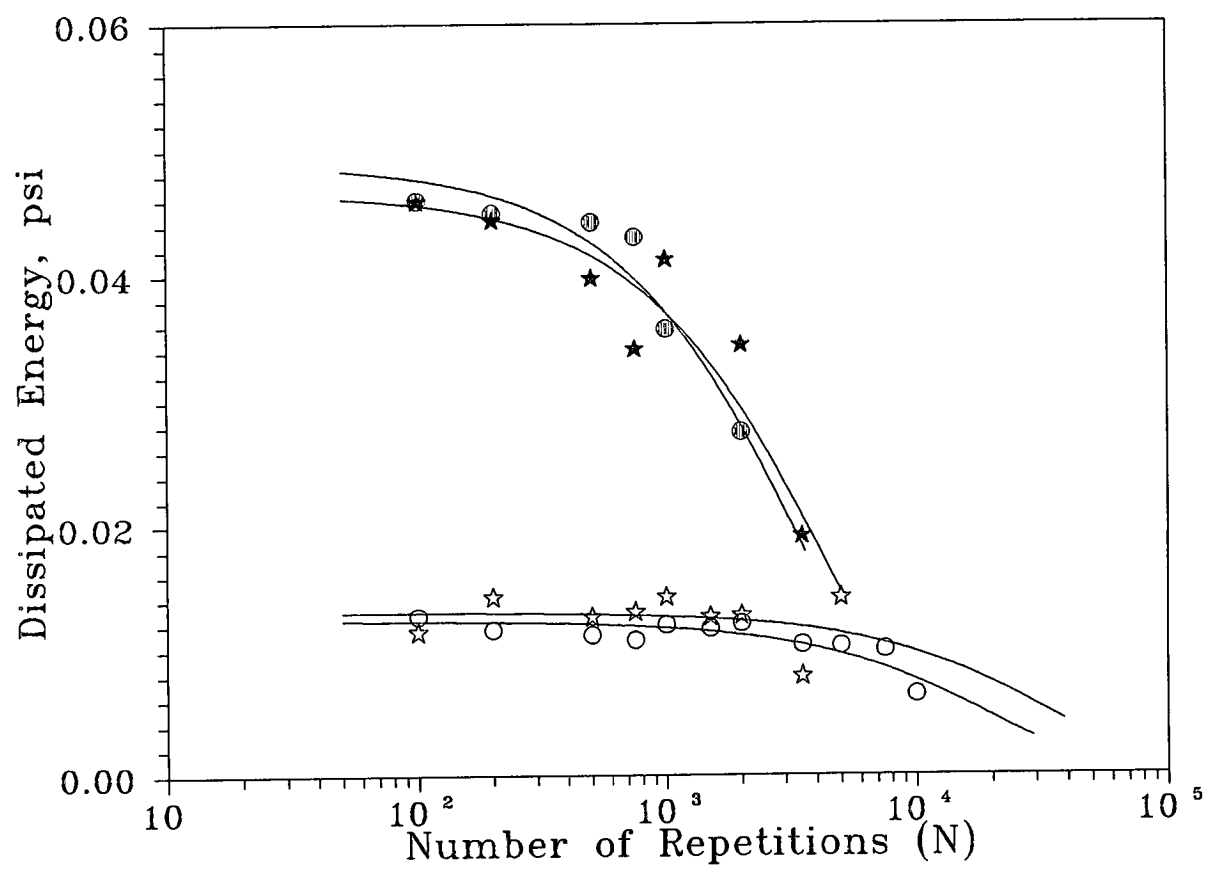


Figure 5. Dissipated Energy versus Load Cycles (Repetitions)

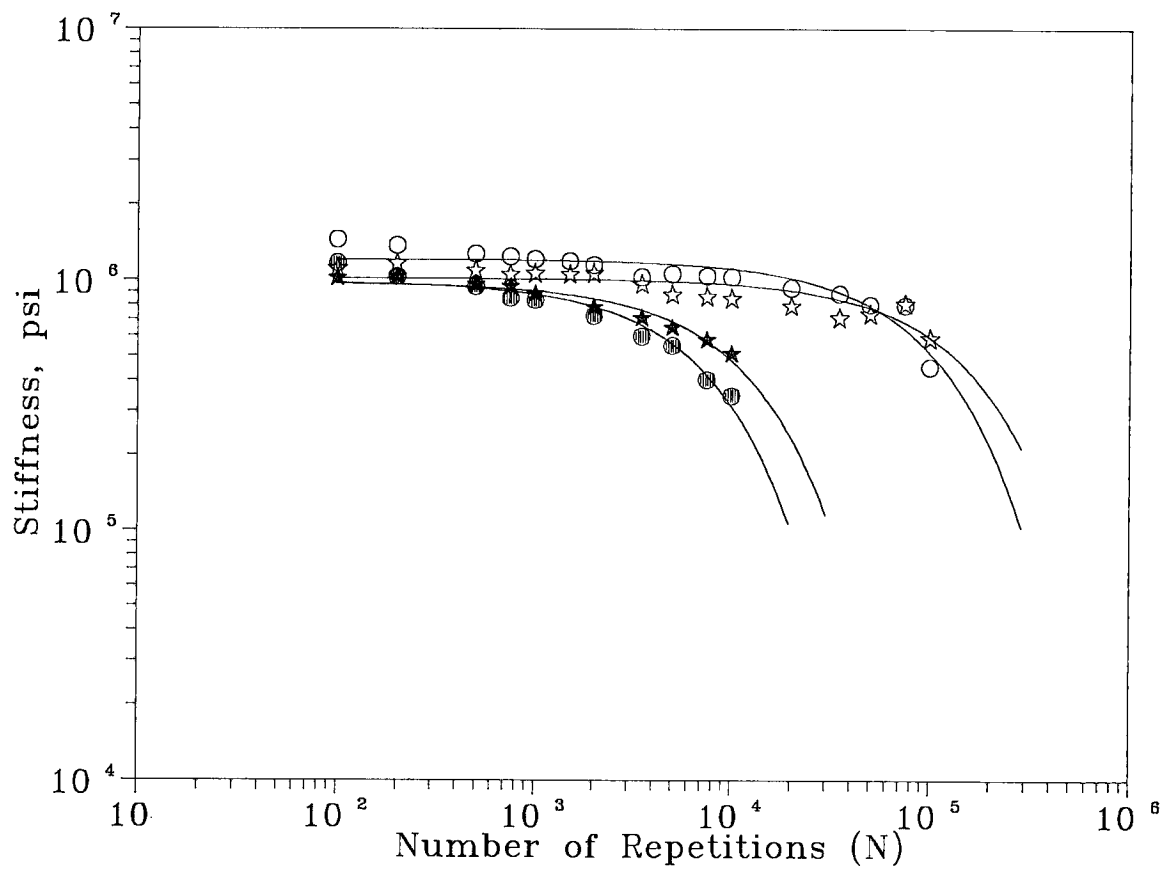


Figure 6. Stiffness versus Load Cycles (Repetitions)

Standard Method for

**Determining the Fracture Strength and Temperature
of Modified and Unmodified Hot Mix Asphalt
Subjected to Cold Temperatures**

SHRP Designation: M-010¹

1. SCOPE

1.1 This method determines the tensile strength and temperature at fracture of compacted bituminous mixtures by measuring the tensile load in a specimen which is cooled at a constant rate while being restrained from contraction.

1.2 The values stated in SI units are to be regarded as the standard.

1.3 *This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems 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. APPARATUS

2.1 Test System—A test system capable of cooling a bituminous mixture specimen at a constant rate while restraining the specimen from contraction and periodically measuring the tensile load and the specimen temperature from the beginning of the test to specimen failure.

Figures 1 through 3 present diagrams of a closed-loop test system that is capable of performing the required testing. As the environmental chamber is cooled by periodic injections of liquid nitrogen, the specimen contracts. The computer monitors the output of the LVDTs and when the average displacement (relative to the original specimen position) becomes greater than 0.0025 inch (10 micro-strain), the computer sends a signal to the step motor and the motor applies a tensile load to the specimen until it stretches back to its original position. This process is repeated as the specimen is continually cooled. By restraining the specimen from contraction, tensile stress in the specimen increases until it exceeds the tensile strength of the specimen and the specimen fractures. Elapsed time, chamber and specimen surface temperature, displacement, and load are periodically measured and automatically recorded by the computer throughout the test.

¹This standard is based on SHRP Product 1021.

As a minimum, the test system should meet the following requirements:

Load Measurement

Range: 0 to 23kN tension
Resolution: ≤ 0.044 kN
Accuracy: $\pm 0.1\%$ Full Scale

Displacement Measurement

Range: ± 0.5 mm
Resolution: < 0.00125 mm
Accuracy: $\pm 0.1\%$ Full Scale

Displacement Control

Operating Range: 150 to 435 mm
Resolution: < 0.00125 mm
Accuracy: < 0.005 mm

Temperature Measurement

Range: -50 to $+25^{\circ}\text{C}$
Resolution: $< 0.1^{\circ}\text{C}$
Accuracy: $\pm 0.3^{\circ}\text{C}$

Temperature Control

Range: -50 to $+10^{\circ}\text{C}$
Resolution: $< 0.1^{\circ}\text{C}$
Accuracy: $\pm 0.54^{\circ}\text{C}$

2.2 Specimen Alignment Stand—A device capable of providing concentric and perpendicular alignment between the platens and the specimen, and of securing the specimen and platens while the epoxy sets (figure 4). True alignment is critical to obtaining meaningful test results. Therefore, not only must the alignment device provide true alignment but it must be supported in a level position.

2.3 Miscellaneous Apparatus:

- 150-mm diameter, 50-mm thick specimen platens
- Two 6.35-mm diameter, 457-mm-long threaded rods with 2 nuts each
- Epoxy (Thermoset DC-80 or equivalent)

NOTE.—The instructions herein for specimen preparation relate to Thermoset DC-80 made by Meyer Plastics, Inc. If another epoxy brand is used, its manufacturer should be contacted regarding proper mixing proportions, application and curing requirements.

- Modeling clay
- Duct tape
- Plumb bob
- Balance of 5 kg capacity and sensitive to 0.1 g, and spatula for proportioning and mixing epoxy components
- Oven of 120°C capability
- metal pans
- spatula
- gloves
- solvent
- 240-grit sandpaper for removing failed specimen ends from platens, cleaning platens, and providing a rough surface on platens to promote epoxy adhesion
- U-joint clevises, clevis eyelets, and clevis pins

3. TEST SPECIMENS

3.1 *Compacted Bituminous Concrete Specimens*—Specimens shall be sawn on all sides with a diamond blade from a slab or beam of bituminous mixture prepared by kneading compaction or rolling wheel compaction. Specimens shall be 50 ± 3.5 mm² square and 250 ± 6.3 mm in length.

3.2 *Measurement of Specimen Size*—Measure each width dimension of the specimen at the middle of the specimen length and at points on each side of the middle point. Report width measurements to the nearest 0.02 mm. Average the three measurements for each width dimension and report to the nearest 0.2 mm. Multiply the average width dimensions to obtain the average cross-sectional area of the specimen and report to the nearest 1 mm².

3.3 *Specimen Platen Preparation and Specimen Alignment*—Platens shall be clean and free of all materials or films and shall be rough to promote adhesion of the epoxy. After cleaning the platens, sand the platen surface with a piece of 240-grit sandpaper to remove any remaining epoxy from prior tests and to provide a rough surface for epoxy adhesion.

With the ink marker, trace diametral lines across the top face of the bottom platen such that they connect the alignment holes on opposite sides of the platen. Also trace lines longitudinally along each side of the specimen such that each line divides the side by its midpoint. Lines on the specimen and platen will be used to provide concentric alignment.

Screw the specimen platens into the alignment stand. Adjust the position of the platens to a length approximately 25 mm longer than the specimen length. Insert the threaded rods into holes on opposite sides of platens but do not tighten yet. Use the plumb bob to align the holes between the top and bottom platens.

3.4 Epoxy Preparation—Obtain 50 ± 5 g *each* of epoxy resin and epoxy hardener in a container suitable for mixing. Thoroughly mix the two epoxy components at a 1:1 ratio until a uniform color and consistency results.

3.5 Epoxying Specimen to Platens—Apply a 3- to 6-mm thick film of epoxy over a 50-mm diameter area on both the top and bottom platens in the specimen alignment stand. Place the specimen between the platens and carefully lower the top platen so that the specimen ends, epoxy and platens are in contact.

Check the alignment of the specimen by comparing the marked lines on the sides of the specimen to the marked lines on the bottom platen. Rotate the specimen, if necessary, to achieve concentric alignment.

Equally apply the remaining epoxy to the corners between the specimen sides and the platen faces, being careful not to disturb the position of the specimen. Build up the epoxy approximately 25 mm along the sides of the specimen (relative to the platen face). The buildup of epoxy is necessary to provide adequate adhesion between the specimen and the platen such that failure occurs in the middle portion of the specimen rather than at the specimen/platen interface.

Again, check the alignment of the specimen by comparing the marked lines on the sides of the specimen to the marked lines on the bottom platen. Rotate the specimen, if necessary, to achieve concentric alignment.

The specimen shall remain in the alignment stand for 4 to 24 hours to allow the epoxy to harden. The ambient temperature around the specimen should be 20°C to 25°C to obtain sufficient curing of the epoxy. Cooler temperatures will require longer cure periods.

3.6 Pre-Cooling Specimen—After the epoxy has cured, tighten the nuts on the threaded rods with fingers only. Remove the specimen/platen assembly from the alignment stand and screw a clevis eyelet into the top platen. Hang the specimen/platen assembly from the eyelet in a $5^\circ\text{C} \pm 2^\circ\text{C}$ environment for 6 h prior to testing. By pre-cooling the specimen, the test can begin at a low temperature, thus reducing the total duration of the test. It has been determined that pre-cooling does not significantly affect the test results.

4. TEST PROCEDURE

4.1 *Test Setup*

Connect the specimen/platen assembly to the top U-joint clevis by inserting the eyelet between the clevis opening, aligning the holes, and inserting a pin through the holes. Screw another eyelet into the bottom platen and similarly connect the bottom eyelet to the bottom U-joint clevis.

Attach the two clamps used to secure the LVDTs to the bottom platen with nuts and screws.

Attach the thermistors to the specimen with modeling clay. Place one thermistor each at the bottom end, the center, and the top end of the specimen, each on a different side of the specimen. The thermistors are used to measure the temperature of the specimen surface.

Attach the cable of the resistance temperature device (RTD) to the middle portion of the specimen on a free side. Secure the cable with duct tape. The RTD is used in monitoring and controlling the environmental cabinet temperature.

Attach the two clamps used to secure the invar rods to the top platen with nuts and screws.

Insert the LVDTs into the bottom clamps and the invar rods into the top clamps. Make sure each rod and LVDT pair are aligned properly. Adjust the clamps to obtain proper alignment. After aligning the rod and LVDT, secure the clamps to the platens and secure the invar rod in the top clamp.

Adjust the position of the LVDT in the bottom clamp such that its voltage output is near zero. This is necessary to ensure the LVDT operates in its linear range during the test.

Sufficiently loosen the threaded rods attached on opposite sides of the platens. Close and secure the environmental cabinet door, and begin the test procedure.

4.2 *Testing*

Start the flow of liquid nitrogen to cool the environmental cabinet to 5°C (typical). Monitor the specimen surface temperature and wait until the average surface temperature is $5 \pm 1^\circ\text{C}$ before applying the initial tensile load to the specimen.

Apply an initial tensile load of 0.04 ± 0.004 kN to the specimen by manually turning the hand-crank on the step-motor to raise the top platen.

Start cooling the cabinet at a rate of $10^\circ\text{C} \pm 1^\circ\text{C}$ per hour.

Occasionally monitor the test outputs (environmental cabinet temperature, specimen temperature, elapsed time, specimen displacement, load) as the test progresses to ensure all instrumentation is functioning correctly and a valid test is being conducted.

5. CALCULATIONS

After the specimen fails, perform the following calculations.

5.1 Calculate the fracture strength to the nearest 5 kPa as follows:

$$\text{Fracture Stress} = P_{\text{ult}}/A$$

where

P_{ult} = ultimate tensile load at fracture in kilonewtons

A = average cross-sectional area of specimen in millimeters squared

5.2 Calculate the slope of the thermally induced stress curve as follows:

$$\text{Slope} = \delta S / \delta T$$

where

δS = average change in stress along the linear portion of the curve just prior to failure, in kilopascals

δT = average change in temperature along the linear portion of the curve just prior to failure, in degrees Celsius

6. REPORT

The test report shall include the following information:

6.1 *Bituminous Mixture Description*—bitumen type, bitumen content, aggregate gradation, and air void percentage.

6.2 *Time to Failure*—hours:minutes:seconds

6.3 *Specimen Temperature at Failure*—average of 3 thermistor readings to the nearest 0.1°C

6.4 *Cross-Sectional Area of Specimen*—average as per section 3.2, to the nearest 1 mm²

6.5 *Ultimate Load at Failure*—maximum tensile load, to the nearest 0.04 kN

6.6 *Fracture Strength*—kilopascals as per section 5.1, to the nearest 5 kPa

6.7 *Slope of the Thermally Induced Stress Curve*—kilopascals per degree Celsius as per section 5.2, to the nearest kPa

6.8 Failure Description—location of break along specimen length and the nature of break (angular, flat, broken aggregate, etc.).

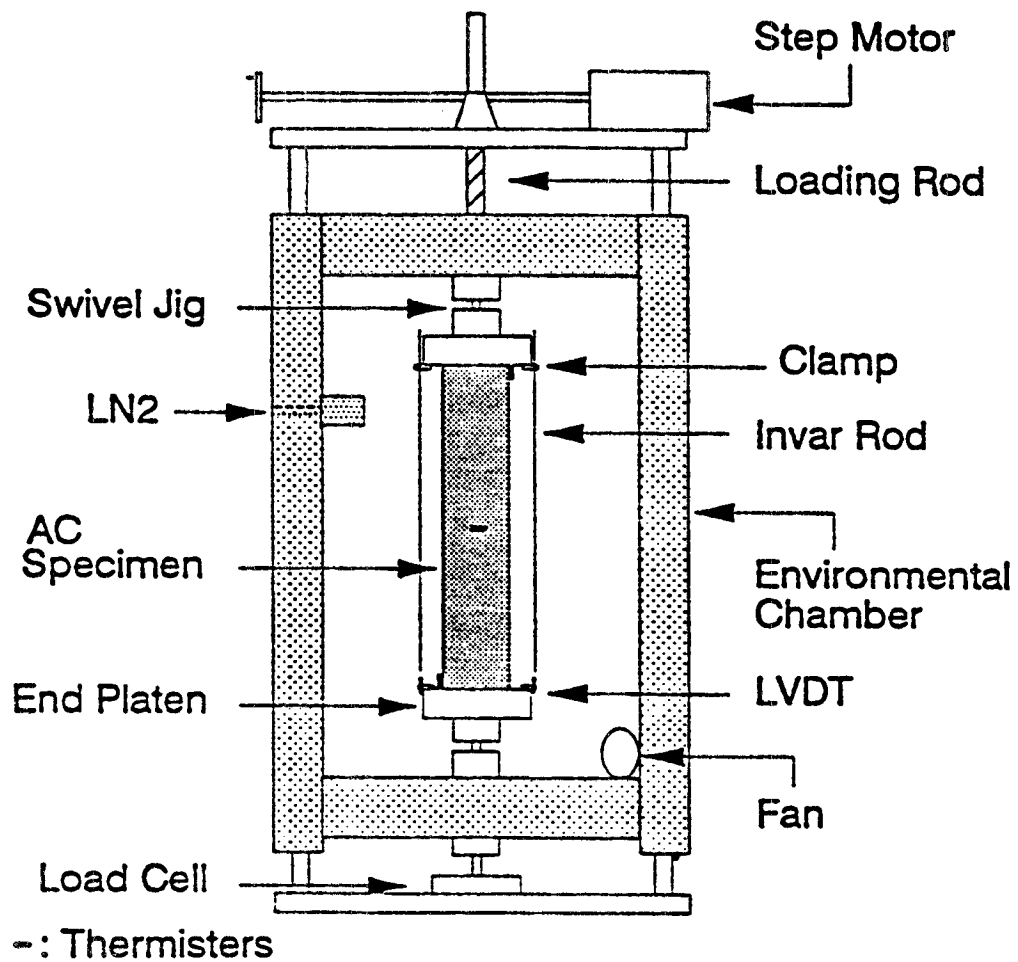


Figure 1. Schematic of Testing Apparatus

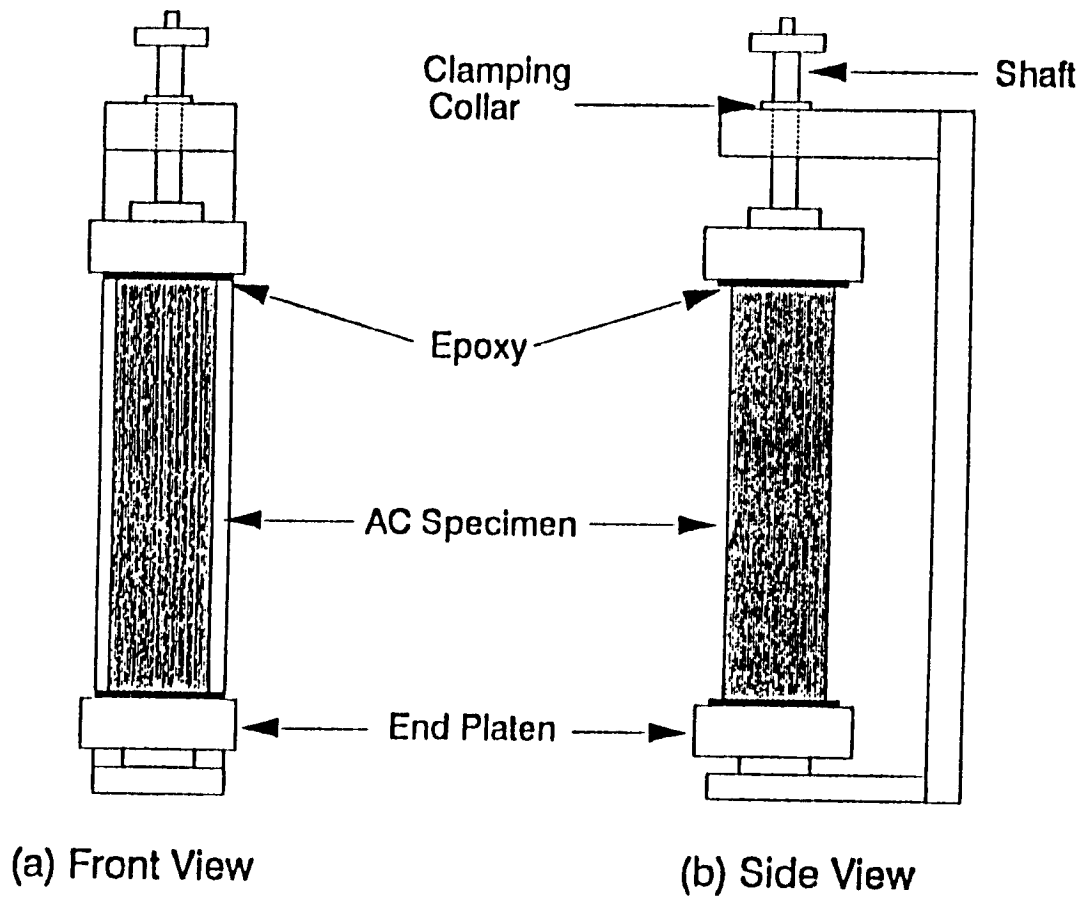


Figure 2. Data Acquisition System

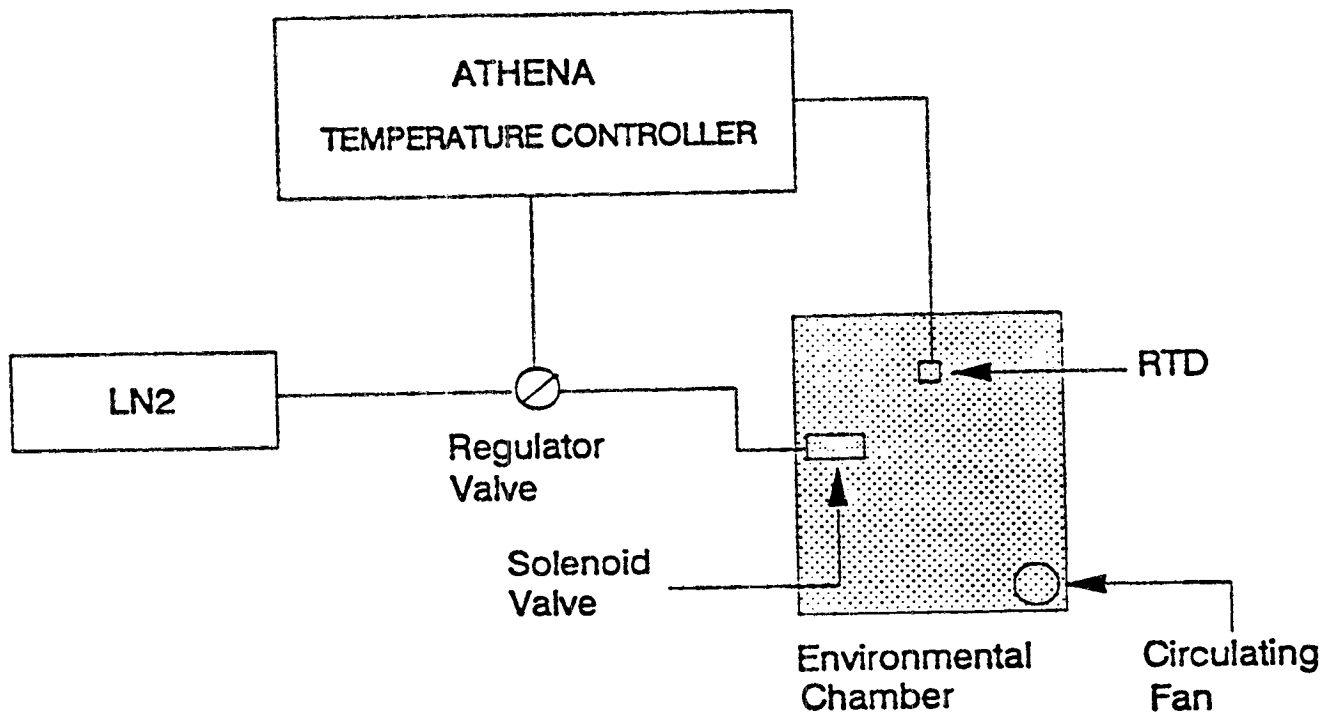


Figure 3. Schematic of Temperature Control System

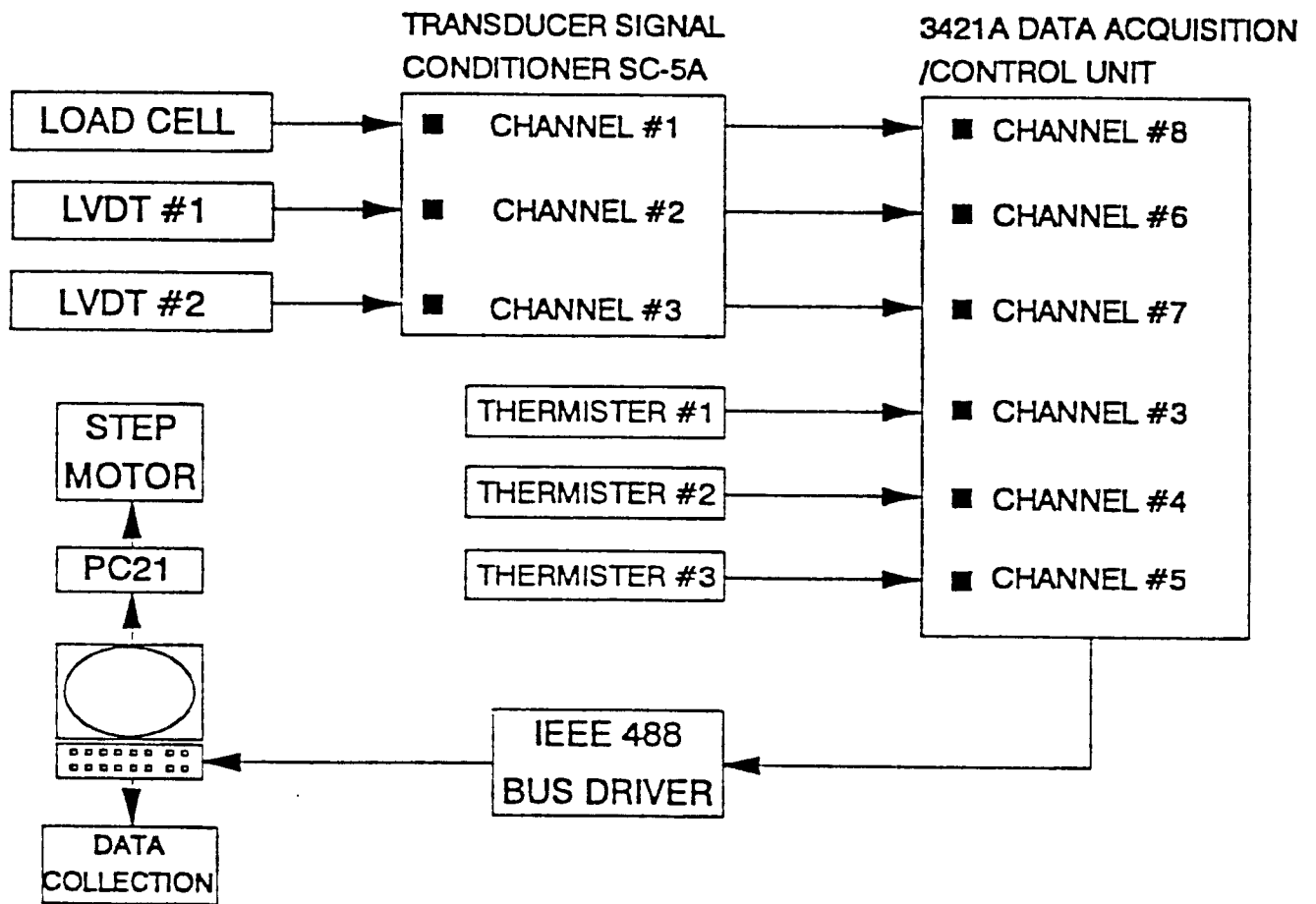


Figure 4. Schematic of Specimen Alignment Stand

Standard Practice for

**The Laboratory Evaluation of
Modified Asphalt Systems**

AASHTO Designation: PP5¹

1. SCOPE

1.1 This practice provides procedures for 1) evaluating the use of and the need for modified asphalt binders and paving mixes within the SUPERPAVE® mix design system, 2) for determining whether modified asphalt binders satisfy the Method for Performance-Graded Asphalt MP1 and 3) modified paving mixes satisfy the SUPERPAVE® mix specification. It utilizes the performance-based asphalt binder and paving mix tests, specifications, and pavement performance prediction developed in the SHRP asphalt research program.

1.2 This practice provides procedures for evaluating modified binders and modified paving mixes using performance-based tests and criteria, and for estimating their performance characteristics in pavement service.

1.3 This practice can be used for the evaluation of modified asphalt binders that meet the requirements of MP1, aggregates, paving mixes or any combination of these. The practice has two main topics: modified asphalt binders and modified paving mixes. Distinct evaluation procedures for aggregate modifiers are not covered in this practice. Aggregate modification is covered under the topic of modified paving mixes.

1.4 This practice provides for two distinct treatments of modified asphalt binder. A modified asphalt binder proposed for use in an asphalt concrete pavement may be directly evaluated. Alternatively, a modifier can be combined with a base asphalt cement to produce a modified binder which meets MP1.

1.5 The values stated in SI units are to be regarded as standard.

1.6 *This practice may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety problems associated with its use. It is the responsibility of whomever uses this practice to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

¹ This standard is based on SHRP Product P001.

2. REFERENCED DOCUMENTS

2.1 AASHTO Standards

- MP1 Method of Test for Performance-Graded Asphalt Binder
- M92 Specification for Wire-Cloth Sieves for Testing Purposes
- PP1 Practice for Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel
- PP6 Practice for Grading or Verifying the Performance Grade of an Asphalt Binder
- TP1 Method of Test for Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer
- TP3 Method of Test for Determining the Fracture Properties of Asphalt Binder in Direct Tension
- TP5 Method of Test for Determining Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer
- T44 Method of Test for Solubility of Bituminous Materials in Organic Solvents
- T48 Method of Test for Flash and Fire Points by Cleveland Open Cup
- T164 Method of Test for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
- T166 Method of Test for Bulk Specific Gravity of Compacted Bituminous Mixtures
- T170 Method of Test for Recovery of Asphalt from Solution by Abson Method
- T179 Method of Test for Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)
- T209 Method of Test for Maximum Specific Gravity of Bituminous Paving Mixtures
- T228 Method of Test for Specific Gravity of Semi-Solid Bituminous Materials
- T240 Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin Film Oven Test)
- T283 Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage

2.2 SHRP Documents

- B-006 Extraction and Recovery of Asphalt Cement for Rheological Testing
 - B-007 Separation of Asphalts by Ion Exchange Chromatography
 - B-008 Separation and Analyses of Asphalts by Size Exclusion Chromatography
 - M-001 Measurement of Initial Asphalt Adsorption and Desorption in the Presence of Water (Net Adsorption Test)
 - M-002 Preparation of Compacted Specimens of Modified and Unmodified Hot Mix Asphalt Test Specimens by Means of the SHRP Gyrotory Compactor
 - M-003 Determining the Shear and Stiffness Behavior Deformation Characteristics of Modified and Unmodified Hot Mix Asphalt with SUPERPAVE Shear Test Device
 - M-004 Measurement of the Permanent Deformation and Fatigue Cracking Characteristics of Modified and Unmodified Hot Mix Asphalt
 - M-005 Determining the Creep Compliance and Strength of Modified and Unmodified Hot Mix Asphalt Using Indirect Tensile Loading Techniques
 - M-006 Determining the Moisture Susceptibility Characteristics of Compacted Bituminous Mixtures Subjected to Hot and Cold Climate Conditions
 - M-007 Short- and Long-Term Aging of Bituminous Mixes
 - M-008 Preparation of Test Specimens of Bituminous Mixtures by Means of Rolling Wheel Compaction
 - M-009 Determining the Fatigue Life of Compacted Bituminous Mixtures Subjected to Repeated Flexural Bending
 - P-002 Guide for Grading or Verifying the Performance Grade of a Asphalt Binder
 - P-004 Volumetric Analysis of Compacted Hot Mix Asphalt
 - P-005 Measurement of the Permanent Deformation and Fatigue Cracking Characteristics of Modified and Unmodified Hot Mix Asphalt
 - P-00X Superpave Mix Design (Being Developed)
 - P-00Y Guidelines for Asphalt Refiners and Suppliers (Being Developed)
- SUPERPAVE® Mix Design Manual for New Construction and Overlays

2.3 Other Documents

2.3.1 National Aggregates Association Test Method A—Fine Aggregate Angularity

2.3.2 Pennsylvania Test Method No. 621 (April 1987)—Determining the Percentage of Crushed Fragments in Gravel

2.3.3 Task Force 31—Polymer Modified Asphalts, Joint Committee of AASHTO-AGC-ARTBA, Subcommittee on New Highway Materials (January 1991)—Guide Specifications for Polymer Modified Asphalt, Version 2.7.

3. DEFINITIONS

3.1 *Modifier*—a material incorporated in hot mix asphalt (HMA) or other types of asphalt paving mixes in addition to the asphalt cement, aggregate and mineral filler, in order to control the development of pavement distresses and enhance overall pavement performance. Modifiers may be any organic or inorganic material of suitable manufacture, used in virgin or recycled condition, that is dissolved, dispersed or reacted in asphalt cement or HMA or coated on aggregate particles.

3.2 *Base Asphalt Binder*—an unmodified asphalt cement used in the production of a modified asphalt binder. The performance grade of a base asphalt cement may be substantially different from that of an unmodified asphalt binder customarily used in a particular location.

3.3 *Conventional Asphalt Binder*—an unmodified asphalt cement customarily used in a particular location.

3.4 *Type I Polymer Modified Asphalt Binder*—a conventional asphalt cement to which styrene block copolymers have been added (*Guide Specifications for Polymer Modified Asphalt*).

3.5 *Type II Polymer Modified Asphalt Binder*—a conventional asphalt cement to which styrene butadiene rubber (SBR) latex or neoprene latex has been added (*Guide Specifications for Polymer Modified Asphalt*).

4. SUMMARY OF THE PRACTICE

4.1 This practice presents a procedure for the laboratory evaluation of modified asphalt binder and paving mixes for HMA pavements. It utilizes the SUPERPAVE® performance-based binder and paving mix tests, specifications, mix design system, and pavement performance prediction models. Materials are evaluated as a single component and/or as a multi-phase component in the final paving mix produced for roadway placement

using the same SUPERPAVE® performance criteria established for conventional (unmodified) materials.

4.2 The selected modifiers are characterized by standard physical and chemical properties used to identify them for future reference. Modified materials are then characterized according to the SUPERPAVE® performance-based specifications and mix design system. Any properties specifically intended for quality control of production or performance of the modified asphalt binder, aggregate, or paving mix are identified.

4.3 The final choice of materials (modifier, base asphalt cement, and aggregate) is guided by reference to the criteria that led to the decision to use a modifier and to any restrictions on the availability of materials.

NOTE 1.—The information required for the selection of modifiers for asphalts, aggregates or paving mixes will usually be provided by the modifier producer. However, it can also be obtained from the literature and by contacting other modifier users. The targeted pavement distress(es) should be indicated. The effect of the modifier on other pavement performance areas must also be considered in the selection process. This information and the historical pavement and laboratory performance will aid in determining whether a given modifier will address the key pavement problems in the targeted climatic and traffic conditions.

NOTE 2.—The results of the characterization of each modified material should be compared with MP1 criteria, historical data and the characteristics of conventional asphalt binders. Based on this comparison, if the expected pavement performance is acceptable, the evaluation should proceed to the next step (modified asphalt binder, aggregate, paving mix or pavement evaluation).

4.4 If the expected performance is unacceptable at the completion of any step in the laboratory evaluation of a modifier, the modifier is rejected or the process is repeated with another modifier, base asphalt binder, or aggregate to optimize the formulation. The evaluation may also go forward to the next step, even if the properties and performance of the modified asphalt binder or paving mix are unfavorable, in order to develop additional data for making a final decision on the use of a candidate modifier.

4.5 The cost of producing and placing the materials is estimated to aid in the decision regarding the use of the modified system. In addition, a simple analysis of the life-cycle cost of using the modified materials is made from the results of the SUPERPAVE® performance-based mix tests and pavement performance prediction models, where appropriate, and compared to the use of conventional asphalt binders and paving mixes.

4.6 The modified HMA production and laydown should be completed using only the equipment and procedures recommended by the modifier producer. The pavement should be produced in accordance with the material proportions and volumetric properties developed in the SUPERPAVE® mix design.

5. SIGNIFICANCE AND USE

5.1 This practice presents detailed procedures for evaluation of modified asphalt binder, aggregate, and paving mix, singly or in combination. The laboratory tests used in

this practice measure fundamental properties that directly govern the response of a pavement to load. From these data, pavement performance, in terms of the development of permanent deformation (rutting), fatigue cracking, and low-temperature cracking over the service life of the pavement, is estimated. The influence of aging and water sensitivity on pavement performance is also explicitly considered.

5.2 Use of this practice allows the evaluation and selection of a modified asphalt binder, aggregate, or paving mixes on the basis of a required level of pavement performance under the present and predicted traffic, environmental, and structural conditions.

6. MATERIALS SELECTION

6.1 Select the modifier, base asphalt cement, and aggregate to satisfy the specific performance criteria that led to the decision to use a modifier. The performance criteria arise from the need to eliminate or reduce one or more pavement distresses or improve the overall performance or service life of the pavement. Consider the availability, compatibility, and cost of the requisite materials in the selection process.

6.2 Modified asphalt binder or paving mix are usually used because conventional, locally available materials do not satisfy the SUPERPAVE® specification for the site-specific traffic, environmental, and structural conditions. Choose a modifier for a base asphalt binder, aggregate, or paving mix after considering the recommendations of the modifier producer and historical performance data.

NOTE 3.—Some conventional asphalt binders or aggregates may not be chemically or physically compatible with a modifier or may not develop the specific levels of performance expected from the use of the modifier. Any method recommended by the producer for screening asphalts or aggregates should be utilized to aid in the selection process. However, there may be cases where the objective is to improve the characteristics of a specific base asphalt cement and the evaluation of the modifier may be pursued even though the asphalt cement or aggregate is not the ideal candidate.

6.3 Table 1 presents information required for the selection of modifiers for asphalt binders, aggregates or paving mixes. Obtain this information from the modifier producer, the highway literature, and contacts with other agencies using modifiers.

6.4 Prepare “Fact Sheets” from the information called for in section 6.3 to assist in the selection of modifiers. The fact sheets shall include: the name of the modifier; any effects on material properties; restrictions; a description of the modifier; any special handling or production requirements. Identify the targeted pavement distress(es) and note the effect of the modifier on other pavement performance areas. This information and the historical pavement and laboratory performance data will aid in determining if a particular modifier will address the key pavement problems identified for the proposed application and use.

6.5 Measure the significant physical and chemical characteristics and specifications for the modifier, particularly the properties that are critical for monitoring the quality of the product. Obtain recommendations concerning the type of asphalts and aggregates that can or

must be used with the modifier from the modifier producer. Also obtain unique or specialized procedures for determining asphalt or aggregate compatibility with the modifier.

NOTE 4.—Chemical characterization of the modifier and the base asphalt binder may aid in determining the effect of modifier use on pavement performance. Chemical properties such as molecular weight and size, composition, association, and functionality are indicators of asphalt binder performance. Size exclusion chromatography, ion exchange chromatography, and infrared spectroscopy are key tools for determination of performance-related chemical properties of asphalt binder. A complete discussion and relevant experimental procedures are presented in the SHRP publication *Guidelines for Asphalt Refiners and Suppliers*.

6.6 Characterize the base asphalt binder with the SUPERPAVE® performance-based conditioning procedures and tests for asphalt binders (table 2). This information will allow comparison of the base asphalt binder with the modified asphalt binder using performance-based properties. Base the selection of the modifier on improved performance as indicated by the change in the binder performance grade achieved by modification, and on the accompanying change in the costs of HMA production and laydown.

6.7 The bending beam rheometer characterizes asphalt binders by measuring creep stiffness at low temperatures. The dynamic shear rheometer measures the shear stiffness at high temperatures. The direct tension test characterizes the strain tolerance of the asphalt binder at low temperatures. The rolling thin film oven test (T240) and the thin-film oven test (T179) simulates short-term aging (HMA production). The pressurized aging vessel test simulates long-term aging that occurs in the pavement after construction.

7. MODIFIED ASPHALT BINDERS AND PAVING MIXES

7.1 General—Obtain information from the modifier producer concerning the equipment, procedures and amount necessary for the laboratory production of the modified asphalt binder, aggregates, or paving mixes. This information shall include health and safety data, special conditions for handling and storage, and any unique quality control parameters recommended by the producer. Pay particular attention to procedures and equipment not common to the HMA industry. Identify any special needs or problems prior to beginning the evaluation process.

NOTE 5.—For example, there are several important special handling and storage conditions for sulfur-extended asphalt. Any tank or silo in which sulfur-extended asphalt binder or HMA is stored must be carefully vented before opening to avoid exposure of workers to toxic hydrogen sulfide (H₂S) or sulfur dioxide (SO₂) gases. If access to such storage is required, workers must wear the correct level of protective clothing. Sulfur and asphalt binder must not be contacted or stored together at temperatures above 150°C to minimize formation of toxic gases.

7.2 Modified asphalt binder—Production processes for modified asphalt binders depend greatly on the physical and chemical characteristics of the modifier and base asphalt binder. They may vary from simple, low-energy mixing, to high-shear blending that requires close control of time and temperature, to actual reaction of the component materials. At a minimum, achieve quality control during production by monitoring the appropriate performance-based rheological properties listed in table 2. Other properties recommended by the modifier producer may also be measured periodically. Use the same physical, chemical

and performance-based properties (table 3) used to characterize the base asphalt binder to evaluate and characterize the modified asphalt binder. Include any property critical to the performance of the modified asphalt binder, but not applicable to the conventional asphalt binders in the characterization.

7.3 Modified Aggregate—Modified aggregate production may vary greatly depending on the characteristics of the modifier and the aggregate. The procedure may be just simple mixing or may involve a complicated coating process. Identify quality control methods by the modifier producer or process designer.

7.4 Modified Paving Mix—Table 3 presents information necessary for the laboratory production and characterization of modified paving mixes. Use the same physical and performance-based tests used to characterize conventional paving mixes to characterize the modified paving mixes. Methods and procedures for the design of conventional and modified paving mixes are briefly presented in the sections 8.3 and 8.4 of this practice and in detail in the *SUPERPAVE® Mix Design Manual for New Construction and Overlays*.

8. LABORATORY EVALUATION OF MODIFIED ASPHALT BINDERS

8.1 General—There are hundreds of potential modifiers that may change or alter asphalt binder properties. This practice is intended to provide a framework for the objective, quantitative evaluation of these candidate materials. It does not provide specific blending and preparation procedures. Develop these procedures in consultation with the producers of specific modifiers (note 6). Use the procedures listed in table 2 to evaluate modified asphalt binders. These procedures measure fundamental properties related to pavement performance, and they apply equally to modified and unmodified binders (note 7).

NOTE 6.—Several test procedures presented in this section apply to specific types of modified asphalt binders. These procedures may also apply to other modifiers in present use or to novel materials that may be employed in the future. However, their applicability should be decided in consultation with modifier producers.

NOTE 7.—MP1 grades binders on the basis on their performance capabilities at low ($< -10^{\circ}\text{C}$) and high ($> 52^{\circ}\text{C}$) pavement temperatures. Grading is based on the properties of the asphalt binder aged to simulate a pavement service period of nominally five to ten years. Asphalt binders must meet the same specification property limits across the entire range of pavement service temperatures.

8.2 Homogeneity

8.2.1 Modified asphalt binders are generally multi-phase systems in which the modifiers are dispersed into the liquid asphalt cement phase. Many of these systems require a certain amount of incompatibility between the phases for the modifiers to provide any benefit, e.g., modifiers intended to disperse, not dissolve, in the base asphalt binder.

8.2.2 Excessive incompatibility is not desirable for proper storage and handling. Therefore, all modified systems should have a requirement for limiting separation of the modifier from the asphalt cement by measurement of rheological properties after aging of the modified binder in the rolling thin film oven test (T240).

8.2.3 Sections 8.3 and 8.4 present specific separation tests for type I and type II polymer modified asphalt binders. Actual limits should be reported when sufficient data exists to support such criteria. A separation test for one type of material, however, may not provide appropriate data for other types. Consult modifier producers to determine appropriate separation tests and test limits for their particular materials.

NOTE 8.—These separation tests and the nomenclature are adapted from the *Guide Specifications For Polymer Modified Asphalt*.

8.3 *Separation Test for Type I Polymer Modified asphalt binder*

8.3.1 Evaluate a type I polymer modifier from asphalt cement during hot storage by comparing the dynamic shear stiffness of the top and bottom samples taken from a conditioned, sealed tube of polymer-modified asphalt binder. Condition the modifier by placing a sealed aluminum tube of polymer-modified asphalt binder in a vertical position in a 165°C oven for 48 hours.

8.3.2 Place the empty aluminum tube with its sealed end down in the rack. Carefully heat the sample until sufficiently fluid to pour. Avoid localized overheating. Strain the fluid sample through a 0.300-mm sieve conforming to M92. After thorough stirring, pour 50.0 g into the vertically held tube. Fold the excess tube over two times, crimp, and seal.

NOTE 9.—Aluminum tubes 25.4 mm in diameter by 139.7 mm long may be obtained from Sheffield Industries, P.O. Box 351, New London, CT 06320. Incidents have been reported regarding leakage of asphalt from the bottom of these tubes during the conditioning period. Other tubes may be required if this leakage is significant.

8.3.3 Place the rack containing the sealed tubes in a $163 \pm 5^\circ\text{C}$ oven. Allow the tubes to stand undisturbed in the oven for a period of 48 ± 1 hour. At the end of the heating period, remove the rack from the oven and immediately place in the freezer at $-5 \pm 5^\circ\text{C}$, taking care to keep the tubes in a vertical position at all times. Leave the tubes in the freezer for a minimum of 4 hours to completely solidify the sample.

8.3.4 Upon removing the tube from the freezer, place the tube on a flat surface. Cut the tube into three equal length portions with appropriate tools. Place each section of tube into a separate 100 mL beaker in a $163 \pm 5^\circ\text{C}$ oven until the modified binder is sufficiently fluid to remove the pieces of aluminum tube.

8.3.5 After a thorough stirring, prepare specimens from the top and bottom samples for testing by TP5 (dynamic shear rheometer). Record and compare the shear stiffness of the top and bottom portions of the sample. Duplicate separation tests should be run. Test results shall be within 5%.

NOTE 10.—Other physical and chemical residue tests may be run at this time, if desired.

8.4 *Separation Test for Type II Modifiers*

8.4.1 This test is a simple qualitative test for compatibility of low-density polymers in asphalt.

8.4.2 After a blend of polymer in unmodified asphalt binder has been prepared and is still at elevated temperature, pour enough of the blend into a clean 177 mL penetration tin to fill it to the formed roll on the cup (approximately 6 mm \pm 0.25 mm from the top). Place the sample in a controlled temperature oven at 163 \pm 5°C for 15 to 18 hours. Remove the sample carefully from the oven without disturbing the surface and observe the sample. After the initial observation, a spatula may be used to gently probe the sample. While the sample is still hot and within 5 minutes after removal from the oven, check the consistency of any surface layer and inspect for sludge on the bottom.

8.4.3 Depending on the physical characteristics of the polymer and the compatibility of the particular asphalt cement/polymer modifier system, varying conditions will be noted. Report the condition of the modifier observed using the guidance provided in table 4.

8.4.4 If these descriptions do not match the particular sample, note the exact phenomena encountered and retain the sample.

8.5 Safety—Safety aspects of the modified asphalt binders are addressed in MP1 by a minimum Cleveland Open Cup flash point (T48) of 230°C. The modifier producer shall provide all other relevant safety information and requirements in the form of a Materials Safety Data Sheet and supporting documents.

8.6 Purity—The base asphalt cement used in modified asphalt binders shall meet a minimum requirement for solubility of 99% by T44. This helps ensure that the polymer-modified asphalt binder is not contaminated with unwanted mineral fines or fillers. The requirement is not placed on the blended, modified asphalt binder because many modifiers do not dissolve readily in the solvents presently used in the paving industry.

8.7 Workability—Ideally, construction of asphalt concrete pavements with modified asphalt binder should not require unusual procedures in any part of the construction process. Because the formulation of modified asphalt binders has the potential to produce extremely high stiffness values, however, a high-temperature viscosity limit of 3 Pa·s at 135°C has been placed in MP1 to assure adequate pumpability of the modified binder at the HMA plant. This requirement may be waived if the modifier producer or HMA supplier warrants that the modified asphalt binder can be adequately pumped and mixed at temperatures that meet all applicable safety standards.

8.8 Performance Testing of Modified Asphalt Binders—This section provides a method for determining the performance characteristics and performance grade of a modified asphalt binder according to the properties and limits contained in MP1. Comparison of these characteristics with those of conventional asphalt cements or of other modified asphalt binders commonly employed by a specifying agency permits an objective decision on the benefits of using a new modifier in a particular situation.

8.8.1 Specimen Preparation—At least 400 g of the modified binder are required for evaluation. All test specimens should be prepared and blended (if required) in accordance with the producer's instructions. Select the initial concentration of modifier in the modified asphalt binder after consultation with the producer.

8.8.2 Conditioning and Testing—Carry out conditioning and testing of the modified asphalt binder in accordance with section 6 or 7 of PP6.

8.8.3 Evaluation—Evaluate the modified asphalt binder by comparing the results of the performance-based tests to the limits contained in MP1. This permits the capabilities of the modified asphalt binder to be objectively measured and gauged against those of conventional asphalt binders.

8.8.3.1 Control the contribution of the asphalt binder to permanent deformation by specifying a minimum value for the stiffness parameter, $G^*/\sin \delta$ ($= 1/J''$, the inverse of the loss compliance), at a maximum pavement design temperature. Correlate this parameter to that portion of the accumulated, non-recoverable deformation occurring in a pavement that is attributable to the asphalt binder. Comparison of the value of $G^*/\sin \delta$ for the modified asphalt binder with that of the base asphalt cement or of the conventional asphalt binder (under similar loading and temperature conditions), or with the limits in MP1, will indicate how well the modified asphalt binder will perform with respect to permanent deformation.

8.8.3.2 Control the contribution of the asphalt binder to low temperature cracking by specifying limits for the creep stiffness, slope of the stiffness-time relationship, and the tensile strain at failure at test temperatures related to the lowest expected pavement design temperature. These properties affect the ability of the pavement to dissipate the tensile strains that result from rapid reductions in temperature or continual low-temperature cycling. Comparison of the measured values of these three properties for the modified asphalt binder with those of the base asphalt cement or the conventional asphalt binder (under similar loading and temperature conditions), or with the limits in MP1, will indicate how well the modified asphalt binder will perform with respect to low temperature cracking.

8.8.3.3 Control the contribution of the asphalt binder to fatigue cracking by specifying a maximum value for the stiffness parameter, $G^*\sin \delta$ ($= G''$, the loss modulus), at the average pavement design temperature. This parameter is related to the contribution of the asphalt binder to the dissipation of energy in a pavement during each loading cycle. Comparison of the value of $G^*\sin \delta$ for the modified asphalt binder with that of the base asphalt cement or of the conventional asphalt binder (under similar loading and temperature conditions), or with the limits in MP1, will indicate how well the modified asphalt binder will perform with respect to fatigue cracking.

8.8.3.4 Aging may be divided into the changes which occur during construction (short term) and the changes which occur during the service life of the pavement (long term). Measure the binder property related to permanent deformation on asphalt binders aged by T240 or T179 to simulate changes that take place during construction. This helps limit the occurrence of early failure of the pavement due to rutting. Measure the binder properties related to fatigue cracking and low-temperature cracking on asphalt binders additionally aged by PP1 to simulate approximately 5 to 10 years pavement service. These types of distress tend to arise later in the service life of the pavement.

NOTE 11.—The confounding effect of aging may be removed by also conducting the performance-based tests on unaged conventional asphalt binder and unaged modified asphalt binder. The test results for the aged and unaged binders can be compared to determine the relative effects of aging on the different binders.

NOTE 12.—T240 is the recommended procedure. Modified asphalt binder may phase separate or form skims during conditioning with T179 (TFOT); the results from subsequent testing of this residue in TP5, TP1, and TP3 may be distorted.

8.8.3.5 The specifications include requirements related to the behavior of the asphalt binder during hot mix production and pavement construction. A minimum flash point is specified for safety. Viscosity ranges for mixing and compaction are identified so that equivalence compaction temperatures can be specified. These values should be noted for the modified asphalt binder and compared to those of the conventional asphalt binder to determine if any special procedures will be required for hot mix production and pavement construction. The effect of shear on the rheological properties of the modified asphalt binder at mixing and compaction conditions must also be evaluated. This should be determined by testing with the high-temperature rotational viscometer and the dynamic shear rheometer at temperatures and frequencies similar to those encountered during blending and mixing at the HMA plant.

8.8.3.6 The results of the performance-based tests for the modified asphalt binder are compared to the MP1 specification values and the performance grade is determined. The comparison indicates the level of enhancement that the modified asphalt binder will produce in the targeted distress areas. This conclusion should then be compared with the level of enhancement promised by the producer and with any historical field performance data. Table 5 presents the suggested minimum ratio of modified to conventional asphalt binder for MP1 properties that should provide significant enhancement of binder performance. This table is for guidance only and should not be used for specification purposes.

8.8.3.7 If the performance properties and grade of the modified asphalt binder are acceptable, initiate modified laboratory paving mix production and evaluation. Review the physical properties of the modified asphalt binder that relate to production and pavement construction and identify any potential problems.

8.8.3.8 If the performance properties and grade of the modified asphalt binder are unacceptable, halt the evaluation of the modifier. Review the results of the evaluation to this point to determine if the modification process was completed properly or if further optimization of the modification is warranted. For example, the level of modifier addition or the selection of a different base asphalt cement may have a large effect on the performance capabilities of the modified asphalt binder. If further optimization does not appear warranted, the evaluation should be terminated and the modifier rejected.

NOTE 13.—The specifying agency may choose to further optimize the modified asphalt binder composition even though the results are favorable. It may also choose to proceed to the modified paving mix evaluation regardless of the results of the binder evaluation in order to develop additional data for a final decision on the use of the candidate modifier.

9. LABORATORY EVALUATION OF AGGREGATE

9.1 The SUPERPAVE® mix design system requires measurement of the gradation, apparent specific gravity, bulk specific gravity, sand equivalent, Los Angeles abrasion, soundness, and deleterious material content of all aggregates, both unmodified and modified. Empirical guidelines are presented that relate several of these parameters to pavement performance. These tests are not considered performance-based for purposes of judging the effect of modification, and as such, are not covered by this practice. Modifications to the aggregate are evaluated strictly in terms of changes to the performance properties of the modified paving mix.

10. LABORATORY EVALUATION OF PAVING MIXES

10.1 The ultimate benefits of the use of modifiers are demonstrated by their effect on the performance characteristics of modified paving mixes. The SUPERPAVE® system addresses the primary pavement distress modes of permanent deformation (rutting), fatigue cracking, and low-temperature cracking. It also accounts for the effects of aging and moisture in the development of these distresses. Environmental conditions and traffic are also explicitly considered.

10.2 The asphalt binder makes up only about 5 weight percent of a paving mix. As a rule, the magnitude of the change in performance attributable to the modifier is smaller for the paving mix than for the asphalt binder. Moreover, the role of the asphalt binder, whether modified or not, in influencing pavement performance varies with the type of distress investigated. About 40% of the resistance of a paving mix to permanent deformation is attributable to properties of the asphalt binder; in contrast, binder properties can account for about 60% of a mix's resistance to fatigue cracking and as much as 90% of its resistance to low-temperature cracking.

10.3 The SUPERPAVE® accelerated mix performance tests and mix design system are the key tools for laboratory evaluation of modified paving mixes. As in the case of modified asphalt binders, the SUPERPAVE® performance-based mix specification provides an objective measure against which the ability of specific modifiers to enhance pavement performance may be gauged.

10.4 *Performance Testing of Modified Paving Mixes*—This section provides a method for determining the performance characteristics of modified paving mixes, comparing them with criteria contained in the SUPERPAVE® performance-based mix specification, and estimating their influence on long-term pavement performance. Correlation of these performance characteristics with those of conventional paving mixes (or of other modified mixes commonly employed by the specifying agency) permits an impartial decision on the benefits of using a new modifier in a particular situation.

NOTE 14.—The SUPERPAVE® pavement performance prediction models were used to develop the SUPERPAVE® mix specification limits. Since the mix design system incorporates accelerated performance tests that

measure fundamental material properties that govern pavement performance, the SUPERPAVE® system is applicable to either standard asphalt-aggregate paving mixes or modified asphalt-aggregate paving mixes.

10.4.1 Specimen Preparation—Prepare all required cylindrical specimens of modified mix using the SHRP gyratory compactor in conformance with SHRP M-002. Blend or combine modifiers with the base asphalt cement, aggregate, or paving mix, as appropriate, in accordance with the producer's instructions.

NOTE 15.—When required, prismatic beam specimens may be prepared in conformance with SHRP M-008 (rolling wheel compaction) or other appropriate means.

10.4.2 Conditioning and Testing—Condition and test the modified mix in accordance with the *SUPERPAVE® Mix Design Manual for New Construction and Overlays* and relevant procedures and methods referenced therein. Table 6 presents a summary of the conditioning procedures and performance-based test methods generally employed.

10.4.3 Evaluation—Accomplish evaluation by estimating the performance of a pavement constructed with the modified paving mix. Make calculations using the pavement performance prediction algorithms in the SUPERPAVE® software. This permits an objective comparison of the performance characteristics of the modified paving mix to the standard or conventional paving mix.

10.4.3.1 Conduct laboratory aging of the modified paving mix principally to condition the specimens used in the performance-based mix tests in table 6. This conditioning simulates the short- and long-term aging that occurs during HMA production and pavement service. In addition, if the dynamic modulus of aged specimens is measured and compared with that of unaged specimens, the rate and degree to which the modified paving mix will age, compared to a conventional asphalt paving mix, can be estimated.

10.4.3.2 Conduct moisture conditioning in the laboratory to identify candidate paving mixes that have an unacceptable moisture susceptibility. These mixes can then be eliminated or subjected to remedial treatment. Changes in tensile strength or dynamic modulus provide a direct measure of moisture susceptibility. Optionally, test the conditioned specimens in any of the performance-based mix tests to determine the effect of moisture on the development of specific pavement distresses.

10.4.3.3 The contribution of the paving mix to permanent deformation is gauged by the results of SHRP M-003. This simulates the high shear stresses that develop near the pavement surface at the edges of tires, and that lead to both lateral and vertical deformations. Estimate the rut depth after any selected number of ESALs (equivalent single axle loads of 80 kN) from the number of shear repetitions (in the repetitive shear, constant height test) needed to reach an accumulated permanent strain of 5%. Conduct this test at a test temperature related to the maximum expected pavement temperature. Evaluate the potential for catastrophic, tertiary creep in the pavement with the repetitive shear test at a field state of stress. Conduct this test for 4000 cycles at an effective temperature and stress state appropriate for the paving project. Finally, use the results of the uniaxial strain, simple

shear, volumetric and frequency sweep tests in the SUPERPAVE® software to estimate the development of rutting over the service life of the pavement.

10.4.3.4 Estimate the contribution of the paving mix to low-temperature cracking from the results of the indirect tensile creep and failure tests. Determine the master stiffness curve and the maximum stress and strain at failure of the paving mix directly over the entire low temperature service range. These test results measure the ability of the pavement to dissipate the tensile strains that result from rapid reductions in temperature or continual low-temperature cycling. They are used in the SUPERPAVE® software to estimate the rate and extent of development of low-temperature cracking over the service life of the pavement.

10.4.3.5 Estimate the contribution of the paving mix to fatigue cracking in the SUPERPAVE® mix design system by a surrogate procedure. Conduct frequency sweeps with the SHRP shear device at temperatures between 4 and 20°C to develop the shear modulus and phase angle at intermediate service temperatures. Use stiffness values calculated from these data with tensile strength results from the indirect tensile failure test to estimate the course of crack initiation and propagation in the paving mix. Use the test results in the SUPERPAVE® software to estimate the rate and extent of development of fatigue cracking over the service life of the pavement.

NOTE 16.—The surrogate procedure employs a regression equation that estimates the number of cycles to crack initiation from the mix stiffness. This equation was developed principally from test results for unmodified paving mixes. It should be applied to the results from modified paving mixes with caution. In cases where a modifier is considered primarily as a means to control fatigue cracking, it is recommended that flexural beam fatigue tests be conducted in place of the surrogate procedure on the modified mix.

10.4.3.6 Compare the results of the SUPERPAVE® performance-based tests for the standard or conventional paving mix with the results for the modified paving mix. This will allow a direct estimate of the extent to which use of the modified paving mix will reduce the incidence of each pavement distress over the service life of the pavement. In cases where reliable historical records are available, this estimate can be verified by comparing the known pavement performance of the conventional paving mix with the predicted performance. A rudimentary estimate of the cost-benefit ratio of using the modified paving mix in place of the conventional paving mix can also be made from these comparative results and the first costs of the modified and conventional HMA. The exact details of this calculation will depend upon agency policies, e.g., whether maintenance and rehabilitation are scheduled on a periodic basis or triggered by a specific level of distress.

10.4.3.7 If the estimated pavement performance of the modified paving mix and its cost-benefit ratio are favorable, modified pavement construction may be initiated at the discretion of the specifying agency. This may entail completion of a mix design for the modified mix in order to optimize its performance characteristics. The volumetric and engineering properties of the modified paving mix that relate to field control of HMA production and pavement construction should also be determined, and any potential problems identified to the HMA contractor and agency inspectors.

10.4.3.8 If the estimated performance of the modified paving mix or its cost-benefit ratio are unacceptable, then the evaluation of this modifier can be abandoned or the evaluation repeated to optimize the selection of materials or the mix design.

NOTE 17.—The specifying agency may choose to further optimize the modified paving mix even though the results are favorable. It may also choose to proceed to pavement construction regardless of the results of the modified mix evaluation in order to develop additional data for a final decision on the use of the candidate modifier.

11. THE SUPERPAVE® MIX DESIGN SYSTEM

11.1 The performance-based testing described in sections 8 and 10 may all be conducted, if desired, within the context of the SUPERPAVE® mix design system. This system is founded on measurement of fundamental material properties of the asphalt binder and paving mix, and is fully applicable to unmodified and modified systems. It should be routinely employed to produce optimized mix designs incorporating those modifiers shown effective for enhancing pavement performance through the procedures in sections 8 and 10.

11.2 The SUPERPAVE® mix design system develops an initial mix design based on volumetric mix properties. This design is then optimized on the basis of pavement performance estimates calculated from fundamental material properties of the trial paving mix.

11.3 Only the volumetric design is required for low traffic levels. At intermediate traffic levels (typically 10^6 to 10^7 total design ESALs), the volumetric design and a streamlined series of performance-based paving mix tests selected from those in table 6 are conducted. For high traffic levels, the volumetric design and the full set of accelerated performance tests summarized in table 6 are advised. The SUPERPAVE® system provides unique specification guidelines and criteria for each level of mix design.

11.4 For modifiers with established performance capabilities, the mix design system can be used alone to develop modified paving mixes with optimal performance characteristics. The comparative testing of conventional asphalt binders or paving mixes is not necessary.

12. MODIFIED ASPHALT PAVEMENT EVALUATION

12.1 Table 7 presents key information that should be developed to guide the production, construction, and evaluation of modified asphalt pavements. Information should be supplied by the modifier producer concerning the equipment and procedures necessary for the field production and construction of the modified asphalt pavements. Any atypical HMA operations should be carefully reviewed jointly with the HMA contractor and the modifier producer. This will help identify any potential operational problems or special equipment needs. This information must include health and safety data, conditions for handling and storage of the modified asphalt binder and paving mix, and special field control requirements to ensure that the plant mix will provide the expected performance.

12.2 The HMA plant should produce the mix according to the parameters developed in the SUPERPAVE® mix design discussed in section 8.4. The plant mix should be sampled and compared to the job mix formula developed in the mix design. In addition, and at the discretion of the specifying agency, modified asphalt binder and paving mix samples may be tested in accordance with the performance-based binder and mix tests used in the laboratory evaluation. This will ensure conformance of the plant-produced mix with the job mix formula.

12.3 The construction of the modified asphalt pavement should follow normal practice except where special procedures are required by the modifier producer or from the results of the laboratory evaluation. For example, the equiviscous temperature for compaction may be different than for conventional asphalts binders.

12.4 The compacted pavement should be evaluated for the key physical properties identified by the mix design procedure. At the discretion of the specifying agency, core samples or slabs may be taken and tested according to the SUPERPAVE® performance-based binder and mix tests used in the laboratory evaluation and mix design. This will help ensure that the level of compaction is satisfactory and that the actual pavement performance will be commensurate with the mix design predictions.

12.4.1 Evaluate the completed modified asphalt pavement initially by comparing the results of the performance-based tests of the pavement samples with the results of the laboratory evaluation and with the relevant mix specification. Compare the properties of the completed pavement with those of standard HMA pavements. Use the SUPERPAVE® performance prediction models in the SUPERPAVE® software to predict the expected pavement life based on the actual pavement properties.

12.4.2 Long-term evaluation of the modified asphalt pavement requires the periodic monitoring of the pavement's performance and properties. It may be necessary to sample the pavement periodically and determine the performance-based properties to assess real-world effects of aging, traffic, and the environment on pavement performance. This will also facilitate the further validation and calibration of the SUPERPAVE® prediction models. The best way to manage this task is through a good pavement management system (PMS).

12.5 The actual cost of constructing the modified asphalt pavement should be determined and recorded in the PMS for future evaluation and life-cycle cost analysis. A life-cycle cost estimate should be based on the predicted life of the modified asphalt pavement as determined from actual pavement data and the actual cost of construction. This estimate should be updated periodically when pavement performance data and/or performance-based laboratory data is received from field samples. This cost and performance data should be compared to those of conventional asphalt pavements in similar service.

12.6 The evaluation will be complete when the service life of the pavement is reached and the final performance and costs can be compared with predicted values and conventional systems. The value of the modifier in all likelihood can be established sooner if significant differences in performance are noted early in the life of the pavement.

13. REPORT

13.1 The report on the laboratory evaluation of the modifier system may include the following:

13.1.1 name, concentration(s), and characterization information for the modifier recommended;

13.1.2 mixing procedures, equipment, and hazards involved in the handling of the modifier;

13.1.3 results of performance-based tests of all materials;

13.1.4 results of SUPERPAVE® mix design procedure including final job mix formula;

13.1.5 cost and performance comparison of the modified system with the unmodified system.

14. KEY WORDS

Aggregate, asphalt, characterization, field control, mix design, modifier, performance, performance-based, SUPERPAVE®.

Table 1. Modifier Selection and Characterization

<p>Selection</p> <ul style="list-style-type: none"> • Target pavement distress(es) • Effect on other performance areas • Historical performance (laboratory and Field) • Health and safety data • Handling and storage requirements • Production procedures • Construction (laydown) procedures • Asphalt recommendations or requirements • Aggregate recommendations or requirements <p>Characterization</p> <ul style="list-style-type: none"> • Physical properties • Chemical properties • Quality control properties • SUPERPAVE® performance characteristics of modified asphalt binders and paving mixes
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Table 2. Performance-Based Binder Conditioning Procedures and Tests

Procedure	Measured Properties	Pavement Distress
TP5	high-temperature shear stiffness	permanent deformation fatigue cracking
TP1	low-temperature creep stiffness	low-temperature cracking
TP3	stress, strain, and energy to failure	low-temperature cracking
T240	mass loss and change in shear and creep stiffness	short-term aging
PP1	change in shear and creep stiffness	long-term aging

Table 3. Modified Asphalt Paving Mix Laboratory Production and Characterization

Laboratory Production	
Recommendation from the Modifier Producer	
Equipment	
Procedures	
Health and Safety Information	
Quality Control Parameters and Test Methods	
Storage and Procedures	
Mix Design Procedures	
Producer Information	
SUPERPAVE® Mix Design Manual	
Characterization	
Physical Properties (Developed in Mix Design Procedure)	
<ul style="list-style-type: none"> • Voids in the Mineral Aggregate • Air Voids • Voids Filled with Asphalt • Asphalt Binder Content 	
Chemical Properties	
<ul style="list-style-type: none"> • Moisture Sensitivity • Effect of Aging 	
Performance-Based Tests and Material Properties	
<ul style="list-style-type: none"> • Permanent Deformation (SHRP Shear Test) • Low-Temperature Cracking (Indirect Tensile Test) • Fatigue Cracking (Flexural Beam Fatigue Test) 	

Table 4. Criteria for Type II Separation Test

Observation	Report
Homogeneous, no skinning or sludge	Homogenous
Slight polymeric skin at edges of cup	Slight Edge Skinning
Thin polymer skin on entire surface	Thin Total Skinning
Thick polymer skin (≥ 1 mm) on entire surface	Thick Total Skinning
No surface skinning but thin sludge at bottom of container	Thin Bottom Sludge
No surface skinning but thick (≥ 6 mm) sludge at bottom of container	Thick Bottom Sludge

Table 5. Guidelines for Binder Modification

Binder Specification Property	Suggested Ratio (Modified/Unmodified Binder)
$G^*/\sin \delta$	≥ 2.5
$G^*\sin \delta$	≤ 0.7
S	≤ 0.7
m	≥ 1.2

Table 6. Performance-Based Laboratory Mix Tests and Conditioning Procedures

Pavement Distress	Equipment & Test	Measurement
Permanent Deformation	SHRP Shear Test Device: <ul style="list-style-type: none"> • Uniaxial Strain Test • Volumetric Test • Simple Shear Test • Frequency Sweep • Repetitive Shear Test at Constant Height • Repetitive Shear Test at a Field State of Stress 	<ul style="list-style-type: none"> • Dilatancy • Accumulation of Permanent Strain • Stiffening under Confining Stress • Tertiary Creep • Shear Modulus • Phase Angle
Low Temperature Cracking	Indirect Tensile Test Device: <ul style="list-style-type: none"> • Indirect Tensile Creep Test • Indirect Tensile Failure Test 	<ul style="list-style-type: none"> • Creep Compliance • Tensile Strength
Fatigue Cracking (Surrogate Method)	Simple Shear Test Device: <ul style="list-style-type: none"> • Frequency Sweep Indirect Tensile Test Device: <ul style="list-style-type: none"> • Indirect Tensile Failure Test 	<ul style="list-style-type: none"> • Shear Modulus • Phase Angle • Tensile Strength
Fatigue Cracking (Referee Method)	Flexural Beam Fatigue Device: <ul style="list-style-type: none"> • Constant Strain Flexural Fatigue at 20°C 	<ul style="list-style-type: none"> • Cycles to Beam Failure
Water Sensitivity	AASHTO T283: <ul style="list-style-type: none"> • Tensile Strength in Dry and Wet Condition <i>or</i> Environmental Conditioning System: <ul style="list-style-type: none"> • Dynamic Modulus in Dry and Wet Condition 	<ul style="list-style-type: none"> • Change in Tensile Strength <i>or</i> <ul style="list-style-type: none"> • Change in Dynamic Modulus
Aging—Short Term	Forced Draft Oven Aging of Loose Mix: <ul style="list-style-type: none"> • Dynamic Modulus in Unaged and Aged Condition 	<ul style="list-style-type: none"> • Change in Dynamic Modulus
Aging—Long Term	Forced Draft Oven Aging of Compacted Mix: <ul style="list-style-type: none"> • Dynamic Modulus in Unaged and Aged Condition 	<ul style="list-style-type: none"> • Change in Dynamic Modulus

Table 7. Modified Asphalt Pavement Production, Construction, Characterization, and Evaluation

Pavement Production and Construction

- Recommendations from the Modifier Producer
 - Equipment
 - Procedures
 - Health and Safety Information
 - Quality Control Parameters and Test Method
 - Storage and Handling Procedures

Mix Design Procedures

- Producer's Recommendations
- SUPERPAVE® Mix Design System

Characterization (Production and Cores)

- Volumetric Properties (Developed in Mix Design Procedure)
 - Voids in the Mineral Aggregate
 - Air Voids
 - Voids Filled with Asphalt
 - Asphalt Binder Content
- Performance-Related and Performance-Based Properties
 - Aging
 - Moisture Sensitivity
 - Permanent Deformation
 - Low-Temperature Cracking
 - Fatigue Cracking

Evaluation

- SHRP Performance-Based Specifications
 - Comparison with Conventional Paving Mixes
 - Historical Performance Data (Lab and Field)
 - Pavement Management System
 - Cost Analysis
-

Standard Practice for
**Grading or Verifying the Performance Grade
of an Asphalt Binder**

AASHTO Designation: PP6¹

1. SCOPE

1.1 This practice describes the testing required to determine the performance grade of an asphalt binder. It presents two approaches. In the first, the performance grade of an unknown asphalt binder is determined. In the second, the nominal performance grade of an asphalt binder is verified. It also provides an estimate of the time required to complete a single test sequence.

1.2 The values stated in SI units are to be regarded as standard.

1.3 *This practice may involve hazardous materials, operations, and equipment. This practice does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this practice to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCE DOCUMENTS

2.1 AASHTO Documents:

MP1	Method of Test for Performance-Graded Asphalt Binder
PP1	Practice for Accelerated Aging of an Asphalt Binder Using a Pressurized Aging Vessel
T48	Method for Flash and Fire Points by Cleveland Open Cup
T179	Method for Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)
T240	Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin Film Oven Test)
TP1	Method of Test for Determining the Flexural Creep Stiffness of an Asphalt Binder Using the Bending Beam Rheometer (BBR)
TP3	Method for Determining the Fracture Properties of an Asphalt Binder in Direct Tension (DT)
TP5	Method of Test for Determining Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)

¹ This standard is based on SHRP Product P002.

2.2 ASTM Documents:

D 4402 Measurement of Asphalt Viscosity Using a Rotational Viscometer

3. SUMMARY OF THE PRACTICE

3.1 The tank sample of asphalt binder is tested to determine the flash point in °C (T48), viscosity at 135°C (D 4402), shear modulus (G^*) and phase angle (δ) (TP5).

3.2 The asphalt binder is aged in the rolling thin film oven (T240) or the thin film oven (T179), and the residue is tested to determine the mass loss (T240 or T179), the shear modulus (G^*), and phase angle (δ) (TP5).

NOTE 1.—T240 is the recommended procedure. Modified asphalt binders may phase separate or form skins during conditioning with T179 (TFOT); the results from subsequent testing of this residue in TP5, TP1, and TP3 may be distorted.

3.3 The residue from the rolling thin film oven or thin film oven is aged in the pressurized aging vessel (PP1). This residue is tested to determine the shear modulus (G^*) and phase angle (δ) (TP5), creep stiffness (S) and slope (m) of the log creep stiffness versus log time relationship at 60 seconds (TP1), the failure strain in direct tension (TP3), as necessary, and physical hardening measured by creep stiffness (S) and slope (m) of the log creep stiffness versus log time relationship at 1 and 24 hours (TP1).

3.4 Based on these test results, the asphalt binder is graded according to MP1.

4. SIGNIFICANCE AND USE

This practice describes the testing required for grading or verifying the performance grade of an asphalt binder according to MP1.

5. ESTIMATED TIME NECESSARY FOR TESTING

For both grading and verification, if the analysis is started at the beginning of a morning work shift, all testing and analysis should be completed during the afternoon of the next day. This schedule provides the 20 hours needed for PAV conditioning. (It takes 1 additional day to collect the physical hardening data as 24 hours of conditioning are required at the lowest grading test temperature to determine the extent of physical hardening.) Of course, samples can be aged and analyzed in parallel, and the productivity of the laboratory increased. For the purpose of this document, however, analysis of a single asphalt binder will be discussed.

6. TEST PROCEDURE FOR GRADING AN UNKNOWN ASPHALT BINDER

6.1 Prepare samples and test specimens using the procedures specified in the test methods performed. In the case where the grade of the asphalt binder is unknown, approximately 400 g of unaged asphalt binder is required to complete the tests with the necessary replicates.

6.2 Begin conditioning asphalt binder in the rolling thin film oven (RTFO) or thin film oven (TFO). Condition a sufficient amount of asphalt binder depending on the type and number of tests to be performed.

NOTE 2.—Two BBR beams requiring PAV material are needed at each test temperature. In addition, four DT specimens requiring PAV material may also be needed at each test temperature. A minimum of two test temperatures will be required. Approximately 200 g of RTFO or TFO residue will be required.

6.3 Perform the DSR test (TP5) on the original asphalt binder beginning at 58°C, and increase or decrease the test temperature at 6.0°C increments until a value for $G^*/\sin \delta \leq 1.00$ kPa is obtained. The highest test temperature where the value for $G^*/\sin \delta$ is ≥ 1.00 kPa determines the starting performance grade (PG).

NOTE 3.—For example, if $G^*/\sin \delta$ is 0.6 kPa at 64°C and 1.2 kPa at 58°C, the starting asphalt binder grade is PG 58-.

6.4 Determine the flash point on a sample of original binder using T48. The flash point must be greater than 230°C to meet the requirements of MP1.

6.5 Determine the viscosity of the original asphalt binder at 135°C using ASTM D 4402. The viscosity must not exceed 3 Pa·s to meet the requirements of MP1.

6.6 After the RTFO test (T240) or TFO test (T179) is complete, determine the mass loss of the original asphalt binder. The mass loss must be $\leq 1.00\%$ to meet the requirements of MP1.

6.7 If the original asphalt binder does not meet MP1 requirements for the tests in sections 6.4 and 6.5, no further testing is required.

6.8 Perform the DSR test (TP5) on the RTFO or TFO residue at the test temperature used to determine the starting PG (section 6.3) to confirm the high temperature grade of the asphalt binder (PG 46-, 52-, 58-, etc.). The value for $G^*/\sin \delta$ of the RTFO or TFO residue must be ≥ 2.20 kPa. Choose the lower PG in cases where the test values in sections 6.3 and 6.8 give conflicting grades.

6.9 Age a sufficient quantity of RTFO or TFO residue in the PAV (PP1). Use an aging temperature of 90°C for starting grades PG 46-x and 52-x binders, and 100°C for starting grades PG 58-x and higher. A PAV temperature of 110°C is to be used in simulating desert environments.

NOTE 4.—Two BBR beams (requiring PAV material) are required at each test temperature. In addition, four DT samples may also be needed at each test temperature. A minimum of two test temperatures will be required.

6.10 Complete steps 6.1 through 6.9 during the first day of testing. This will allow further testing to begin on the second day, when the PAV procedure is complete.

6.11 At the conclusion of the PAV procedure, carefully remove the residue from the vessel and combine individual pans of the same aged asphalt binder. Prepare two bending beam specimens for each test temperature according to TP1. Retain sufficient residue to prepare four direct tension specimens for each test temperature if required.

6.12 Perform the DSR test (TP5) on the PAV residue. Begin at a test temperature of 16°C for PG 52; 19°C for PG 58; 22°C for PG 64; and 28°C for PG 70, unless there is other information to suggest the temperature at which $G^* \sin \delta$ is ≤ 5000 kPa. Decrease or increase the test temperature at 3.0°C increments until the value for $G^* \sin \delta$ exceeds 5000 kPa.

6.13 Determine the beginning test temperature for the BBR test (TP1) on the PAV residue from table 1 of MP1. Use the starting PG determined in section 6.3 and the lowest temperature from section 6.12 where the value for $G^* \sin \delta$ did not exceed 5000 kPa, unless there is other information to suggest the temperature at which the stiffness is ≤ 300.0 MPa, and the slope m is ≥ 0.300 .

6.14 Test pairs of BBR specimens according to TP1. Begin at the test temperature selected in section 6.13 and increase at 6.0°C increments, until a stiffness and slope meeting the requirements of MP1 are obtained. Test fresh BBR specimens at each temperature. Determine the extent of physical hardening, report the creep stiffness (S) and the slope (m) of the log creep stiffness versus log time relationship measured at 1 and 24 hours. Prepare two sets each of two BBR specimens of original asphalt binder. Test one set after 1 hour of conditioning and the second set after 24 hours of conditioning. The latter is conducted at the lowest grading test temperature ($T_{\min} + 10^\circ\text{C}$).

6.15 Certain asphalt binders may satisfy the MP1 slope requirement at substantially lower temperatures than they satisfy the stiffness requirement. If the creep stiffness is between 300 and 600 MPa at a test temperature at which the slope (m) is ≥ 0.300 , it may be possible to satisfy the DT (TP3) failure strain requirement in lieu of the creep stiffness requirement. Test four DT specimens according to TP3 at the test temperature at which $m \geq 0.300$, and determine if the failure strain is $\geq 1.0\%$.

6.16 If the failure strain is $< 1.0\%$, test additional sets of four DT specimens. Increase the test temperature in 6.0°C increments until a failure strain $\geq 1.0\%$ is obtained. Determine the test temperature at which $m \geq 0.300$ and the creep stiffness is ≤ 300.0 MPa, or, if the creep stiffness is between 300.0 and 600.0 MPa, the failure strain is $\geq 1.0\%$.

6.17 Using the results of steps 6.12 through 6.16, determine the final grade of the asphalt binder.

7. TEST PROCEDURE FOR VERIFYING THE NOMINAL GRADE OF AN ASPHALT BINDER

7.1 Prepare samples and test specimens using the procedures specified in the test methods performed. In the case where the grade of the asphalt binder is being verified, approximately 250 g of unaged asphalt binder is required to complete the tests with the necessary replicates.

7.2 Begin conditioning asphalt binder in the rolling thin film oven (RTFO) or thin film oven (TFO). Condition a sufficient amount of asphalt binder depending on the type and number of tests to be performed.

NOTE 5.—Two BBR beams that require PAV material are needed. In addition, four DT specimens requiring PAV material may also be required. Only one test temperature will be required. Approximately 100 g of RTFO or TFO residue will be required.

7.3 Perform the DSR test (TP5) on the original asphalt binder at the test temperature indicated by the high-temperature grading designation. For example, test a PG 70-16 asphalt binder at 70°C. The value for $G^*/\sin \delta$ must be ≥ 1.0 kPa to meet the requirements of MP1.

NOTE 6.—This step verifies the starting PG. For example, if $G^*/\sin \delta \geq 1.00$ kPa at 58°C, the high temperature grading designation for the asphalt binder is PG 58-.

NOTE 7.—If the asphalt binder fails to meet the requirements of MP1 for the grade at which it has been designated, it may be treated as a binder of unknown grade and tested according to section 6.

7.4 Determine the flash point on a sample of original binder using T48. The flash point must be greater than 230°C to meet the requirements of MP1.

7.5 Determine the viscosity of the original asphalt binder at 135°C using ASTM D 4402. The viscosity must not exceed 3 Pa·s to meet the requirements of MP1.

7.6 After the RTFO test (T240) or TFO test (T179) is complete, determine the mass loss of the original asphalt binder. The mass loss must be $\leq 1.00\%$ to meet the requirements of MP1.

7.7 If the original asphalt binder does not meet MP1 requirements for any of the tests performed in sections 7.4, 7.5 or 7.6, no further testing is required.

7.8 To verify the high temperature properties of the binder, perform the DSR test (TP5) on the RTFO or TFO residue at the test temperature indicated by the high-temperature grading designation. For example, test a PG 70-16 asphalt binder at 70°C. The value for $G^*/\sin \delta$ of the RTFO residue must be ≥ 2.20 kPa to meet the requirements of MP1 (note 7).

7.9 Age a sufficient quantity of RTFO or TFO residue in the PAV (PP1). Use an aging temperature of 90°C for binders having a high-temperature grading designation of PG

46-x or PG 52-x, 100°C for binders having high-temperature grading designations of PG 58-x and higher. A PAV temperature of 110°C is used in simulating desert environments.

NOTE 8.—Two BBR beams requiring PAV material are required. In addition, four DT samples may also be needed requiring about 60 g of PAV-conditioned asphalt binder.

7.10 Complete steps 7.1 through 7.9 during the first day of testing. This will allow further testing to begin on the second day, when the PAV procedure is complete.

7.11 At the conclusion of the PAV procedure, carefully remove the residue from the vessel and combine individual pans of the same aged asphalt binder. Prepare two bending beam specimens according to TP1. Retain sufficient residue to prepare four direct tension specimens if required.

7.12 Perform the DSR test (TP5) on the PAV residue at the test temperature specified in table 1 of MP1 indicated for the high-temperature and low-temperature grading designation of the binder being verified. For example, test a PG 64-40 asphalt binder at 16°C. The value for $G^*\sin \delta$ must not exceed 5000 kPa to meet the requirements of MP1 (note 7).

7.13 Test two BBR specimens according to TP1 at the test temperature specified in table 1 of MP1 indicated for the high temperature and low temperature grading designation of the binder being verified. For example, test a PG 58-28 asphalt binder at -18°C . The value of the slope m must be ≥ 0.300 to meet the requirements of MP1. Certain asphalt binders may satisfy the BBR slope requirement at substantially lower temperatures than they satisfy the BBR stiffness requirement (note 7).

7.14 Determine the extent of physical hardening, report the creep stiffness (S) and the slope (m) of the log creep stiffness versus log time relationship measured at 1 hour (conducted above in section 7.13) and 24 hours. Prepare two BBR specimens of original asphalt binder. Condition and test the specimens at the test temperature, selected from table 1 of MP1, appropriate for the performance grade of the asphalt binder. For example, if the binder grade being verified is a PG 64-34 asphalt binder, condition and test the BBR specimens at -24°C . Test one set after 1 hour of conditioning and the second set after 24 hours of conditioning.

7.15 If the creep stiffness is between 300.0 and 600.0 MPa and the slope m is ≥ 0.300 at the test temperature, it may be possible to satisfy the DT failure strain requirement in lieu of the creep stiffness requirement. Test four DT samples according to TP3 at the same test temperature used to test the BBR specimens. The failure strain must be $\geq 1.0\%$ to meet the requirements of MP1 (note 7).

8. REPORT

8.1 If the grade of the asphalt binder tested is determined, report the results of all tests performed and the high temperature grading designation determined followed by the low temperature designation (for example: PG 52-34).

8.2 If the grade of an asphalt binder is verified, report the results of all tests performed and if the binder meets the requirements of MP1.

9. KEY WORDS

Asphalt binder, performance grading.

Standard Practice for
Volumetric Analysis of Compacted Hot Mix Asphalt

SHRP Designation: P-004

NOTE 1.—This practice is based upon chapter VI, *Analysis of Compacted Paving Mixtures*, of Asphalt Institute Manual MS-2.¹

NOTE 2.—This practice is intended to **supplement** the volumetric analysis and design procedures contained in the *SUPERPAVE® Mix Design Manual for New Construction and Overlays*.²

1. SCOPE

1.1 This practice provides procedures to accomplish the volumetric analysis of compacted hot mix asphalt (HMA) specimens.

1.2 It presents methods for determining:

- the volume percent of air voids (V_a , also termed the *air voids content*);
- the volume percent of voids in the mineral aggregate (VMA);
- the voids filled with asphalt (VFA);
- the effective volume of asphalt binder (V_{be}); and
- the effective asphalt content (P_{be})

of compacted HMA specimens.

Values of these properties are calculated from the measured specific gravities of the asphalt binder, the coarse and fine aggregate, and the compacted HMA.

1.3 This practice is applicable to specimens compacted in the laboratory or to specimens which are cut or cored from field pavements.

¹Manual MS-2, *Mix Design Methods for Asphalt Concrete*, 5th ed., The Asphalt Institute, Lexington, Ky.: 1988.

²R.J. Cominsky and E.T. Harrigan, *SUPERPAVE® Mix Design Manual for New Construction and Overlays*, SHRP, National Research Council, Washington, DC: 1993, Forthcoming.

1.4 In order to attain adequate precision in the measured properties and calculated quantities, only compacted HMA specimens with a volume of $5.25 \times 10^5 \text{ mm}^3$ or larger (equivalent to a cylindrical specimen approximately 100 mm in diameter and 65 mm high) should be tested.

1.5 The values stated in SI units are to be regarded as the standard.

1.6 *This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems 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. APPLICABLE DOCUMENTS

2.1 AASHTO Standards

T84	Specific Gravity and Absorption of Fine Aggregate
T85	Specific Gravity and Absorption of Coarse Aggregate
T100	Specific Gravity of Soils
T164	Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
T166	Bulk Specific Gravity of Compacted Bituminous Mixtures
T170	Recovery of Asphalt from Solution by Abson Method
T209	Maximum Specific Gravity of Bituminous Paving Mixtures
T228	Specific Gravity of Semi-Solid Bituminous Materials

3. SIGNIFICANCE AND USE

3.1 The proper design and field control of HMA volumetric parameters are critical to achieving satisfactory long-term pavement performance.

4. DEFINITIONS

NOTE 3.—Definitions 4.1, 4.2, 4.3, 4.5 and 4.6 are excerpted from Asphalt Institute Manual MS-2.

4.1 *Air Voids (V_v)*—the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as percent of the bulk volume of the compacted paving mixture.

4.2 *Voids in the Mineral Aggregate (VMA)*—the volume of intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the specimen.

4.3 *Effective Asphalt Content (P_{be})*—the total asphalt content of a paving mixture less the portion of asphalt binder that is lost by absorption into the aggregate particles.

4.4 Voids Filled with Asphalt (VFA)—the portion of the voids in the mineral aggregate that contain asphalt binder. This represents the volume of the effective asphalt content.

4.5 Bulk Specific Gravity (G_{sb})— the ratio of the mass in air of a unit volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the mass in air (of equal density) of an equal volume of gas-free distilled water at a stated temperature.

4.6 Effective Specific Gravity (G_{se})—the ratio of the mass in air of a unit volume of a permeable material (excluding voids permeable to asphalt) at a stated temperature to the mass in air (of equal density) of an equal volume of gas-free distilled water at a stated temperature.

4.7 Theoretical Maximum Specific Gravity (G_{mm})— the ratio of the mass of a given volume of voidless ($V_a = 0$) HMA at a stated temperature (usually 25°C) to a mass of an equal volume of gas-free distilled water at the same temperature.¹

4.8 Volume of Absorbed Asphalt (V_{ba})—the volume of asphalt binder in the HMA that has been absorbed into the pore structure of the aggregate. V_{ba} is the volume of asphalt binder in the HMA for which the effective asphalt content cannot account.

5. PROCEDURE

NOTE 4.—The accuracy of determinations of specific gravity for mix design is extremely important. Unless specific gravities are determined to three decimal places (four significant figures) an absolute error in the calculation of the air voids content of as much as 0.8% can occur (e.g., an actual value of 4.2% may be measured anywhere in the range of 3.4 to 5.0%). Therefore, balances of appropriate sensitivity must be used to measure the masses employed in the specific gravity determinations.

5.1 Determine the percent of asphalt binder and aggregate by the total weight of the mixture (T164 and T170). Report as P_b and P_s , respectively.

5.2 Separate the coarse (retained on the 4.75 mm sieve) and fine aggregate fractions from the mineral filler fraction (passing the 75 μm sieve). Calculate the percent of each fraction by the total weight of the aggregate and report as P_1 , P_2 and P_3 , respectively.

5.3 Measure the specific gravity of: the asphalt binder (T228); the coarse aggregate (T85); the fine aggregate (T84); and the mineral filler (T100). Report as G_b , G_1 , G_2 and G_3 , respectively.

¹Caution should be used when measuring the theoretical maximum specific gravity of HMA containing highly absorptive aggregates. Work conducted in SHRP Contract A-003B demonstrated that absorption may continue over a period of hours, and the value of G_{mm} may change significantly until absorption is completed.

5.4 Calculate the bulk specific gravity, G_{sb} , of the combined aggregate recovered from the HMA by the following equation:

$$G_{sb} = \frac{(P_1 + P_2 + P_3)}{\left[\frac{P_1}{G_1} + \frac{P_2}{G_2} + \frac{P_3}{G_3}\right]}$$

5.5 Measure the theoretical maximum specific gravity of the compacted HMA (T209) and report as G_{mm} .

5.6 Measure the bulk specific gravity of the compacted HMA (T166) and report as G_{mb} .

5.7 Calculate the effective specific gravity of the aggregate, G_{se} , by the following equation:

$$G_{se} = \frac{(100 - P_b)}{\left(\frac{100}{G_{mm}} - \frac{P_b}{G_b}\right)}$$

5.8 Calculate the absorbed asphalt, P_{ba} , as a percent by weight of the aggregate by the following equation:

$$P_{ba} = \frac{(G_b)(G_{se} - G_{sb})}{(G_{sb}G_{se})} \times 100$$

5.9 Calculate the effective asphalt content, P_{be} of the HMA by the following equation:

$$P_{be} = P_b - \left[\frac{(P_{ba}P_s)}{100}\right]$$

5.10 Calculate the percent voids in the mineral aggregate (VMA) by the following equation:

$$\text{VMA} = 100 - \left[\frac{G_{mb}P_s}{G_{sb}}\right]$$

where P_s is the percent of aggregate by the total weight of the mixture.

5.11 Calculate the percent air voids, V_a , in the compacted HMA by the following equation:

$$V_a = \frac{G_{mm} - G_{mb}}{G_{mm}} \times 100$$

5.12 Calculate the percent of voids filled with asphalt binder (VFA) as a portion of the voids in the mineral aggregate by the following equation:

$$\text{VFA} = \frac{\text{VMA} - V_a}{\text{VMA}} \times 100$$

6. REPORT

6.1 Report specific gravity results to the nearest 0.001 and percent voids (VMA, V_a and VFA) to the nearest 0.1.

Standard Practice for

**Measurement of the Permanent Deformation and
Fatigue Cracking Characteristics of
Modified and Unmodified Hot Mix Asphalt**

SHRP Designation: P-005¹

1. INTRODUCTION

1.1 This practice provides a laboratory guide for the analysis of the permanent deformation and fatigue cracking behavior of modified and unmodified (hot mix asphalt) (HMA) paving mixes with the SUPERPAVE® shear test device.

1.2 A sequence of tests conducted with the shear test device are required in both the SUPERPAVE® level 2 and level 3 mix designs. These test results are used to calculate the pavement performance characteristics of a paving mix with the SUPERPAVE® software.

1.3 In addition to summarizing the test procedures, this practice provides guidance on the time requirements for completion of the level 2 and level 3 test sequences.

1.4 The SUPERPAVE® shear test device is equipped with dual load actuators and is capable of simultaneously applying an axial and a shear load on the test specimen. It is also capable of applying a repetitive axial or shear load throughout a range of frequencies. This equipment is described in SHRP Standard Test Method M-003.

1.5 The values stated in SI units are to be regarded as the standard.

1.6 *This standard may involve hazardous materials, operations and equipment. This standard does not purport to address all of the safety problems 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. SCOPE

2.1 This is a practice for the performance-based testing of compacted specimens of modified or unmodified paving mix with the SUPERPAVE® shear test device.

¹This standard is based on SHRP Product 1017.

2.2 This practice is applicable to specimens prepared in a laboratory mix design procedure or cored from a pavement for post-construction performance analysis.

2.3 Complete analysis of the test results from the SUPERPAVE® shear test device requires the *SUPERPAVE® Specification, Mix Design and Support Program*.

3. REFERENCED DOCUMENTS

3.1 *The SUPERPAVE® Mix Design Manual for New Construction and Overlays*

3.2 SHRP Test Method M-002, *Preparation of Compacted Specimens of Modified and Unmodified Hot Mix Asphalt Test Specimens by Means of the SHRP Gyrotory Compactor*.

3.3 SHRP Test Method M-003, *Determining the Shear and Stiffness Behavior of Modified and Unmodified Hot Mix Asphalt with the SUPERPAVE® Shear Test Device*.

3.4 AASHTO Test Method T166, *Bulk Specific Gravity of Compacted Bituminous Mixtures*.

4. SUMMARY OF THE PRACTICE

4.1 SUPERPAVE® Level 2 Mix Design

4.1.1 A sequence of three tests is performed with the shear test device in the level 2 mix design. At each asphalt binder content, four specimens are tested at two different test temperatures. The level 2 test matrix is summarized in table 1.

4.2 SUPERPAVE® Level 3 Mix Design

4.2.1 A sequence of five tests is performed with the shear test device in the level 3 mix design. At each asphalt binder content, six specimens are tested at four different test temperatures. The level 3 test matrix is summarized in table 2.

4.3 The following sequence of steps is common to each of the tests shown in tables 1 and 2.

4.3.1 Prepare test specimens. Saw specimen ends perpendicular to the longitudinal axis of the specimen; clean; measure dimensions; and determine specific gravity of each specimen.

Table 1. Test Matrix for Level 2 Mix Design

Test Method	Number of Specimens at Test Temperature	
	$T_{eff}(PD)$	$T_{eff}(FC)$
Repeated Shear at Constant Stress Ratio (Tertiary Creep)	2	—
Simple Shear at Constant Height	2*	2*
Frequency Sweep at Constant Height	2*	2*

*The simple shear test at constant height and the frequency sweep at constant height are conducted on the same two specimens at both temperatures.

Notes: $T_{eff}(PD)$ is the calculated effective temperature for permanent deformation.
 $T_{eff}(FC)$ is the calculated effective temperature for fatigue cracking. See chapter 4 of the SUPERPAVE® Mix Design Manual for New Construction and Overlays.

Table 2. Test Matrix for Level 3 Mix Design

Test Method	Number of Specimens at Test Temperature			
	4°C	20°C	40°C	$T_{eff}(PD)$
Repeated Shear at Constant Stress Ratio (Tertiary Creep)	—	—	—	2
Volumetric	2 ^a	2 ^a	2 ^a	—
Uniaxial Strain	2 ^a	2 ^a	2 ^a	—
Simple Shear at Constant Height	2 ^b	2 ^b	2 ^b	—
Frequency Sweep at Constant Height	2 ^b	2 ^b	2 ^b	—

^aTests performed on the same two specimens.

^bTests performed on the same two specimens.

Notes: $T_{eff}(PD)$ is the calculated effective temperature for permanent deformation. See chapter 4 of the SUPERPAVE® Mix Design Manual for New Construction and Overlays.

4.3.2 Assemble the test assembly. As required, bond the platens to the test specimen; where required, surround the specimen with a membrane; and affix the linear variable differential transducers (LVDTs) to the specimen in the configuration required by the specific test.

4.3.3 Load the completed test assembly into the shear test device.

4.3.4 Conduct the test per SHRP M-003 and the manufacturer's instructions for the shear test device.

4.3.5 At the completion of the test, remove the test assembly from the shear test device.

4.3.6 Disassemble the test assembly. Discard or retain the test specimen and clean the end caps for reuse.

5. GUIDELINES

5.1 The following guidelines must be carefully followed before attempting to perform any of the tests described in this practice.

5.1.1 Ensure that all load cells and LVDTs are accurately calibrated.

5.1.2 Ensure that the correct channels and gains are entered into the system software before beginning any test.

5.1.3 Clearly define the test conditions and enter them into the test device software.

5.1.4 Allow sufficient time for the system to stabilize after the specimen is placed in the apparatus and before the test begins. This time will vary depending on the test temperature and the stiffness of the specimen. A typical stabilization time is 15 to 30 minutes.

5.1.5 Clearly identify the variables which are to be measured during the test.

5.1.6 Turn on the hydraulic system 1 hour before starting the test to allow sufficient warm-up time.

5.1.7 Condition all specimens at their initial test temperature for 2 hours before testing. For testing at 40°C or higher, the specimen should be placed in a 40°C (or designated temperature) oven for a period of at least 2 hours but not more than 4 hours.

5.1.8 After the specimen is placed in the shear test device, apply a pre-load of 100 to 150 N before the specimen is clamped in place.

5.1.9 Perform a thorough check of the system for leakage before any test requiring specimen confinement with air pressure.

5.1.10 Ensure that all measurement devices have reasonable sensitivities, commensurate with the load intensity and specimen deformation expected during each test. For example, the frequency sweep test requires a much more sensitive LVDT for horizontal deformation measurement than for vertical deformation.

6. SPECIMEN PREPARATION

6.1 All test specimens must be 150 mm in diameter and 50.0 ± 2.5 mm high. Any appropriate procedure, such as AASHTO T166, *Bulk Specific Gravity of Compacted Bituminous Mixtures*, can be used to determine the specific gravity of the specimen. The dimensions of the specimens must be accurately measured and the top and bottom faces of the specimen must be smooth and parallel.

6.2 Clean the platens and ensure that they are dust free.

6.3 Place a pair of platens into the gluing jig provided with the shear test device, align them and clamp them into place.

NOTE 1.—The platens are bonded to the specimen for all tests except the volumetric and uniaxial tests.

6.4 Proportion and mix epoxy resin and hardener together in accordance with the manufacturer's instructions.

NOTE 2.—Devcon 5-Minute Plastic Steel Epoxy Cement has been found to provide satisfactory performance for testing conducted at 20°C and higher. For low-temperature testing (typically at 4°C), Devcon Plastic Steel Epoxy Cement proved adequate.

6.5 Ensure that the test specimen is dust free. Apply a thin coating of epoxy cement (~ 1.5 mm) to each end of the test specimen. Assure that the epoxy cement completely covers the specimen end and that it is of uniform thickness.

6.6 Bond the specimen to the platens under a pressure of 30 to 40 kPa for the period of time recommended by the epoxy cement manufacturer.

6.7 Remove the test assembly from the gluing jig. Allow the epoxy to cure for the time period recommended by the manufacturer.

NOTE 3.—For Devcon 5-Minute Plastic Steel Epoxy, a curing time of 2 hours at room temperature is recommended.

6.8 As required for specific tests, attach mounting screws for the horizontal LVDT(s) to the sides of the test specimen with epoxy cement (see notes 4 and 5).

NOTE 4.—Gluing the specimen to the platens and attaching mounting screws for the LVDT takes about 15 minutes.

NOTE 5.—There are several alternative methods for mounting LVDTs. LVDTs measuring axial (vertical) deformation are generally attached directly to the platens. Similarly, LVDTs measuring shear (horizontal) deformation are typically mounted on blocks that are in turn attached to screws bonded to the specimen. They must measure the difference in horizontal displacement between two points on the specimen separated by at least 40 mm. Consult figure 5 in SHRP test method M-003 for specific LVDT mounting recommendations.

7. TESTING OF SPECIMENS IN THE SUPERPAVE® SHEAR TEST DEVICE

7.1 Repeated Shear Test at Constant Stress Ratio (Tertiary Creep)

7.1.1 Prepare the test specimen in accordance with section 6.

7.1.2 Mount two LVDTs on the test assembly in such a manner that axial (vertical) and shear (horizontal) deformations can be measured during the test with an accuracy and precision commensurate with the requirements of M-003.

NOTE 6.—This stress-controlled test will usually be performed at an effective temperature for permanent deformation calculated from weather data for the site of the paving project. During the test, the ratio of the axial stress to the shear stress is kept constant in order to simulate the field state of stress in a pavement. To accomplish this, the feedback to the horizontal load actuator servovalve is from the magnitude of the shear load. The feedback to the vertical load actuator servovalve is from the magnitude of the axial load.

7.1.3 Place the specimen inside the shear test device and clamp it securely in place.

7.1.4 Adjust the controls for the environmental chamber to the requisite test temperature and allow the chamber and the test assembly to stabilize at that temperature.

7.1.5 Precondition the specimen by applying 100 cycles of synchronized haversine axial and shear load pulses with a peak magnitude of 7 kPa for shear stress. The axial stress for preconditioning should not exceed 7 kPa with the ratio axial to shear stress held constant at a value of 1.2 to 1.5. Each cycle is 0.7 second in duration, and consists of the application of a 0.1 second haversine load followed by a 0.6 second rest period.

7.1.6 At the conclusion of the preconditioning, perform the repeated shear test for a duration of 5000 load cycles or until the permanent accumulated strain reaches a level of 5%. A haversine shear load is applied with a maximum shear stress level determined from table 3. The ratio of the haversine axial to shear load is maintained at a constant value between 1.2 and 1.5. Each test cycle is 0.7 second in duration, and consists of the application of a 0.1 second haversine load followed by a 0.6 second rest period.

Table 3. Maximum Shear Stress Levels

Base Condition ²	Asphalt Binder Content ¹		
	Above Design	At Design	Below Design
Weak Base	84 – 119 kPa	63 – 98 kPa	49 – 56 kPa
Strong Base	98 – 175 kPa	84 – 105 kPa	56 – 91 kPa

¹The design asphalt binder content refers to the binder content selected in the SUPERPAVE® level 1 (volumetric) design method.

²A weak base is defined as an unbound granular or crushed stone material, e.g., new construction; a strong base is defined as an existing asphalt concrete or portland cement concrete pavement, cement-stabilized or asphalt-stabilized base, or a strong crushed stone base material (with a resilient modulus of 560,000 kPa or greater).

7.1.7 Record axial deformation, shear deformation, axial load, and shear load during the test at the intervals shown in table 4 or at other appropriate intervals.

NOTE 7.—The test takes about 70 to 80 minutes to complete from the time the specimen is placed in the apparatus until it is removed.

Table 4. Suggested Data Collection for the Repeated Shear Test at a Field State of Stress

Data Collected During Cycles:	
1 through 10	1,747 through 1,750
20 through 22	2,000 through 2,002
30 through 32	2,247 through 2,250
50 through 52	2,500 through 2,502
80 through 82	2,748 through 2,750
100 through 102	2,997 through 3,000
200 through 202	3,200 through 3,202
300 through 302	3,400 through 3,402
400 through 402	3,600 through 3,602
500 through 502	3,800 through 3,802
600 through 602	3,997 through 4,000
800 through 802	4,200 through 4,202
1,000 through 1,002	4,500 through 4,502
1,247 through 1,250	4,998 through 5,000
1,500 through 1,502	

Notes: The duration of each cycle is 0.7 second.

A data collection rate of 60 data points per second is satisfactory.

7.2 Volumetric Test

7.2.1 Place the specimen (prepared in accordance with sections 6.1 and 6.2) between the top and bottom platens.

7.2.2 Surround the specimen with a membrane, 150 mm in diameter and 0.6 mm thick, that is open at both ends and free of any defects.

7.2.3 Fix the membrane tightly to the platens with rubber O-rings.

7.2.4 Mount a radial LVDT around the circumference of the specimen to measure its radial deformation. Then mount LVDTs on both sides of the specimen to measure axial deformation from platen to platen.

7.2.5 Since the specimen will be subjected to confining pressure with compressed air during the test, confirm that the system is not leaking before starting the test. Thoroughly check the membrane and all connecting hoses and fittings, and replace or tighten as necessary.

NOTE 8.—Vacuum can be used to check for defective connections or a faulty membrane which may cause leakage. Two hoses connect the platens to the outside of the confining cell and to the atmosphere. These hoses prevent the buildup of air pressure between the specimen and the membrane, and serve to warn of any leaks in the membrane or the seals between the membrane and the platens.

7.2.6 Place the completed specimen test assembly into the testing cell in the shear test device. Confirm that the specimen is in the center of the cell and not in contact with the surrounding walls, and that the radial LVDT can move freely around the specimen without any interference from other objects.

7.2.7 Lower the confining cell and lock in place. Bring the specimen assembly to the required test temperature and allow sufficient time for the temperature to stabilize.

7.2.8 Open the air pressure valve to begin the test. Precondition the specimen by rapidly applying, then removing hydrostatic pressure. Ramp the pressure to 70 kPa in one second and immediately reduce it to 7 kPa.

7.2.9 Conduct the volumetric test by increasing the hydrostatic pressure at a rate of 70 kPa/s to: 550 kPa at 40°C, 690 kPa at 20°C, or 830 kPa at 4°C. Maintain the pressure at that level for 10 seconds and then reduce it to 7 kPa at a rate of 25 kPa/s. Hold the specimen at this pressure for an additional 30 seconds.

7.2.10 Record the axial deformation on both sides of the specimen, the radial deformation, and the hydrostatic pressure at a rate of about 10 data points per second.

NOTE 9.—The volumetric test takes about 30 minutes to complete. This includes set-up, placing of the specimen in the cell, running the test, and removing the specimen from the apparatus.

7.3 *Uniaxial Strain Test*

7.3.1 Place the specimen (prepared in accordance with sections 6.1 and 6.2) between the top and bottom platens.

7.3.2 Surround the specimen with a membrane, 150 mm in diameter and 0.6 mm thick, that is open at both ends and free of any defects.

7.3.3 Fix the membrane tightly to the platens with rubber O-rings.

7.3.4 Mount a radial LVDT around the circumference of the specimen to measure its radial deformation. Then mount LVDTs on both sides of the specimen to measure axial deformation from platen to platen.

7.3.5 Since the specimen will be subjected to confining pressure with compressed air during the test, confirm that the system is not leaking before starting the test. Thoroughly check the membrane and all connecting hoses and fittings, and replace or tighten as necessary (note 8).

7.3.6 Place the completed specimen test assembly into the testing cell in the shear test device with a 75 mm circular loading unit placed between the vertical (axial) load cell and the top platen to provide a uniform stress distribution. Confirm that the specimen is in the center of the cell and not in contact with the surrounding walls, and that the radial LVDT can move freely around the specimen without any interference from other objects.

7.3.7 Lower the confining cell and lock in place. Bring the specimen assembly to the required test temperature and allow sufficient time to stabilize the temperature.

NOTE 10.—During the test the confining pressure is adjusted by closed loop feedback control from the radial LVDT to maintain the circumference of the specimen at a constant value and prevent radial deformation of the specimen during the test.

7.3.8 Open the air pressure valve to begin the test. Precondition the specimen by applying an axial load which is induced at the rate of 70 kPa/s for one second and immediately reduced to 7 kPa.

7.3.9 Conduct the uniaxial strain test by increasing the axial stress at a rate of 70 kPa/s to: 345 kPa at 40°C, 550 kPa at 20°C, or 655 kPa at 4°C. Maintain the stress at that level for 10 seconds and then reduce it to 7 kPa at a rate of 25 kPa/s. Hold for an additional 30 seconds at this stress level.

7.3.10 Record the axial deformation on both sides of the specimen, the radial deformation, the axial load, and the confining pressure at appropriate intervals and at a rate of about 10 data points per second.

NOTE 11.—The uniaxial strain test takes about 30 minutes to complete. This includes setup, placing of the specimen in the cell, running the test, and removing the specimen from the apparatus.

7.4 *Simple Shear Test at Constant Height*

7.4.1 Prepare the test specimen in accordance with section 6.

7.4.2 Mount two LVDTs on the test assembly in such a manner that axial (vertical) and shear (horizontal) deformations can be measured during the test with an accuracy and precision commensurate with the requirements in Test Method M-003.

NOTE 12.—This is a stress-controlled test. During the test, the height of the specimen is kept constant. To accomplish this, the vertical load actuator is controlled by feedback from the vertical (axial) LVDT. The feedback to the horizontal (shear) load actuator is from the magnitude of the shear load.

7.4.3 Place the specimen inside the shear test device and clamp it securely in place.

7.4.4 Adjust the controls for the environmental chamber to the requisite test temperature and allow the chamber and the test assembly to stabilize at that temperature.

7.4.5 Precondition the specimen for 100 cycles with a shear stress of 7 kPa. Each cycle is 0.7 second in duration, and consists of the application of a 0.1 second haversine load followed by a 0.6 second rest period.

7.4.6 At the conclusion of the preconditioning, perform the simple shear test by increasing the shear stress at a rate of 70 kPa/s to: 345 kPa at 40°C or $T_{\text{eff}}(PD)$, 105 kPa at 20°C or $T_{\text{eff}}(FC)$, or 35 kPa at 4°C. Maintain the stress at that level for 10 seconds and then reduce it to 0 kPa at a rate of 25 kPa/s. Continue the test for an additional 10 seconds at a stress level of 0 kPa.

7.4.7 Record axial deformation, shear deformation, axial load, and shear load at a rate of about 10 data points per second.

NOTE 13.—The test takes about 20 to 30 minutes to complete from the time the specimen is placed in the apparatus until it is removed.

7.5 *Frequency Sweep Test at Constant Height*

7.5.1 Prepare the test specimen in accordance with section 6.

7.5.2 Mount two LVDTs on the test assembly in such a manner that axial (vertical) and shear (horizontal) deformations can be measured during the test with an accuracy and precision commensurate with the requirements in M-003 (note 5).

NOTE 14.—This is a strain-controlled test. The maximum strain is limited to 1×10^{-4} mm/mm. During the test, the height of the specimen is kept constant. To accomplish this, the vertical load actuator is controlled by feedback from the vertical (axial) LVDT. The feedback to the horizontal (shear) load actuator is from the LVDT measuring the horizontal (shear) deformation.

7.5.3 Place the specimen inside the shear test device and clamp it securely in place.

7.5.4 Adjust the controls for the environmental chamber to the requisite test temperature and allow the chamber and the test assembly to stabilize at that temperature.

7.5.5 Precondition the specimen by applying a sinusoidal shear (horizontal) strain of approximately 1×10^{-4} mm/mm at a frequency of 10 Hz for 100 cycles.

7.5.6 At the conclusion of the preconditioning, perform the frequency sweep test in which 100 cycles of 1×10^{-4} mm/mm sinusoidal shear (horizontal) strain is applied at the each of the following frequencies in descending order: 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, and 0.02 Hz. Repeat the test on each specimen at three different temperatures, typically 4, 20 and 40°C, starting at the lowest temperature.

7.5.7 Record axial deformation, shear deformation, axial load, and shear load at a rate of about 50 data points per load cycle.

NOTE 15.—At each temperature, the test takes about 45 to 55 minutes per specimen to complete from the time the specimen is placed in the apparatus until it is removed.

8. CLEANUP

8.1 At the conclusion of each test requiring specimens bonded to the platens, place the specimen-platen assembly in a 135°C oven for 15 to 20 minutes to disbond specimen and epoxy from the platens. Clean the platens with acetone (or other suitable solvent recommended by the manufacturer of the epoxy cement) in an operating fume hood and dry with compressed air before use with a new specimen.

9. TESTING TIME AND SCHEDULE

9.1 The time required to complete the test sequence needed for a level 2 or level 3 mix design will depend upon a number of factors: the speed with which the test temperature can be changed and stabilized in the SUPERPAVE® shear test device; work-shift scheduling; the skill and number of technicians; and the technicians' familiarity with the shear test device and its ancillary equipment.

9.2 Table 5 is a guide to the time required to accomplish different segments of the procedure for one trial paving mix (one asphalt binder content) under normal laboratory conditions in a level 3 mix design.

Table 5. Time Estimate for Level 3 Mix Design

Procedure or Test Method	Number of Tests per Temperature	Number of Temperatures	Time (hrs)
Compaction and Preparation of Eight Specimens	—	—	6
Bonding to Platens and Mounting of LVDT Screws	—	—	1
Repetitive Shear at Constant Stress Ratio	2	1	3
Frequency Sweep	2	3	4
Simple Shear	2	3	2
Volumetric	2	3	2.5
Uniaxial Strain	2	3	2.5
Data Preparation	—	—	2
Temperature Changes	—	—	6
Total hours:			27

9.3 The length of the total test period is also affected by the initial time required to set up the systems and calibrate the measurement devices. A more efficient testing schedule is achievable if several paving mixes are tested simultaneously; the average time spent per paving mix will be less than, for instance, the time needed when only one paving mix is being tested.

9.4 Table 6 presents an estimated testing schedule for a complete level 3 mix design, involving three asphalt binder contents and the testing of 24 specimens.

Table 6. Testing Schedule for a Level 3 Mix Design

Activity	Time Period
<ul style="list-style-type: none"> • Compact specimens and cut parallel faces. • Measure specimen dimensions and specific gravities. • Set up equipment and calibrate measurement devices. • Bond specimens to platens and mount LVDT screws. 	Days 1 through 4
<ul style="list-style-type: none"> • Run repeated shear test (constant stress ratio) at $T_{eff}(PD)$. 	Day 5
<ul style="list-style-type: none"> • Run frequency sweep and simple shear tests at 4°C. 	am of Day 6
<ul style="list-style-type: none"> • Run frequency sweep and simple shear tests at 20°C. 	pm of Day 6
<ul style="list-style-type: none"> • Run frequency sweep and simple shear tests at 40°C. 	am of Day 7
<ul style="list-style-type: none"> • Run volumetric and uniaxial strain tests at 4°C. 	pm of Day 7 through am of Day 8
<ul style="list-style-type: none"> • Run volumetric and uniaxial strain tests at 20°C. 	pm of Day 8
<ul style="list-style-type: none"> • Run volumetric and uniaxial strain tests at 40°C. 	am of Day 9
<ul style="list-style-type: none"> • Preparation of data files for analysis in SUPERPAVE® software. 	pm of Day 9

9.5 A level 2 mix design requires significantly fewer specimens and tests, and consequently, substantially less testing time. Table 7 is a guide to the time required to accomplish different segments of the procedure for one trial paving mix (one asphalt binder content) under normal laboratory conditions in a level 2 mix design.

9.6 Table 8 presents an estimated testing schedule for a complete level 2 mix design, involving three asphalt binder contents and the testing of 18 specimens.

Table 7. Time Estimate for Level 2 Mix Design

Procedure or Test Method	Number of Tests per Temperature	Number of Temperatures	Time (hrs)
Compaction and Preparation of Six Specimens	–	–	4
Bonding to Platens and Mounting of LVDT Screws	–	–	1
Repetitive Shear at Constant Stress Ratio	2	1	3
Frequency Sweep	2	1	2
Simple Shear	2	1	1
Data Preparation	–	–	2
Temperature Changes	–	–	2
Total Hours:			15

Table 8. Testing Schedule for a Level 2 Mix Design

Activity	Time Period
<ul style="list-style-type: none"> • Compact specimens and cut parallel faces. • Measure specimen dimensions and specific gravities. • Set up equipment and calibrate measurement devices. • Bond specimens to platens and mount LVDT screws. 	Days 1 through 3
<ul style="list-style-type: none"> • Run repeated shear test (constant stress ratio) at $T_{\text{eff}}(PD)$. 	Day 4
<ul style="list-style-type: none"> • Run frequency sweep and simple shear tests at $T_{\text{eff}}(FC)$. 	am of Day 5
<ul style="list-style-type: none"> • Run frequency sweep and simple shear tests at $T_{\text{eff}}(PD)$. 	pm of Day 5
<ul style="list-style-type: none"> • Preparation of data files for analysis in SUPERPAVE® software. 	am of Day 6

10. REPORT

10.1 Report all test results as computer files compatible with and readable by the *SUPERPAVE® Specification, Mix Design and Support Program*.

ANNEX

A1. OPTIONAL RAPID METHOD FOR ESTIMATION OF RUT DEPTH USING THE REPEATED SHEAR TEST AT CONSTANT HEIGHT

A1.1 *Scope*

A1.1.1 This method permits a rapid estimation of rut depth for any mix design over the service life of a pavement (expressed as total design ESALs).

NOTE A1.1.—This method is based upon the research results presented in the *Asphalt-Aggregate Mix Design Using the Constant Height Repetitive Simple Shear Test* prepared by Jorge B. Sousa of the University of California at Berkeley for the 1994 Annual Meeting of the Transportation Research Board.

A1.2 *Procedure for Estimation of Rut Depth*

A1.2.1 Estimate the total number of design ESALs, *ESAL*, expected on the pavement during its effective service life.

A1.2.2 Using the *SUPERPAVE*® *Specification, Mix Design and Support Program* software, estimate $T_{max}(d)$, the maximum pavement design temperature expected at depth *d* in the pavement from historical air temperature data. This is the maximum average pavement temperature during the hottest 7-day period in an average year.

A1.2.3 Calculate the number of loading cycles in the repeated shear test at constant height that are equivalent to the total design ESALs from the equation:

$$\log(\text{cycles}) = -4.36 + [1.24 \times \log(\text{ESAL})]$$

A1.2.4 Conduct the repeated shear test at constant height at $T_{max}(d)$ according to the procedure in section A1.3 and determine the maximum permanent shear strain at the number of load cycles determined in A1.2.3.

A1.2.5 Estimate the rut depth in mm expected at the total number of design ESALs from the equation:

$$\text{Rut Depth}(mm) = 279.4 \times [\text{Maximum Permanent Shear Strain}]$$

A1.3 *Repeated Shear Test at Constant Height*

A1.3.1 Prepare the test specimen in accordance with section 6.

A1.3.2 Mount two LVDTs on the test assembly in such a manner that axial (vertical) and shear (horizontal) deformations can be measured during the test with an accuracy and precision commensurate with the requirements in Test Method M-003 (see note 5).

NOTE A1.2.—This stress-controlled test will usually be performed at a maximum pavement design temperature calculated at depth d in the pavement from weather data for the site of the paving project. During the test, the height of the specimen is kept constant. To accomplish this, the vertical load actuator is controlled by feedback from the vertical (axial) LVDT. The feedback to the horizontal (shear) load actuator is from the magnitude of the shear load.

A1.3.3 Place the specimen inside the shear test device and clamp it securely in place.

A1.3.4 Adjust the controls for the environmental chamber to the requisite test temperature and allow the chamber and the test assembly to stabilize at that temperature.

A1.3.5 Precondition the specimen for 100 cycles with a shear stress of 7 kPa. Each cycle is 0.7 second in duration, and consists of the application of a 0.1 second haversine load followed by a 0.6 second rest period.

A1.3.6 At the conclusion of the preconditioning, perform the repeated shear test for a duration of 5000 load cycles or until the permanent accumulated strain reaches a level of 5%. Apply a haversine shear load with a maximum shear stress level of 48 kPa. The axial load is varied automatically during each cycle to maintain the specimen at constant height. Each test cycle is 0.7 second in duration, and consists of the application of a 0.1 second haversine load followed by a 0.6 second rest period.

A1.3.7 Record axial deformation, shear deformation, axial load, and shear load during the test at the intervals shown in table 4 or at other appropriate intervals.

NOTE A1.3.—The test takes about 60 to 70 minutes to complete from the time the specimen is placed in the apparatus until it is removed.