APPENDIX

LABORATORY MANUAL

The laboratory tests discussed in this appendix can be performed as a part of the civil and construction engineering materials course. More tests are included in this manual than typically can be performed in one semester. The extent of tests provided gives the instructor flexibility to choose the appropriate tests. In order for the students to get the most benefit from the laboratory sessions, tests should be coordinated with the topics covered in the lectures.

This laboratory manual summarizes the main components of each test method. Students are encouraged to read the corresponding ASTM or AASHTO test methods for the detailed laboratory procedures. The ASTM and AASHTO standards are usually available in college libraries.

In many cases, the time available for a laboratory session is not sufficient to permit the performance of the complete test, as specified in the ASTM or AASHTO procedure. Therefore, the instructor may limit the number of specimens or eliminate some portions of the test. However, the student should be aware of the complete test procedure and the specification requirements.

In some cases, different experiments are used to obtain the same material properties, such as the air content of freshly mixed concrete. In such cases, the instructor may require the specific test used by the state or the test for which equipment is available.

Typically a laboratory report is required by the student after each laboratory session. The format of the report can vary, depending on the requirements of the instructor. A suggested format may include the following items:

- Title of the experiment
- ASTM or AASHTO designation
- Purpose
- Significance and use
- Test materials
- Main pieces of equipment
- Summary of test procedure and test conditions
- Test results and analysis
- Comments, conclusions, and recommendations. Any deviations from the standard test procedure should be reported and justified.

Experiment No. 1
Introduction to Measuring Devices

ASTM Designation

There is no ASTM procedure for the main portion of this session. The information at the end of Chapter 1 can be used as a reference. Some discussion on precision and bias can be helpful; this is included in ASTM C670 (Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials).

Purpose

To introduce the students to common measuring devices, such as dial gauges, LVDTs, strain gauges, proving rings, extensometers, etc. An introduction to precision and bias can also be included.

Apparatus

The instructor may demonstrate one or more of the following items:

- A few dial gauges with different ranges and sensitivities (Figures A.1 and 1.24)

FIGURE A.1 Examining the sensitivity and range of a dial gauge.

- LVDT (Figures 1.26–1.28) and necessary attachments such as power supply, signal conditioner, voltmeter, display device, and calibration device
- Extensometer (Figures A.2, 1.25 and 1.29)
- Strain gauge (Figure 1.30) and necessary attachments
- Proving ring (Figures A.3 and 1.31)
- Load cell (Figures A.4 and 1.32)

Calibration

The instructor may require the students to calibrate one or more measuring devices, such as a proving ring or an LVDT. Static loads can be used to calibrate the proving ring to develop a relation between force and the reading of

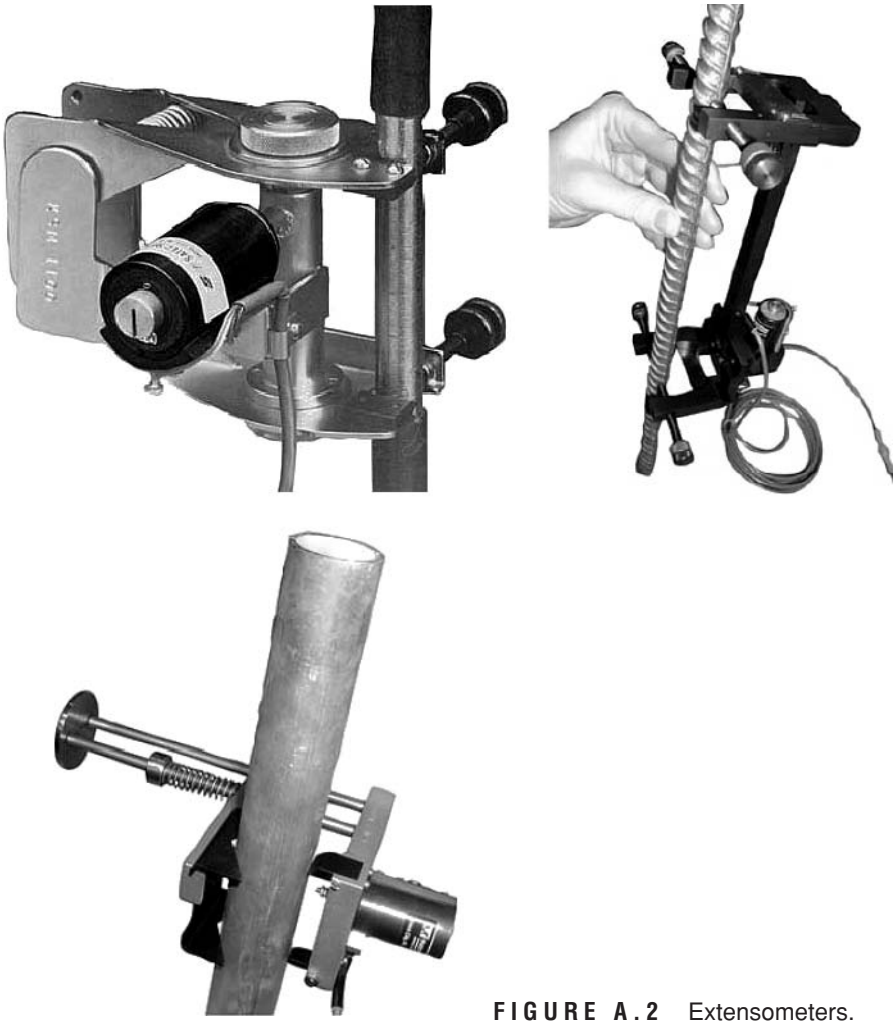

FIGURE A.2 Extensometers.

FIGURE A.3 Calibrating a proving ring using a known-weight object.

(a)

(b)

(c)

(d)

FIGURE A.4 Load cells.

FIGURE A.5 Calibrating an LVDT with a micrometer using a calibration device.

the proving ring (Figure A.3). To calibrate the LVDT, a calibration device equipped with a micrometer, such as that shown in Figures A.5 and 1.27 is used. A relation is developed between voltage and displacement of the LVDT.

Requirements

- Brief description of the demonstrated device(s) including the use, components, theory, sensitivity, etc.
- Calibration table, graph, and equation for each device calibrated

Experiment No. 2
Tension Test of Steel and Aluminum

ASTM Designation

ASTM E8—Tension Testing of Metallic Materials

Purpose

- To determine stress–strain relationship
- To determine yield strength
- To determine tensile strength
- To determine elongation and reduction of cross-sectional area
- To determine modulus of elasticity
- To determine rupture strength

Significance and Use

This test provides information on strength and ductility for metals subjected to a uniaxial tensile stress. This information may be useful in comparison of materials, alloy developments, quality control, design under certain circumstances, and detecting nonuniformity and imperfections, as indicated by the fracture surface.

Apparatus

- A testing machine capable of applying tensile load at a controlled rate of deformation or load. The testing machine could be either mechanical or closed-loop electrohydraulic. The machine could be equipped with a dial gauge to indicate the load or could be connected to a chart recorder or computer to record load and deformation.
- A gripping device, used to transmit the load from the testing machine to the test specimen and to ensure axial stress within the gauge length of the specimen
- An extensometer with an LVDT or dial gauge used to measure the deformation of the specimen
- Caliper to measure the dimensions of the specimen

Test Specimens

Either plate-type or rounded specimens can be used, as shown in Figures A.6 and 3.11. Specimen dimensions are specified in ASTM E8.

Test Procedure

1. Mark the gauge length on the specimen, either by slight notches or with ink.

FIGURE A.6 Rounded and plate-type steel and aluminum tension test specimens.

2. Place the specimen in the loading machine (Figure 3.12).
3. Attach the extensometer to the specimen (Figure A.7).

FIGURE A.7 Extensometer attached to a steel specimen.

4. Set the load reading to zero, then apply load at a rate less than 690 kPa/min (100,000 psi/min). Unless otherwise specified, any convenient speed of testing may be used up to half of the specified yield strength or yield point, or one quarter of the specified tensile strength, whichever is smaller. After the yield strength or yield point has been determined, the strain rate may be increased to a maximum of 0.5 in./in. of the gauge length per minute.
5. Continue applying the load until the specimen breaks.
6. Record load and deformation every 2.2 kN (500 lb) increment for steel and every 890 N (200 lb) increment for aluminum, both before and after the yield point.

Analysis and Results

- Calculate the stress and strain for each load increment until failure.
- Plot the stress versus strain curve.
- Determine the yield strength using the offset method, extension method (Figure 1.7), or by observing the sudden increase in deformation.
- Calculate the tensile strength

$$\sigma = P_{\max}/A_o$$

where

σ = tensile strength, MPa (psi)
$P_{\max}$ = maximum load carried by the specimen during the tension test, N (lb)
A_o = original cross-sectional area of the specimen, mm^2 ($in.^2$)

- Calculate the elongation

$$\text{Percent elongation} = [(L_s - L_0)/L_0] \times 100$$

where

L_s = gage length after rupture, mm (in.)
L_o = original gage length, mm (in.)

For elongation >3.0%, fit the ends of the fractured specimen together and measure L_s as the distance between two gauge marks. For elongation ≤3.0%, fit the fractured ends together and apply an end load along the axis of the specimen sufficient to close the fractured ends together, then measure L_s as the distance between gauge marks.

- Calculate the modulus of elasticity

$$E = \sigma/\varepsilon$$

where

E = modulus of elasticity, MPa (psi)
σ = stress in the proportional limit, MPa (psi)
ε = corresponding strain, mm/mm (in./in.)

- Calculate the rupture strength

  $$\sigma_r = P_f/A_o$$

  where

  σ_r = rupture strength, MPa (psi)
  P_f = final load, N (lb)
  A_o = original cross-sectional area, mm^2 (in.^{2})

- Calculate the reduction of cross-sectional area

  Percent reduction in cross-sectional area = $[(A_o - A_s)/A_o] \times 100$

  where

  A_s = cross section after rupture, mm^2 (in.^{2})

  To calculate the cross section after rupture, fit the ends of the fractured specimen together and measure the mean diameter or width and thickness at the smallest cross section.

Replacement of Specimens

The test specimen should be replaced if

- the original specimen had a poorly machined surface.
- the original specimen had wrong dimensions.
- the specimen's properties were changed because of poor machining practice.
- the test procedure was incorrect.
- the fracture was outside the gauge length.
- for elongation determination, the fracture was outside the middle half of the gauge length.

Report

- Stress–strain relationship
- Yield strength and the method used
- Tensile strength
- Elongation and original gauge length
- Modulus of elasticity
- Rupture strength
- Reduction of cross-sectional area

Experiment No. 3
Torsion Test of Steel and Aluminum

ASTM Designation

ASTM E143—Shear Modulus at Room Temperature

Purpose

To determine the shear modulus of structural materials, such as steel and aluminum.

Significance and Use

Shear modulus is a material property that is useful in calculating the compliance of structural materials in torsion, provided that they follow Hooke's law—that is, that the angle of twist is proportional to the applied torque.

Apparatus

- Torsion testing machine (Figures A.8 and 3.15)
- Grips to hold the ends of the specimen in the jaws of the testing machine
- Twist gauges to measure the angle of twist

Test Specimens

Either solid or hollow specimens with circular cross section can be used (Figure A.9). Specimens should be chosen from sound, clean material. Slight imperfections near the surface, such as fissures that would have negligible effect in determining Young's modulus, may cause appreciable errors in shear modulus. The gauge length should be at least four diameters. The length between grips should at least be equal to the gauge length plus two to four diameters.

Test Procedure

1. Measure the diameter (and the wall thickness in case of tubular specimens (Figure A.10).

FIGURE A.8 Torsion machine.

FIGURE A.9 Torsion specimens.

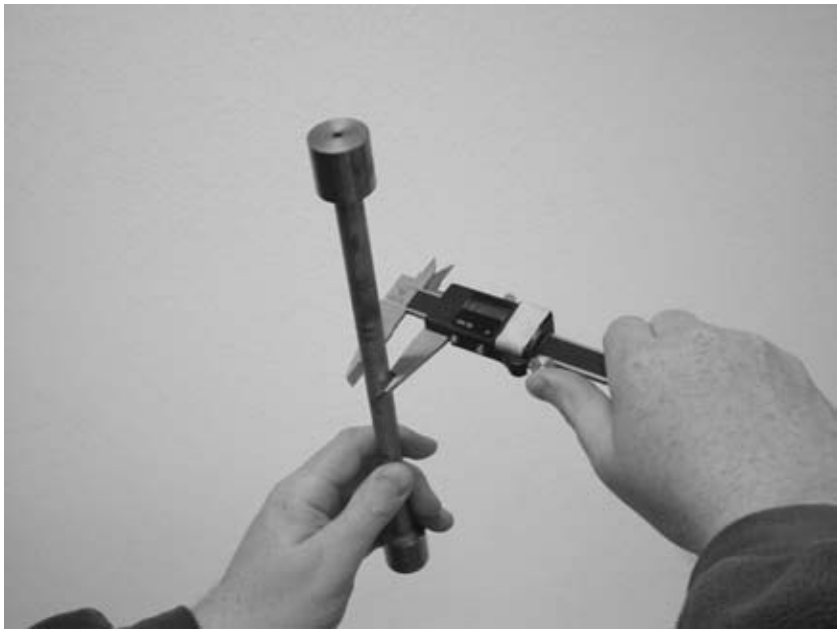

FIGURE A.10 Measuring specimen diameter with a caliper.

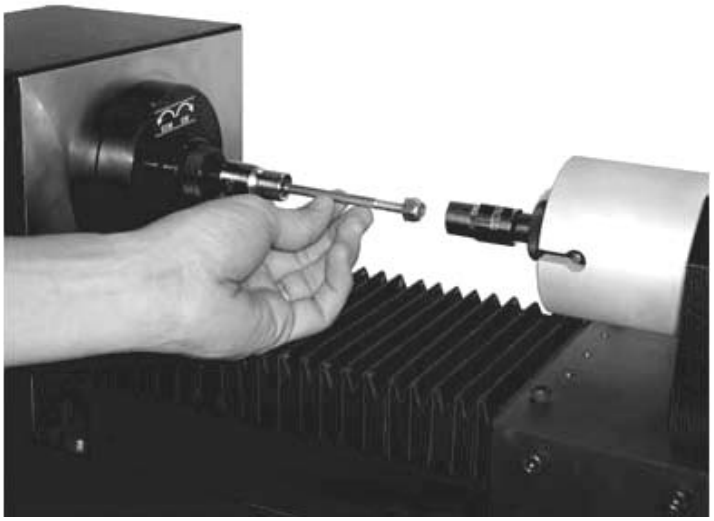

FIGURE A.11 Placing specimen in torsion machine.

2. Place the specimen in the torsion testing machine with careful alignment and apply torque (Figure A.11).
3. Make simultaneous measurements of torque and angle of twist, and record the data.
4. Maintain the speed of testing high enough to make creep negligible.

Analysis and Results

- Calculate the maximum shear stress (τ_{max}) and shear strain (γ) using the formulas

$$\tau_{max} = Tr/J$$
$$\gamma = \theta r/L$$

where

T = torque,
r = radius,
J = polar moment of inertia of the specimen about its center,
θ = angle of twist in radians, and
L = gauge length.

- Plot a graph of shear stress versus shear strain, as shown in Figure 3.16.
- Determine the shear modulus G as the slope of the straight portion of the shear stress versus strain relation

$$G = \tau_{max}/\gamma$$

Report

- Shear stress versus shear strain graph
- Shear modulus

Experiment No. 4
Impact Test of Steel

ASTM Designation

ASTM E23—Test Methods for Notched Bar Impact Testing of Metallic Materials

Purpose

To determine the energy absorbed in breaking notched steel specimens at different temperatures, using the Charpy V Notch test. The energy value is a measure of toughness of the material.

Significance and Use

This test measures a specimen's change in toughness as the temperature changes.

Apparatus

Use an impact testing machine of the pendulum type of rigid construction and of capacity more than sufficient to break the specimen in one blow (Figures A.12 and 3.19).

Test Specimen

Steel specimens prepared according to ASTM E23, as shown in Figure 3.18.

Test Conditions

The test can be performed at the following four temperatures:

- −40°C (−40°F) (dry ice + isopropyl alcohol) (dry alcohol)
- −18°C (0°F) (dry ice + 30% isopropyl alcohol + 70% water)
- 4°C (40°F) (ice + water)
- 40°C (104°F) (oven)

Test Procedure

1. Prepare the impact testing machine by lifting up the pendulum and adjusting the gauge reading to zero. Since the pendulum is heavy, be careful to handle it safely.
2. Remove the test specimen from the temperature medium (Figure A.13) using tongs, and immediately position it on the two anvils in the impact testing machine as shown in Figure A.14.

FIGURE A.12 Charpy V notch impact testing machine.

3. Release the pendulum without vibration by pushing the specified button. The time between removing the specimen from the temperature medium and the completion of the test should be less than 5 seconds.
4. Record the energy required to break the specimen by reading the gauge mark.
5. Observe the fracture surface appearance (Figure 3.20).
6. Measure the lateral expansion of the specimen using a caliper or the lateral expansion gauge specified in ASTM E23.

Report

- Energy required to cause fracture versus temperature plot
- Ductile-to-brittle transition temperature
- Fracture surface appearance (each specimen and temperature)
- Lateral expansion (each specimen and temperature)

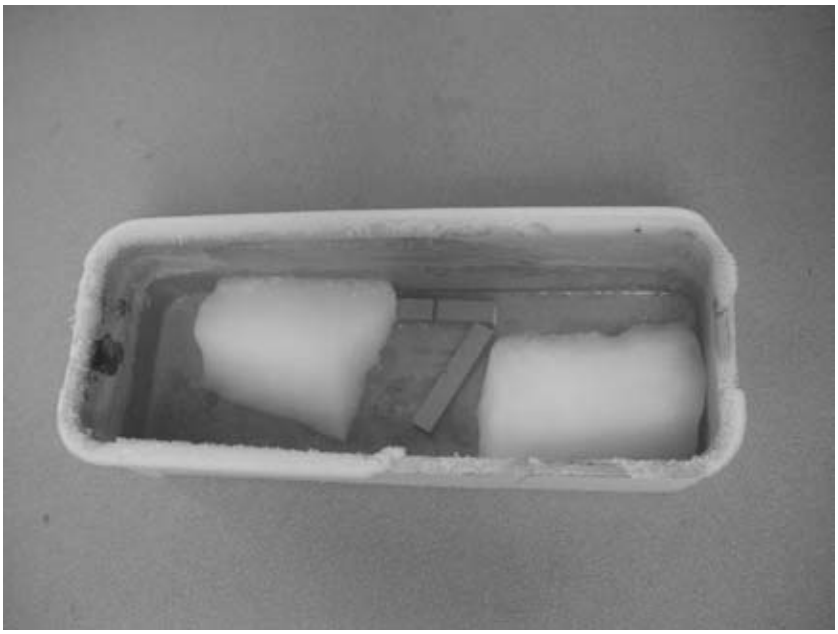

FIGURE A.13 Charpy specimens in dry ice and isopropyl alcohol.

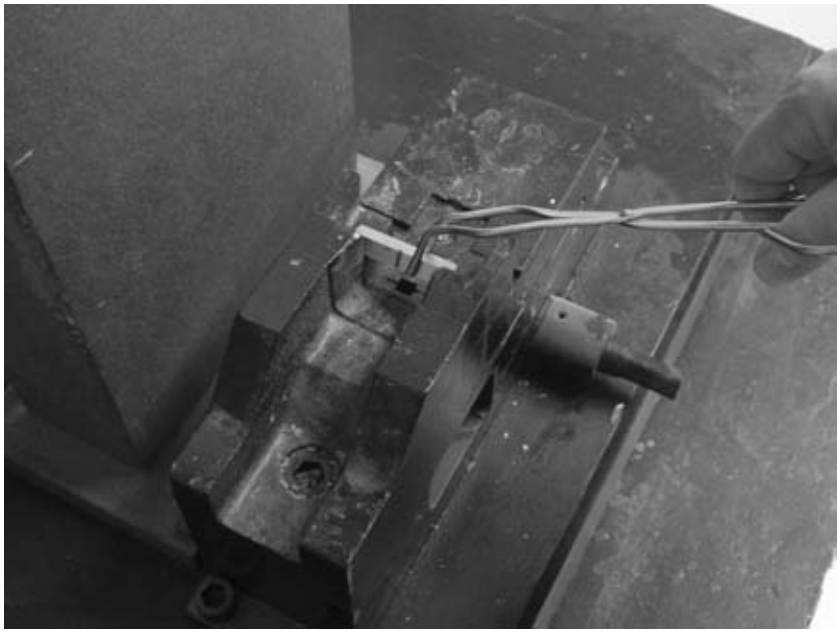

FIGURE A.14 Placing specimen in Charpy machine.

Experiment No. 5
Microscopic Inspection of Materials

ASTM Designation

None.

Purpose

- To observe the microstructural characteristics of materials
- To compare the microstructure of different materials
- To compare metals subjected to different heat treatments
- To observe grain boundaries of metals
- To examine fractured surfaces
- To observe microcracks in concrete (Figure A.15)
- To observe fibers in fiber-reinforced concrete
- To observe the microscopic properties of asphalt concrete
- To observe grains in wood, etc.

Apparatus

Optical microscope (Figure A.16) or scanning electron microscope

Material

Various materials can be used, such as metals, portland cement concrete, asphalt concrete, or wood.

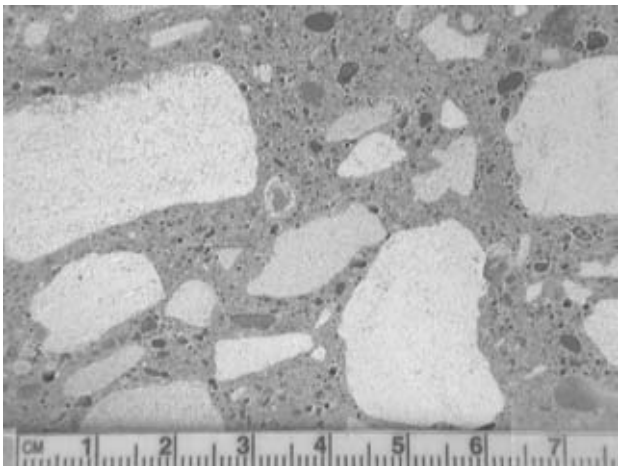

FIGURE A.15 Concrete microstructure using optical microscope.

Report

Compare and discuss the microstructural characteristics of the materials.

FIGURE A.16 Viewing concrete specimen with an optical microscope.

Experiment No. 6
Sieve Analysis of Aggregates

ASTM Designation

ASTM C136—Sieve Analysis of Fine and Coarse Aggregates

Purpose

To determine the particle size distribution of fine and coarse aggregate by dry sieving.

Significance and Use

This test is used to determine the grading of materials that are to be used as aggregates. It ensures that particle size distribution complies with applicable requirements and provides the data necessary to control the material of various aggregate products and mixtures containing aggregates. The data may also be useful in developing relationships concerning porosity and packing.

Apparatus

- Balances or scales with a minimum accuracy of 0.5 g for coarse aggregate or 0.1 g for fine aggregate
- Sieves
- Mechanical sieve shaker (Figures A.17, A.18, and 5.10)
- Oven capable of maintaining a uniform temperature of $110 \pm 5°C$ ($230 \pm 9°F$)
- Sample splitter to reduce the quantity of the material to the size required for sieve analysis (Figure 5.17)

Test Specimens

Thoroughly mix the aggregate sample and reduce it to an amount suitable for testing, using a sample splitter or by quartering. The minimum sample size should be as follows:

	Minimum Mass, kg
Fine aggregate with at least 95% passing 2.36-mm (No. 8) sieve	0.1
Fine aggregate with at least 85% passing 4.75-mm (No. 4) sieve	0.5
Coarse aggregate with a nominal maximum size of 9.5 mm (No. 3/8 in.)	1
Coarse aggregate of a nominal maximum size of 12.5 mm (1/2 in.)	2
Coarse aggregate of a nominal maximum size of 19.0 mm (3/4 in.)	5
Coarse aggregate of a nominal maximum size of 25.0 mm (1 in.)	10
Coarse aggregate of a nominal maximum size of 37.5 mm (1-1/2 in.)	15

FIGURE A.17 Table-top sieve shaker and sieves.

Test Procedure

1. Dry the aggregate test sample to a constant weight at a temperature of 110 ± 5°C, then cool to room temperature.
2. Select suitable sieve sizes to furnish the information required by the specifications covering the material to be tested. Common sieves in millimeters are 37.5, 25, 19, 12.5, 9.5, 4.75, 2.36, 1.18, 0.6, 0.3, 0.15, and 0.075 mm (1 $\frac{1}{2}$ in., 1 in., $\frac{3}{4}$ in., $\frac{1}{2}$ in., $\frac{3}{8}$ in., No. 4, No. 8, No. 16, No. 30, No. 50, No. 100, and No. 200).
3. Nest the sieves in order of decreasing size of opening, and place the aggregate sample on the top sieve (Figure A.19).
4. Agitate the sieves by hand or by mechanical apparatus for a sufficient period. The criterion for sieving time is that, after completion, not more than 1% of the residue on any individual sieve will pass that sieve during 1 minute of continuous hand sieving.

FIGURE A.18 Hanging-type sieve shaker and sieves for small samples of aggregates.

5. Determine the weight of each size increment (Figure A.20).
6. The total weight of the material after sieving should be compared with the original weight of the sample placed on the sieves. If the amounts differ by more than 0.3%, based on the original dry sample weight, the results should not be used for acceptance purposes.

Analysis and Results

1. Calculate percentages passing, total percentages retained, or percentages of various sizes of fractions to the nearest 0.1%, on the basis of the total weight of the initial dry sample.
2. Plot the grain size distribution on a semilog graph paper (Figure A.21).
3. Plot the grain size distribution on a 0.45 power graph paper (Figure A.22).
4. Calculate the fineness modulus.

Report

- Percentage of material retained between consecutive sieves, cumulative percentage of material retained on each sieve, or percentage of material passing each sieve. Report percentages to the nearest whole number, except if percentage passing 0.075 mm (No. 200) sieve is less than 10%, it should be reported to the nearest 0.1%.
- Grain size distribution plots using both semilog and 0.45 power gradation charts.
- Fineness modulus to the nearest 0.01.

FIGURE A.19 Placing aggregate sample in the sieves before sieving.

FIGURE A.20 Weighing aggregate retained in sieves.

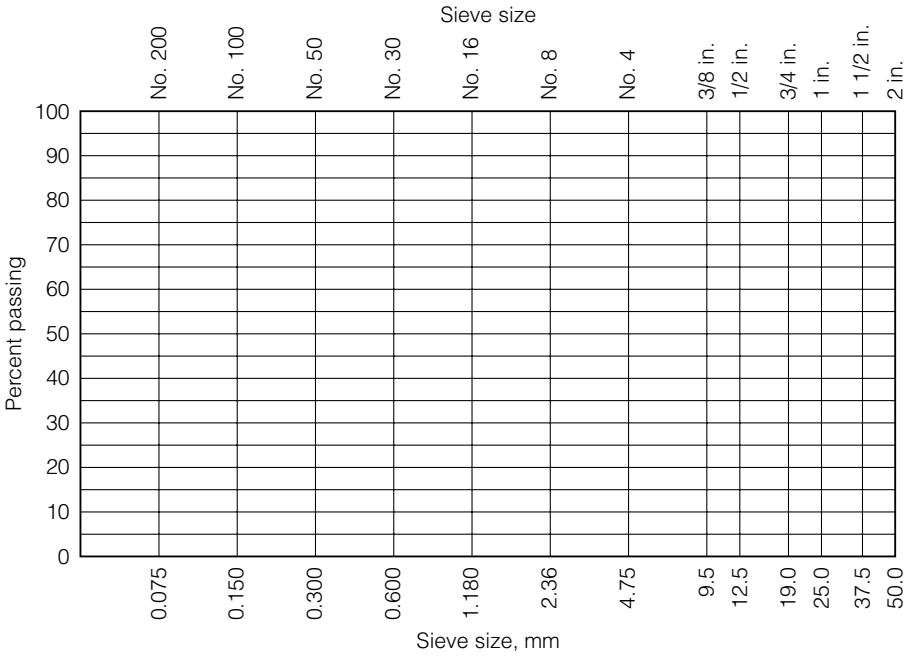

FIGURE A.21 Semi-log aggregate gradation chart.

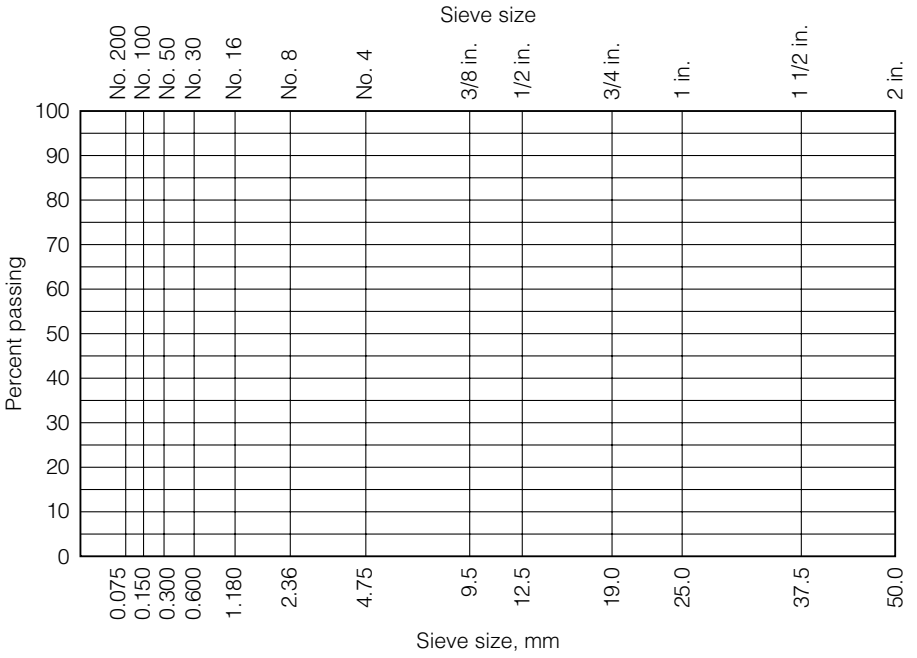

FIGURE A.22 0.45 power gradation chart.

Experiment No. 7
Specific Gravity and Absorption of Coarse Aggregate

ASTM Designation

ASTM C127—Specific Gravity and Absorption of Coarse Aggregate

Purpose

To determine the specific gravity and absorption of coarse aggregate. The specific gravity may be expressed as bulk specific gravity, bulk specific gravity SSD (saturated-surface dry), or apparent specific gravity.

Significance and Use

Bulk specific gravity is generally used for the calculation of the volume occupied by the aggregate in various mixtures containing aggregates, including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis. Bulk specific gravity SSD is used if the aggregate is wet. Absorption values are used to calculate the change in the weight of aggregate due to water absorbed in the pore spaces within the constituent particles, compared with the dry condition.

Apparatus

- Balance accurate to 0.05% of the sample weight or 0.5 g, whichever is greater
- Wire basket 3.35 mm (No. 6) or finer mesh (Figure A.23)
- Water tank
- 4.75-mm (No. 4) sieve or other sizes as needed

FIGURE A.23 Wire basket and water tank used to determine bulk specific gravity and absorption of coarse aggregate.

Test Specimens

- Thoroughly mix the aggregate sample and reduce it to the approximate quantity needed, using an aggregate sample splitter or by quartering.
- Reject all materials passing 4.74 mm sieve by dry sieving and thoroughly washing to remove dust or other coatings from the surface.
- The minimum weight of test specimen to be used depends on the nominal maximum size as follows:

Nominal Maximum Size, mm	Minimum Mass, kg
12.5	2
19.0	3
25.0	4
37.5	5

Test Procedure

1. Immerse the aggregate in water at room temperature for a period of 24 ± 4 hours.
2. Remove the test specimen from water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually.
3. Weigh the test sample in saturated surface–dry condition, and record it as *B.* Record this weight and all subsequent weights to the nearest 0.5 g or 0.05% of the sample weight, whichever is greater.
4. Place the specimen in the wire basket and determine its weight while it is submerged in water at a temperature of 23 ± 1.7°C, and record it as *C.* Take care to remove all entrapped air before weighing it by shaking the container while it is immersed.
5. Dry the test sample to a constant weight at a temperature of 110 ± 5°C, and weigh it and record this weight as *A.*

Analysis and Results

1. Bulk specific gravity = $A/(B - C)$

   where

   A = mass of oven-dry sample in air, g.
   B = mass of saturated surface–dry sample in air, g.
   C = mass of saturated sample in water, g

2. Bulk specific gravity (SSD) = $B/(B - C)$
3. Apparent specific gravity = $A/(A - C)$
4. Absorption, % = $[(B - A)/A] \times 100$

Report

- Bulk specific gravity
- Bulk specific gravity SSD
- Apparent specific gravity
- Absorption

Experiment No. 8

Specific Gravity and Absorption of Fine Aggregate

ASTM Designation

ASTM C128—Specific Gravity and Absorption of Fine Aggregate

Purpose

To determine the specific gravity and absorption of fine aggregate. The specific gravity may be expressed as bulk specific gravity, bulk specific gravity SSD (saturated-surface dry), or apparent specific gravity.

Significance and Use

Bulk specific gravity is the characteristic generally used for calculating the volume occupied by the aggregate in various mixtures, including portland cement concrete, bituminous concrete, and other mixtures that are proportioned or analyzed on an absolute volume basis.

Apparatus

- Balance or scale with a capacity of 1 kg or more, sensitive to 0.1 g or less, and accurate within 0.1% of the test load
- Pycnometer or other suitable container into which the fine aggregate test sample can be readily introduced. A volumetric flask of 500 cm^3 capacity with a pycnometer top is satisfactory for a 500-g test sample of most fine aggregates (Figure A.24).
- Mold in the form of a frustum of a cone
- Tamper having a mass of 340 ± 15 g

Test Procedure

1. Measure the weight of the pycnometer filled with water to the calibration mark. Record the weight as *B*.
2. Obtain approximately 1 kg of the fine aggregate sample.
3. Dry the aggregate sample in a suitable pan to constant weight at temperature of 110 ± 5°C (230 ± 9°F) and allow it to cool; then cover it with water, either by immersion or by the addition of at least 6% moisture to the fine aggregate, and permit it to stand for 24 ± 4 hours.
4. Decant excess water with care to avoid loss of fines, spread the sample on a flat, nonabsorbent surface exposed to a gently moving current of warm air, and stir frequently to cause homogeneous drying. If desired, mechanical aids such as tumbling or stirring may be used to help

FIGURE A.24 Mold, tamper, and volumetric flask used to determine bulk specific gravity and absorption of fine aggregate.

achieve the saturated surface–dry condition. Continue this operation until the test specimen approaches a free-flowing condition.

5. Hold the mold firmly on a smooth, nonabsorbent surface with the large diameter down. Place a portion of the partially dried fine aggregate loosely in the mold by filling it to overflowing and heaping additional material above the top of the mold by holding it with the cupped fingers of the hand.
6. Lightly tamp the fine aggregate into the mold with 25 light drops of the tamper. Each drop should start about 5 mm above the top of surface of the aggregate. Permit the tamper to fall freely under gravitational attraction on each drop.
7. Remove loose sand from the base and lift the mold vertically. If the surface moisture is still present, the fine aggregate will retain the molded shape. If this is the case, allow the sand to dry and repeat steps 4, 5, and 6 until the fine aggregate slumps slightly indicating that it has reached a surface-dry condition.
8. Weigh 500 ± 10 g of SSD sample and record the weight; record as *S*.
9. Partially fill the pycnometer with water and immediately introduce into the pycnometer the SSD aggregate weighed in step 8. Fill the pycnometer with additional water to approximately 90% of the capacity. Roll, invert, and agitate the pycnometer to eliminate all air bubbles. Fill the pycnometer with water to its calibrated capacity.
10. Determine the total weight of the pycnometer, specimen, and water, and record it as *C*.
11. Carefully work all of the sample into a drying pan. Place in a 110 ± 10°C oven until it dries to a constant weight. Record this weight as *A*.

Analysis and Results

- Bulk specific gravity $= A/(B + S - C)$

  where

  A = mass of oven-dry specimen in air, g
  B = mass of pycnometer filled with water, g
  S = mass of the saturated surface-dry specimen, g
  C = mass of pycnometer with specimen and water to the calibration mark, g

  Bulk specific gravity (SSD) $= S/(B + S - C)$
  Apparent specific gravity $= A/(B + A - C)$
  Absorption, % $= [(S - A)/A] \times 100$

Report

- Bulk specific gravity
- Bulk specific gravity SSD
- Apparent specific gravity
- Absorption

Experiment No. 9
Bulk Unit Weight and Voids in Aggregate

ASTM Designation

ASTM C29—Bulk Density (Unit Weight) and Voids in Aggregate

Purpose

To determine the bulk unit weight and voids in aggregate in either a compacted or loose condition.

Significance and Use

The bulk density of aggregate is needed for the proportioning of portland cement concrete mixtures. The bulk density may also be used to determine the mass/volume relationships for conversions in purchase agreements. The percentage of voids between the aggregate particles can also be determined, on the basis of the obtained bulk density.

Apparatus

- Measure. Use a rigid metal watertight container with a known volume. A minimum volume of the measure is required for different nominal maximum sizes of coarse aggregate. For a 25-mm (1 in.) nominal maximum aggregate size, a minimum volume measure of 0.0093 m^3 (9.3 liters) is required.
- Balance, tamping rod, shovel or scoop, and a plate glass.

Test Procedure

1. Calibrate the measure as follows:
   a. Fill the measure with water at room temperature and cover with a plate glass in such a way as to eliminate bubbles and excess water.
   b. Determine the mass of the water in the measure.
   c. Measure the temperature of the water, and determine its density as shown in the table. Interpolate as necessary.

Temperature		Density	
°C	°F	kg/m^3	lb/ft^3
15.6	60	999.01	62.366
21.1	70	997.97	62.301
26.7	80	996.59	62.216
29.4	85	995.83	62.166

d. Calculate the volume of the measure by dividing the mass of the water by its density.

2. Fill the measure with aggregate and compact it, either by rodding [for aggregates having nominal maximum size of 37.5 mm ($1\frac{1}{2}$ in.) or less], jigging [for aggregates having a nominal maximum size of 37.5 to 125 mm ($1\frac{1}{2}$ to 5 in.)], or shoveling (if specifically stipulated).
   a. Rodding Procedure: Fill the measure with aggregate in three layers of approximately equal volumes. Rod each layer of aggregate with 25 strokes of the tamping rod, evenly distributed over the surface (Figure A.25).
   b. Jigging Procedure: Fill the measure with aggregate in three layers of approximately equal volumes. Compact each layer by placing the measure on a firm base, raising the opposite sides alternately about 50 mm (2 in.), and allowing the measure to drop 25 times on each side.
   c. Shoveling Procedure: Fill the measure to overflowing by means of a shovel or scoop, discharging the aggregate from a height not to exceed 50 mm (2 in.) above the top of the measure. Exercise care to avoid segregation.
3. Level the surface of the aggregate with the fingers or a straightedge. Determine the net mass of the aggregate to the nearest 0.05 kg (0.1 lb) (Figure A.26).

FIGURE A.25 Rodding aggregate in the measure.

FIGURE A.26 Weighing the aggregate.

Analysis and Results

$$M = \frac{G - T}{V}$$

$$\%\text{Voids} = \frac{(SW) - M}{SW} \times 100$$

where

M = bulk unit weight of aggregate, kg/m^3 (lb/ft^3)
G = weight of the aggregate plus the measure, kg (lb)
T = weight of the measure, kg (lb)
V = volume of the measure, m^3 (ft^3)
S = bulk specific gravity (dry basis) (ASTM C127 or C128)
W = unit weight of water, 998 kg/m^3 (62.3 lb/ft^3)

Report

- The bulk unit weight (or loose bulk unit weight in case of shoveling), void content, and method of compaction.

Experiment No. 10
Slump of Freshly Mixed Portland Cement Concrete

ASTM Designation

ASTM C143—Slump of Portland Cement Concrete

Purpose

To determine the slump of freshly mixed portland cement concrete, both in the laboratory and in the field.

Significance and Use

This method measures the consistency of freshly mixed portland concrete cement (PCC). To some extent, this test indicates how easily concrete can be placed and compacted, or the workability of concrete. This test is used both in the laboratory and in the field for quality control.

Apparatus

- Mold in the form of lateral surface of frustum with a top diameter of 102 mm (4 in.), bottom diameter of 203 mm (8 in.), and height of 305 mm (12 in.) (Figure 7.3)
- Tamping rod with a length of 0.6 m (24 in.), diameter of 16 mm (5/8 in.), and rounded ends

Test Procedure

1. Mix concrete either manually or with a mechanical mixer (Figure A.27). If a large quantity of mixed concrete exits, obtain a representative sample.
2. Dampen the mold and place it, with its larger base at the bottom, on a flat, moist, nonabsorbent rigid surface.
3. Hold the mold firmly in place by standing on the two foot pieces.
4. Immediately fill the mold in three layers, each approximately one-third of the volume of the mold. Note that one-third of the volume is equivalent to a depth of 67 mm (2-5/8 in.), whereas two-thirds of the volume is equivalent to 155 mm (6-1/8 in.).
5. Rod each layer 25 strokes using the tamping rod (Figure A.28). Uniformly distribute the strokes over the cross section of each layer. Rod the second and top layers each throughout its depth so that the strokes penetrate the underlying layer. In filling and rodding the top layer, heap the concrete above the mold before rodding is started. If the rodding operation results in subsidence of concrete below the top edge of the mold, add additional concrete to keep an excess of concrete above the top of the mold at all times.

FIGURE A.27 Mixing concrete in a mixer.

FIGURE A.28 Rodding fresh concrete in the slump cone with a tamping rod.

FIGURE A.29 Measuring the slump of freshly mixed concrete.

6. After the top layer has been rodded, strike off the surface of concrete by means of a screening and rolling motion of the tamping rod.
7. Remove the mold immediately from the concrete by raising it up carefully without lateral or torsional motion. The slump test must be completed within 2.5 minutes after taking the sample.
8. Measure the slump by determining the vertical difference between the top of the mold and the displaced original center of the top of the specimen, as shown in Figure A.29. If two consecutive tests on a sample of concrete show a falling away or a shearing off of a portion of concrete from the mass of the specimen, the concrete probably lacks the necessary plasticity and cohesiveness for the slump test to be applicable and the test results will not be valid.

Report

- The slump value to the nearest 5 mm (1/4 in.)

Experiment No. 11
Unit Weight and Yield of Freshly Mixed Concrete

ASTM Designation

ASTM C138—Unit Weight, Yield, and Air Content (Gravimetric) of Concrete

Purpose

To determine the unit weight, yield, cement content, and air content of freshly mixed portland cement concrete. Yield is defined as the volume of concrete produced from a mixture of known quantities of the component materials.

Significance and Use

The unit weight value is used to calculate the volume of portland cement concrete produced from a mixture of known quantity.

Apparatus

- Measure. Use a rigid metal watertight container with a known volume. A minimum volume of the measure is required for different nominal maximum sizes of coarse aggregate. For a 25-mm (1 in.) nominal maximum aggregate size, a minimum volume measure of 6 liters (0.2 ft^3) is required.
- Balance, tamping rod, internal vibrator (optional), strike-off plate, and mallet.

Test Procedure

1. Place the freshly mixed concrete in the measure in three layers of approximately equal volume.
2. Rod each layer with 25 strokes of the tamping rod when a 0.014 m^3 (0.5 ft^3) or smaller measure is used, otherwise use 50 strokes per layer. Distribute the strokes uniformly over the cross section of the measure. Rod the bottom layer throughout its depth, but do not forcibly strike the bottom of the measure. For the top two layers, penetrate about 25 mm (1 in.) into the underling layer.
3. Tap the sides of the measure smartly 10 to 15 times with the mallet to release trapped air bubbles.
4. An internal vibrator can be used instead of the tamping rod. In this case, the concrete is placed and vibrated in the measure in two approximately equal layers.

5. When the consolidation is complete, the measure must not contain a substantial excess or deficiency of concrete. A small quantity of concrete may be added to correct a deficiency.
6. After consolidation, strike off the top surface of the concrete, and finish it smoothly with the flat strike-off plate, using great care to leave the measure just level full.
7. After strike-off, clean all excess concrete from the exterior of the measure and determine the net weight of the concrete in the measure (Figure A.30).

Analysis and Results

- W = (Net weight of concrete)/(Volume of the measure)
- $Y(\text{m}^3) = W_1/W$
  $Y_f(\text{ft}^3) = W_1/W$
  $Y(\text{yd}^3) = W_1/(27W)$
- $R_y = Y/Y_d$
- $N = N_t/Y$
- $A = [(T - W)/T] \times 100$

FIGURE A.30 Weighing concrete inside the measure.

where

W = unit weight of concrete, kg/m^3 (lb/ft^3)
Y = yield = volume of concrete produced per batch, m^3 (yd^3)
Y_f = yield = volume of concrete produced per batch, ft^3
W_1 = total weight of all materials batched, kg (lb)
R_y = relative yield
Y_d = volume of concrete that the batch was designed to produce, m^3 (yd^3)
N = actual cement content, kg/m^3 (lb/yd^3)
N_t = weight of cement in the batch, kg (lb)
A = air content (percentage of voids) in the concrete
T = theoretical unit weight of concrete computed on an air-free basis, kg/m^3 (lb/ft^3)

Report

- The unit weight, yield, relative yield, actual cement content, and air content

Experiment No. 12
Air Content of Freshly Mixed Concrete by Pressure Method

ASTM Designation

ASTM C231—Air Content of Freshly Mixed Concrete by Pressure Method

Purpose

To determine the air content of freshly mixed portland cement concrete by the pressure method.

Significance and Use

Air content plays an important role in workability of freshly mixed concrete and the strength and durability of hardened concrete. The air content of freshly mixed concrete is needed for the proper proportioning of the concrete mix.

Apparatus

- Air meter Type B, consisting of a measuring bowl of a capacity at least 0.006 m^3 (0.2 ft^3) and cover assembly fitted with air valves, air bleeder valves, petcocks, and suitable hand pump as shown in Figure 7.11. The air meter must be frequently calibrated according to ASTM C231 procedure to ensure proper measurements.
- Miscellaneous items, including trowel, tamping rod, mallet, and strike-off bar.

Test Procedure

1. Place a representative sample of the plastic concrete in the measuring bowl in three equal layers.
2. Consolidate each layer of concrete by 25 strokes of the tamping rod, evenly distributed over the cross section.
3. After rodding each layer, tap the sides of the measuring bowl 10 to 15 times with the mallet to remove any voids.
4. Strike off the top surface by sliding the bar across the top rim with a sawing motion.
5. Thoroughly clean the flanges and cover the assembly to obtain a pressure-tight seal.
6. Using a rubber syringe, inject water through one petcock until water emerges from the opposite petcock.

FIGURE A.31 Reading pressure meter.

7. Jar the meter gently until all air is expelled from the same petcock.
8. Pump air into the air chamber until the gauge indicator is on the initial line.
9. Open the air valve between the air chamber and the measuring bowl.
10. Tap the sides of the measuring bowl sharply, and lightly tap the pressure gauge.
11. Read the percentage of air content on the dial gauge (Figure A.31).
12. Determine the aggregate correction factor according to ASTM C231, and subtract it from the reading obtained in step 11.

Report

- The air content and the method used (pressure method).

Experiment No. 13
Air Content of Freshly Mixed Concrete by Volumetric Method

ASTM Designation

ASTM C173—Air Content of Freshly Mixed Concrete by Volumetric Method

Purpose

To determine the air content of freshly mixed portland cement concrete by the volumetric method.

Significance and Use

Air content plays an important role in the workability of freshly mixed concrete and the strength and durability of hardened concrete. The air content of freshly mixed concrete is needed for the proper proportioning of the concrete mix.

Apparatus

- Air meter, consisting of a bowl and a top section, as shown in Figure 7.12
- The bowl has a diameter of 1 to 1.25 the height and a minimum capacity of 0.002 m^3 (0.075 ft^3). The capacity of the top section is 1.2 times the capacity of the bowl.
- Miscellaneous items including funnel, tamping rod, strike-off bar, measuring cup, syringe, pouring vessel, trowel, scoop, isopropyl alcohol, and mallet.

Calibration

1. The volume of the bowl must be calibrated by accurately weighing the amount of water required to fill it at room temperature and dividing this weight by the unit weight of water at the same temperature.
2. The accuracy of the graduation on the neck of the top section and the volume of the measuring cup must be calibrated according to ASTM C173.

Test Procedure

1. Fill the bowl with freshly mixed concrete in three layers of equal depth.
2. Rod each layer 25 times with the tamping rod.
3. After each layer is rodded 10 to 15 times, tap the sides of the measuring bowl with the mallet to release air bubbles.

4. After placement of the third layer of concrete, strike off the excess concrete with the strike-off bar until the surface is flush with the top of the bowl. Wipe the flanges of the bowl clean.
5. Clamp the top section on the bowl, insert the funnel, and add water until it appears in the neck. Remove the funnel and adjust the water level, using the rubber syringe, until the bottom of the meniscus is leveled with the zero mark. Attach and tighten the screw cap.
6. Invert and agitate the unit many times until the concrete settles free from the base.
7. When all the air rises to the top of the apparatus, remove the screw cap. Add, in 1-cup increments using the syringe, sufficient isopropyl alcohol to dispel the foamy mass on the surface of the water. Note that the capacity of the cup is equivalent to 1.0% of the volume of the bowl.
8. Make a direct reading of the liquid in the neck to the bottom of the meniscus to the nearest 0.1% (Figure A.32).
9. The percent air content is calculated as the reading in step 8 plus the amount of alcohol used.

Report

- The air content and the method used (volumetric method).

FIGURE A.32 Reading air meter.

Experiment No. 14
Making and Curing Concrete Cylinders and Beams

ASTM Designation

ASTM C31—Making and Curing Concrete Test Specimens

Purpose

To determine how to make and cure concrete cylindrical and beam specimens.

Significance and Use

This practice provides standardized requirements for making and curing portland cement concrete test specimens. Specimens can be used to determine strength for mix design, quality control, and quality assurance.

Apparatus

- Cylindrical molds made of steel or another nonabsorbent and nonreactive material. The standard specimen size used to determine the compressive strength of concrete is 152 mm (6 in.) diameter by 304 mm (12 in.) high for a maximum aggregate size up to 50 mm (2 in.). Smaller specimens, such as 102 mm (4 in.) diameter by 203 mm (8 in.) high, are sometimes used, but they are not ASTM standards.
- Beam molds made of steel or another nonabsorbent, nonreactive material. Several mold dimensions can be used to make beam specimens with a square cross section and a span three times the depth. The standard ASTM inside mold dimensions are 152 × 152 mm (6 × 6 in.) in cross section and a length of not less than 508 mm (20 in.), for a maximum aggregate size up to 50 mm (2 in.).
- Tamping rod with a length of 0.6 m (24 in.), diameter of 16 mm (5/8 in.), and rounded ends
- Moist cabinet or room with not less than 95% relative humidity and 23 ± 1.7°C (73 ± 3°F) temperature or a large container filled with lime saturated water for curing
- Miscellaneous items including vibrator (optional), scoop, and trowel.

Test Procedure

1. Weigh the required amount of coarse aggregate, fine aggregate, portland cement, and water.
2. Mix the materials in the mixer for 3 to 5 min. If an admixture is used, it should be mixed with water before being added to the other materials.

3. Check slump, air content, and temperature of concrete.
4. For cylindrical specimens, place concrete into the mold using a scoop or trowel. Fill the cylinder in three equal layers, and rod each layer 25 times. Tap the outside of the cylinder 10 to 15 times after each layer is rodded. Strike off the top and smooth the surface. Vibrators can also be used to consolidate the concrete instead of rodding. Vibration is optional if the slump is between 25 mm to 75 mm (1 in. to 3 in.) and is required if the slump is less than 25 mm (1 in.) (Figures A.33–A.35).
5. For beam specimens, grease the sides of the mold and fill the molds with concrete in two layers. Consolidate the concrete by either tamping each layer 60 times until uniformly distributed throughout or by vibrating. After consolidation, finish the surface by striking off the surface and smoothing.
6. Cover the mold with wet cloth to prevent evaporation.
7. Remove the molds after 16 hours to 32 hours.
8. Cure the specimen in a moist cabinet or room at a relative humidity of not less than 95% and a temperature of 23 ± 1.7°C (73 ± 3°F) or by submersion in lime-saturated water at the same temperature (Figure A.36).

FIGURE A.33 Making concrete cylinders and beams.

FIGURE A.34 Filling and rodding concrete in beams.

FIGURE A.35 Consolidating concrete in a beam mold using an external vibrator.

FIGURE A.36 Curing concrete cylinders in lime saturated water.

Precautions

1. Segregation must be avoided. Over vibration may cause segregation.
2. In placing the final layer, the operator should attempt to add an amount of concrete that will exactly fill the mold after compaction. Do not add nonrepresentative concrete to an under-filled mold.
3. Avoid overfilling by more than 6 mm (1/4 in.).

Report

- Record mix design weights, slump, temperature of the mix, and air content.
- Specimen type, number of specimens, dimensions, and any deviations from the standard preparation procedure.
- Include this information with the report on the strength of the concrete.

Experiment No. 15
Capping Cylindrical Concrete Specimens with Sulfur or Capping Compound

ASTM Designation

ASTM C617—Capping Cylindrical Concrete Specimens

Purpose

To cap hardened portland cement concrete cylinders and drilled concrete cores with sulfur mortar or other capping compounds to prepare the specimen for compressive strength testing.

Significance and Use

This procedure provides plane surfaces perpendicular to the specimen axis on the ends of concrete cylinders before performing the compression test.

Apparatus

- Alignment device consisting of a frame with guide bars and a cup, as shown in Figure A.37. The size of the alignment device should match the specimen size.
- Melting pot, used for melting sulfur mortars or capping compound, equipped with automatic temperature control. The melting pot should be used either outdoors or under an exhaust hood. Heating over an open flame is dangerous, because the mixture may ignite if overheated.

Capping Procedure

1. Prepare the sulfur mortar or capping compound by heating to about 130°C (265°F). Use a metal thermometer to check the temperature. Make sure to empty any old mortar and to use fresh mortar to avoid the loss of strength due to successive heating. The fresh sulfur mortar must be dry when it is placed in the pot, because dampness may cause foaming.
2. Warm the capping cup or device slightly before use to slow the rate of hardening and to permit the production of thin caps.
3. Oil the capping cup lightly and stir the molten sulfur mortar or the capping compound immediately prior to pouring into the cup. Make sure the ends of moist-cured specimens are dry enough at the time of capping, so there will be no steam or foam pockets.

FIGURE A.37 Capping a concrete cylinder using an alignment device.

4. Hold the concrete cylinder with two hands and push it against the guide bars of the capping device. Carefully lower the specimen until it rests in the cup (Figure A.37). This step must be completed quickly before the sulfur or capping compound solidifies. The thickness of the cap should be about 3 mm (1/8 in.) and not more than 8 mm (5/16 in.) in any part.
5. Before the cylinder is tested for compressive strength, the cap should be cured, in order to have strength comparable to that of the concrete.

Experiment No. 16
Compressive Strength of Cylindrical Concrete Specimens

ASTM Designation

ASTM C39—Compressive Strength of Cylindrical Concrete Specimens

Purpose

To determine the compressive strength of cylindrical PCC specimens, such as molded cylinders and drilled cores.

Significance and Use

This test provides the compressive strength of concrete, which is used universally as a measure of concrete quality.

Apparatus

Loading machine with two hardened steel breaking blocks. The upper block is spherically seated, and the bottom block is solid surface (Figure A.38).

FIGURE A.38 Concrete cylindrical specimen being tested for compressive strength.

Test Specimens

- The standard specimen size used to determine the compressive strength of concrete is 152 mm (6 in.) diameter by 304 mm (12 in.) high for a maximum aggregate size up to 50 mm (2 in.). Smaller specimens, such as 102 mm (4 in.) diameter by 203 mm (8 in.) high, are sometimes used, but they are not ASTM standardized.
- Conduct the compression test on the moist-cured specimens directly after removing them from the curing room. Test specimens must be moist when tested.
- Neither end of compressive test specimen shall depart from perpendicularity by more than 0.5°, approximately 3 mm in 0.3 m (1/8 in. in 12 in.)
- If the ends of the specimen are not plane within 0.05 mm (0.002 in.), they should be capped with sulfur or capping compound. Neoprene caps may be used (Figure A.39), but they are not ASTM standards.
- Specimen age, at time of testing, should be 24 hours ± 0.5 hours, 3 days ± 2 hours, 7 days ± 6 hours, 28 days ± 20 hours, or 90 days ± 2 days.

Test Procedure

1. Measure the diameter of the test specimen to the nearest 0.25 mm (0.01 in.) by averaging two diameters measured at right angles to each other at the middle height of the specimen.
2. Adjust the bearing blocks into position.

FIGURE A.39 Neoprene caps used for capping a concrete cylinder.

3. Clean the faces of the bearing blocks and the specimen.
4. Carefully align the axis of the specimen with the center of the thrust of the spherically seated block.
5. Apply the load continuously and without shock. For screw-type machines, use a rate of loading of 1.25 mm/min (0.05 in./min). For hydraulically operated machines, apply the load at a constant rate within the range of 138 kPa/s to 335 kPa/s (20 psi/sec to 50 psi/sec). During the first half of the anticipated loading phase, a higher rate of loading is permitted. No adjustment in the control of the testing machine should be made while the specimen is yielding rapidly, immediately before failure.
6. Continue applying the load until the specimen fails.
7. Record the maximum load carried by the specimen during the test.
8. Note the type of failure and the appearance of concrete (Figure A.40).

Analysis and Results

- Calculate the compressive strength as

$$f'_c = P_{max}/A$$

where

f'_c = compressive strength, MPa (psi)
P_{max} = maximum applied load, N (lb)
A = cross-sectional area, mm^2 ($in.^2$)

Report

- Specimen identification number.
- Diameter (and length, if outside the range of 1.8 to 2.2 times the diameter).
- Cross-sectional area.
- Maximum load.
- Compressive strength, calculated to the nearest 0.07 MPa (10 psi).
- Type of failure, if other than the usual one.
- Defects in either specimen or caps.
- Age of specimen.

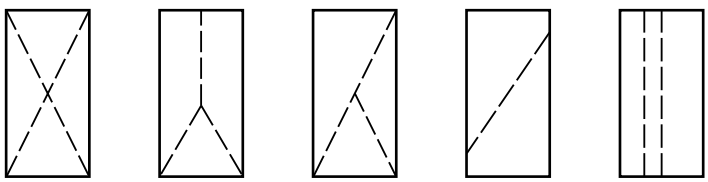

FIGURE A.40 Types of fracture of concrete cylinders: (a) cone, (b) cone and split, (c) cone and shear, (d) shear, and (e) columnar.

Experiment No. 17
Flexural Strength of Concrete

ASTM Designation

ASTM C78—Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

Purpose

To determine the flexural strength of portland cement concrete by using a simple beam with third-point loading.

Significance and Use

The flexural strength of concrete is a measure of concrete quality.

Apparatus

- Loading machine capable of applying loads at a uniform rate
- Loading device capable of applying load configuration as shown in Figure 7.32. Forces applied to the beam shall be perpendicular to the face of the specimen and applied without eccentricity.

Test Specimens

- The standard ASTM specimen dimensions are 152 mm × 152 mm (6 in. × 6 in.) in cross section and a length of not less than 508 mm (20 in.) for a maximum aggregate size up to 50 mm (2 in.).
- Sides of the specimen should be at right angles to its top and bottom. All surfaces in contact with load-applying and support blocks should be smooth and free of scars, indentations, holes, or inscribed identifications.

Test Procedure

1. Turn the test specimen on its side, with respect to its position as molded, and center it on the bearing blocks.
2. Center the loading system in relation to the applied force. Bring the load-applying blocks in contact with the surface of the specimen at the third points between the supports (Figure A.41).
3. If full contact is not obtained at no load between the specimen and the load-applying blocks and the supports so that there is a 25 mm (1 in.) or larger gap in excess of 0.1 mm (0.004 in.), grind or cap the contact surfaces of the specimen, or shim with leather strips.

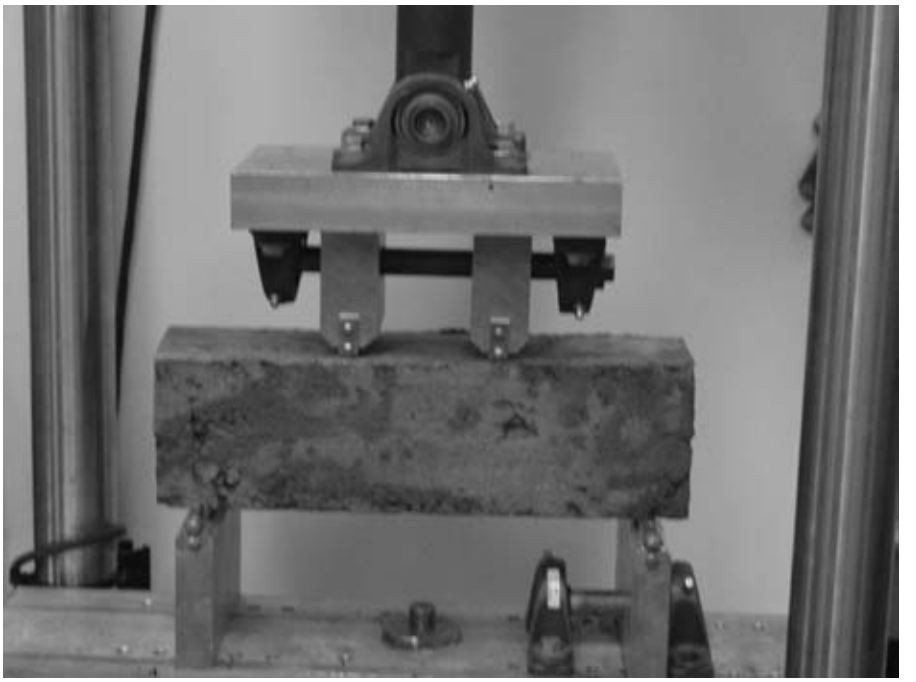

FIGURE A.41 Testing concrete beam in the flexure testing machine.

4. Apply the load rapidly up to approximately 50% of the breaking load. Thereafter, apply the load continuously at a rate that constantly increases the extreme fiber stress between 860 kPa and 1210 kPa (125 psi and 175 psi)/min until rupture occurs.

Analysis and Results

- Take three measurements across each dimension (one at each edge and at the center) to the nearest 1.3 mm (0.05 in.) to determine the average width, average depth, and line of fracture location of the specimens at the section of fracture.
- If the fracture initiates in the tension surface within the middle third of the span length, calculate the modulus of rupture as follows:

$$R = \frac{Mc}{I} = \frac{PL}{bd^2}$$

where

R = modulus of rupture, MPa (psi)

M= maximum bending moment, N·mm (lb.in.)

$c = \frac{d}{2}$, mm (in.)

I = moment of inertia

$= \frac{bh^3}{12}$, mm^4 (in^4.)

P = maximum load, N (lb)

L = span length, mm (in.)

b = average width, mm (in.)

d = average depth, mm (in.)

- If the fracture occurs in the tension surface outside the middle third of the span length, by not more than 5% of the span length, calculate the modulus of rupture as follows:

$$R = \frac{3Pa}{bd^2}$$

where

a = average distance between line of fracture and the nearest support on the tension surface of the beam in millimeters (inches)

- If the fracture occurs in the tension surface outside the middle third of the span length, by more than 5% of the span length, discard the results of the test.

Report

- Specimen identification number.
- Average width.
- Average depth.
- Span length.
- Maximum applied load.
- Modulus of rupture to the nearest 0.03 MPa (5 psi).
- Curing history and apparent moisture condition at time of testing.
- If specimens were capped, ground, or if leather shims were used.
- Defects in specimens.
- Age of specimens.

Experiment No. 18
Rebound Number of Hardened Concrete

ASTM Designation

ASTM C805—Rebound Number of Hardened Concrete

Purpose

To determine the rebound number of hardened portland cement concrete.

Significance and Use

The rebound number may be used to assess the uniformity and strength of concrete. It can also be used to determine when forms and shoring may be removed.

Apparatus

Rebound hammer (Figures 7.33 and A.42)

FIGURE A.42 Testing concrete slab with a rebound hammer.

Test Procedure

1. Grind and clean the concrete surface by rubbing with the abrasive stone that accompanies the rebound device.
2. Firmly hold the instrument in a position that allows the plunger to strike perpendicularly to the test surface.
3. Gradually increase the pressure on the plunger until the hammer impacts.
4. After impact, record the rebound number to two significant digits.
5. Take 10 readings from each test area.

Test Conditions

1. No two impact tests shall be closer together than 25 mm (1 in.).
2. Discard the reading if the impact crushes or breaks through a near-surface air void.
3. Discard readings differing from the average of 10 readings by more than 7 units, and determine the average of the remaining readings.
4. If more than two readings differ from the average by 7 units or more, discard all readings.
5. The rebound hammer should be periodically serviced and verified using metal anvils, according to manufacturer recommendations.

Report

- Structure identification, location, and curing condition.
- Average rebound number.
- Position of the hammer during the test, such as downward, upward, or at a specific angle.
- Estimated compressive strength using available correlations, such as those obtained from the manufacturer. It should be noted, however, that the rebound hammer test is not intended as an alternative for strength determination of concrete.

Experiment No. 19
Penetration Resistance of Hardened Concrete

ASTM Designation

ASTM C803—Penetration Resistance of Hardened Concrete

Purpose

To assess the uniformity of hardened portland cement concrete and indicate its in-place strength.

Significance and Use

The penetration resistance may be used to assess the uniformity and strength of concrete.

Apparatus

The penetration resistance (Windsor Probe) apparatus (Figure 7.34) consists of the following:

- Driver unit
- Probe made of hardened steel alloy
- Measuring instrument
- Positioning device.

Test Procedure

1. Place the positioning device on the concrete surface at the location to be tested. Two positioning devices are available: a single positioning device and a triangular device.
2. Mount a probe in the driver unit.
3. Position the driver and probe in the positioning device.
4. Fire and drive the probe into the concrete. In case of the triangular device, repeat for each position (Figures A.43 and A.44).
5. In the case of the single positioning device, place the measuring base plate over the probe, and measure the length of the probe not embedded in the concrete with the measuring instrument. In the case of a triangular device, place the triangular plate on the three probes, position the measuring instrument in the hole at the center of the triangular plate, and read the average of the exposed length. Alternatively, the lengths of individual probes not embedded in the concrete can be measured and the average of the three lengths is obtained (Figure A.45).

FIGURE A.43 Firing and driving Windsor probe into concrete using triangular positioning device.

FIGURE A.44 Three probes driven into concrete.

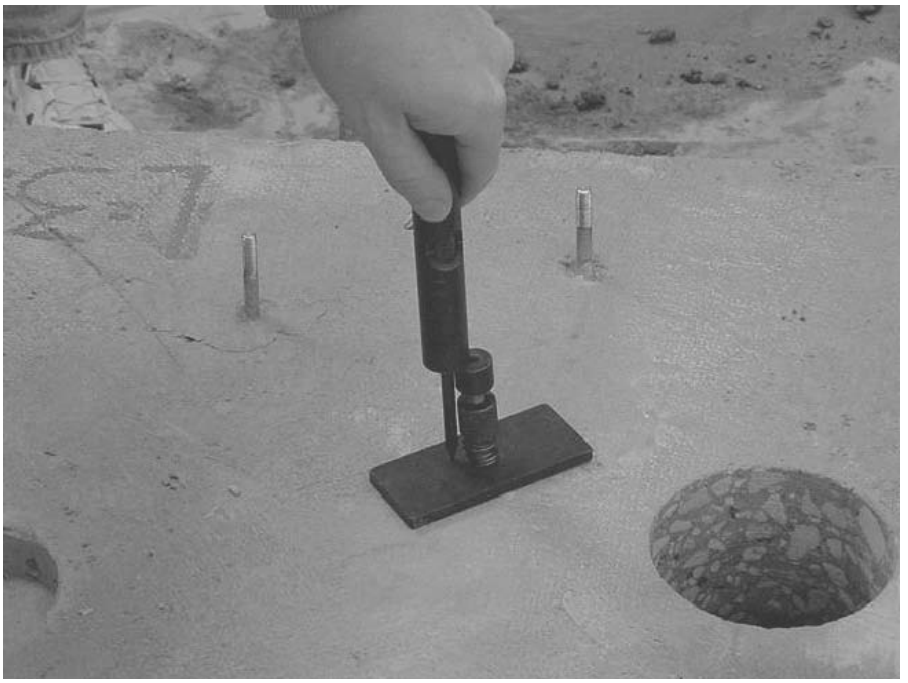

FIGURE A.45 Measuring penetration of one probe.

Report

- Structure identification, location, and curing condition.
- The average exposed length of the probe.
- Estimated compressive strength, using available correlations such as those obtained from the manufacturer. Note, however, that the penetration resistance test is not intended as an alternative for strength determination of concrete.

Experiment No. 20
Testing of Concrete Masonry Units

ASTM Designation

ASTM C140—Sampling and Testing Concrete Masonry Units and Related Units

Purpose

To test concrete masonry units for compressive strength, absorption, moisture content, and density.

Significance and Use

The test produces compressive strength, absorption, moisture content, and density data for the control and specification of concrete masonry units. These data are important for the safety and proper performance of masonry structures.

Apparatus

- Testing machine
- Steel-bearing blocks and plates
- Balance

Test Procedure for Compressive Strength

1. Three representative units are needed for testing within 72 hours after delivery to the laboratory, during which time they are stored continuously in air at a temperature of 24 ± 8°C (75 ± 15°F) and a relative humidity of less than 80%.
2. The test is performed on either a full-sized unit or a part of a unit prepared by saw cutting. A part of a unit is used if the capacity or size of the testing machine does not allow the testing of a full-sized unit.
3. Measure the length, width, and height of the specimen.
4. Cap the bearing surfaces of the unit, using either sulfur and granular materials or gypsum plaster.
5. Position the test specimen with its centroid aligned vertically with the center of thrust of the spherically seated steel-bearing block of the testing machine (Figure A.46).
6. Apply the load up to one-half the expected maximum load at any convenient rate, after which apply the load at a uniform rate of travel of the moving head, so that the test is completed between one and two minutes.
7. Record the maximum compressive load in newtons (pounds) as P_{max}.

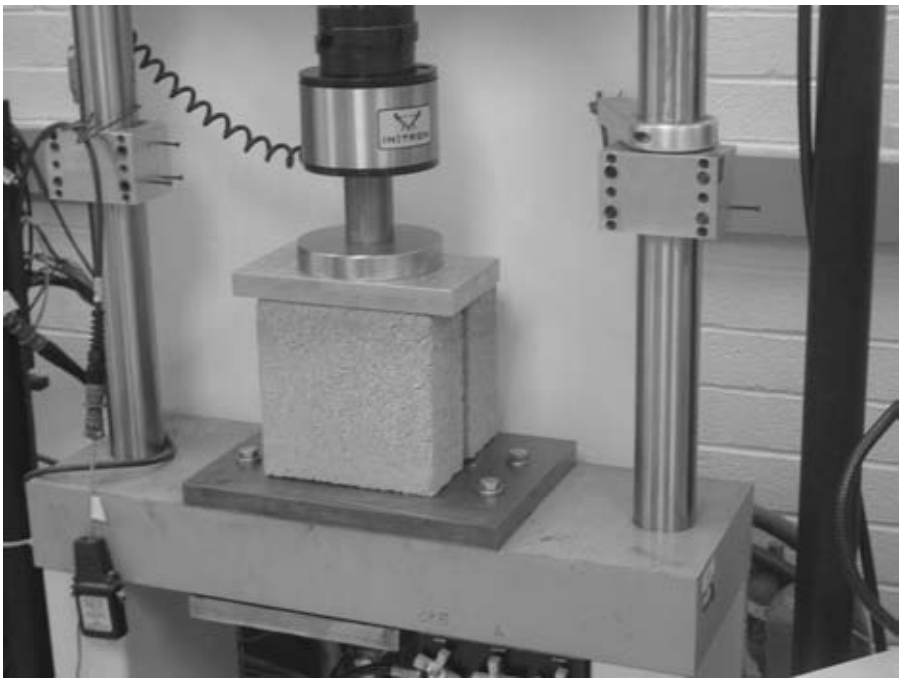

FIGURE A.46 Compression testing of a concrete masonry unit.

Test Procedure for Absorption

1. Three representative full-sized units are needed for absorption testing.
2. Weigh the specimen immediately after sampling and record the weight as the received weight (W_r).
3. Immerse the specimen in water at a temperature of 15°C to 26°C (60°F to 80°F) for 24 hours.
4. Weigh the specimen while it is suspended by a metal wire and completely submerged in water; record the weight as the immersed weight (W_i).
5. Remove the specimen from the water and allow it to drain for 1 min by placing it on a 9.5-mm (3/8-in.) or coarse wire mesh and removing visible surface water with a damp cloth. Weigh the specimen and record the weight as the saturated weight (W_s).
6. Dry the specimen in a ventilated oven at 100°C to 115°C (212°F to 239°F) for not less than 24 hours and until two successive weights at intervals of 2 hours show a difference of not greater than 0.2%. Record the weight as the oven-dried weight (W_d).

Analysis and Results

Gross area compressive strength, MPa (psi) = P_{max}/A_g

where

P_{max} = maximum compressive load, N (lb)
A_g = gross area, mm^2 (in.^{2}) = $L \times W$
L = average length, mm (in.)
W = average width, mm (in.)

Net area compressive strength, MPa (psi) = P_{max}/A_n

where

A_n = average net area, mm^2 = V_n/H
A_n = average net area, in.^{2} = $(V_n \times 1728)/H$
V_n = net volume, mm^3 = $(W_s - W_i) \times 10^6$
V_n = net volume, ft^3 = $(W_s - W_i)/62.4$
H = average height, mm (in.)
W_s = saturated weight of unit, kg (lb)
W_i = immersed weight of unit, kg (lb)

Absorption, kg/m^3 = $[(W_s - W_d)/(W_s - W_i)] \times 1000$
Absorption, lb/ft^3 = $[(W_s - W_d)/(W_s - W_i)] \times 62.4$
Absorption, % = $[(W_s - W_d)/W_d] \times 100$
Moisture content, % of total absorption
= $[(W_r - W_d)/(W_s - W_d)] \times 100$
Density, kg/m^3 = $[W_d/(W_s - W_i)] \times 1000$
Density, lb/ft^3 = $[W_d/(W_s - W_i)] \times 62.4$

where

W_d = oven dry weight, kg (lb)
W_r = received weight, kg (lb)

Report

- Gross area and net area compressive strengths to the nearest 70 kPa (10 psi) for each specimen and the average for three specimens
- Absorption, moisture content as a percent of total absorption, and density.

Experiment No. 21
Viscosity of Asphalt Binder by Rotational Viscometer

ASTM Designation

ASTM D4402—Viscosity Determinations of Asphalt at Elevated Temperatures Using a Rotational Viscometer

Purpose

To determine the apparent viscosity of asphalt binder from 38°C to 260°C (100°F to 500°F) using a rotational viscometer and a temperature-controlled thermal chamber for maintaining the test temperature.

Significance and Use

The viscosity is needed to ensure proper handling of the asphalt binder and for quality control and quality assurance. It is also used to determine the mixing and compaction temperatures of asphalt concrete. This test is used for the Superpave performance grading of asphalt binders.

Apparatus

- Rotational viscometer (Figure 9.15)
- Spindles
- Thermosel system, consisting of thermo-container and sample chamber, SCR controller and probe, and graph-plotting equipment

Test Procedure

1. Turn on the Thermosel power and set the proportional temperature controller to the desired test temperature.
2. Wait 1-1/2 hours (or until equilibrium temperature is obtained) with the spindle in the chamber (check control lamp).
3. Remove sample holder and add the volume of sample specified for the spindle, approximately 8 mL to 10 mL. Exercise caution to avoid sample overheating and to avoid ignition of samples with a low flash point. Do not overfill the sample container. The sample volume is critical to meeting the system calibration standard.
4. Thoroughly stir the filled asphalt container to obtain a representative sample.
5. The liquid level should intersect the spindle shaft at a point approximately 3 mm (1/8 in.) above the upper conical body–spindle shaft interface.
6. Using the extracting tool, put the loaded chamber back into the thermo-container.

7. Lower the viscometer and align the thermo-container.
8. Insert the selected spindle into the liquid in chamber, and couple it to the viscometer (Figure A.47). Either spindle number 27 or spindle number 20 is used for asphalt binders.
9. Allow the asphalt to come to the equilibrium temperature (about 15 min).
10. Start the viscometer at a 20 rpm setting.
11. Record three readings 60 seconds apart at each test temperature.
12. Multiply the viscosity factor by the rotational viscometer readings to obtain viscosity in centipoises.

Report

- Viscosity at each test temperature.
- Spindle number and rotational speed.

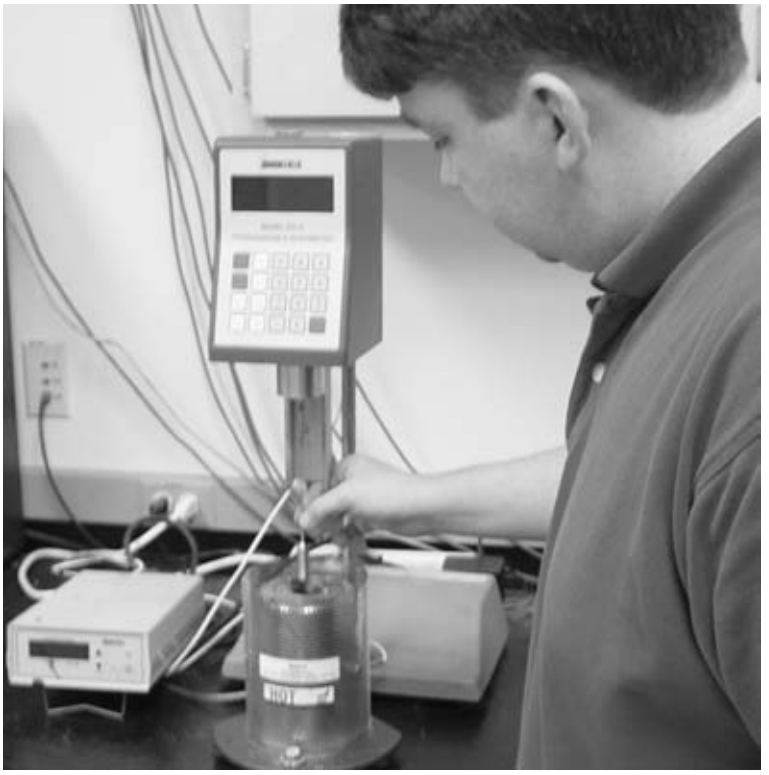

FIGURE A.47 Inserting the spindle into chamber before the rotational viscometer test.

Experiment No. 22
Dynamic Shear Rheometer Test of Asphalt Binder

ASTM Designation

ASTM P246—Determining the Rheological Properties of Asphalt Binder for Specification Purposes Using a Dynamic Shear Rheometer (DSR)

Purpose

To determine the complex shear modulus (G^*) and phase angle (δ) of asphalt binders using the dynamic shear rheometer.

Significance and Use

The complex shear modulus is an indicator of the stiffness resistance of asphalt binder to deformation under load. The complex shear modulus and phase angle define the resistance to shear deformation of the asphalt binder in the viscoelastic region. This test is used for the Superpave performance grading of asphalt binders.

Apparatus

- Dynamic shear rheometer (DSR) (Figure A.48)
- Test plates
- Temperature controller
- Loading device
- Control and data acquisition system
- Miscellaneous items, such as specimen mold, specimen trimmer, environmental chamber, reference thermal detector, and calibrated temperature detector.

Test Procedure

1. Heat the asphalt binder until fluid enough to pour the required specimens.
2. Carefully clean and dry the surfaces of the test plates so that the specimen uniformly adheres to both plates. Bring the chamber to approximately 45°C, so that the plates are preheated prior to the mounting of the test specimen.
3. Place the asphalt binder sample in the DSR, using one of the following methods:
   - Remove the removable plate and, while holding the sample container approximately 15 mm above the test plate surface, pour the asphalt

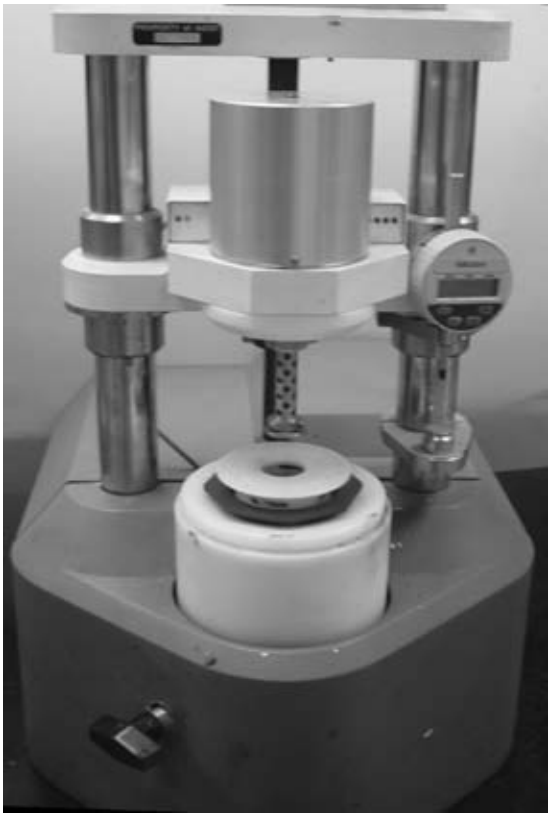

FIGURE A.48 Dynamic shear rheometer aparatus.

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. Wait several minutes for the specimen to stiffen, and then mount the test plate in the rheometer for testing.

- Pour the hot asphalt into a silicon rubber mold that will form a pellet with 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. Allow the silicon rubber to cool to room temperature. Remove the specimen from the mold and center the pellet on the lower plate of the DSR.

4. Move the test plates together to squeeze the asphalt mass between the two plates. Move the plates until the gap between the plates equals the testing gap plus 0.05 mm. Trim the specimen by moving a heated trimming tool around the upper and lower plate perimeters while trimming excess asphalt.
5. After trimming is completed, decrease the gap by 0.05 mm. The sample thickness should now equal the desired test gap.
6. Bring the specimen to the test temperature ±0.1°C (Figure A.49). Start the test after the temperature has remained at the desired temperature,

FIGURE A.49 Water bath for controlling specimen temperature during testing.

±0.1°C, for at least 10 min. The test temperature can be selected from the specifications in Table 9.3.

7. When the temperature has been reached, condition the specimen by applying the required shear strain for 10 cycles at a radial frequency of 10 radians/s. Shear strain values vary from 1% to 12%, depending on the stiffness of the binder being tested. High strain values are used for relatively soft binders tested at high temperatures, whereas low strain values are used for hard binders. The rheometer measures the torque required to achieve the set shear strain and maintains this as the maximum torque during the test.
8. The data acquisition system automatically calculates G^* and δ from test data acquired when properly activated.

Report

- Identification and description of the material tested
- Test temperature and sample dimensions including thickness
- Stress level
- G^* and δ values

Experiment No. 23
Penetration Test of Asphalt Cement

ASTM Designation

ASTM D5—Penetration of Bituminous Materials

Purpose

To determine the penetration of semisolid and solid bituminous materials.

Significance and Use

The penetration test is used as a measure of consistency. High values of penetration indicate soft consistency.

Apparatus

- Penetration apparatus and needle (Figures 9.19 and A.50)
- Sample container, water bath, transfer dish, timing device for hand-operated penetrometers, and thermometers

FIGURE A.50 Apparatus for penetration test of asphalt binder.

Test Procedure

1. Heat the asphalt binder sample until it has become fluid enough to pour.
2. Pour the sample into the sample container and let it cool for at least 1 hour.
3. Place the sample, together with the transfer dish in the water bath at a temperature of 25°C (77°F) for 1 hour to 2 hours.
4. Clean and dry the needle with a clean cloth, and insert the needle into the penetrometer. Unless otherwise specified, place the 50-g mass above the needle, making the total moving load 100 g.
5. Place the sample container in the transfer dish, cover the container completely with water from the constant temperature bath, and place the transfer dish on the stand of the penetrometer.
6. Position the needle by slowly lowering it until its tip just makes contact with the surface of the sample. This is accomplished by bringing the actual needle tip into contact with its image reflected by the surface of the sample from a properly placed source of light.
7. Quickly release the needle holder for the specified period of time (5 seconds) and adjust the instrument to measure the distance penetrated in tenths of a millimeter.
8. Make at least three determinations at points on the surface of the sample not less than 10 mm from the side of the container and not less than 10 mm apart.

Report

- The average of the three penetration values to the nearest whole unit

Experiment No. 24
Absolute Viscosity Test of Asphalt

ASTM Designation

ASTM D2171—Viscosity of Asphalts by Vacuum Capillary Viscometer

Purpose

To determine the absolute viscosity of asphalt by vacuum capillary viscometer at 60°C (140°F).

Significance and Use

The viscosity at 60°C (140°F) characterizes flow behavior and may be used for specification requirements for cutbacks and asphalt cements.

Apparatus

- Viscometers such as the Cannon–Manning vacuum viscometer (Figure 9.20) or modified Koppers vacuum viscometer
- Bath, with provisions for visibility of the viscometer and the thermometer
- Thermometers, vacuum system, and timing device

Test Procedure

1. Maintain the bath at a temperature of 60°C (140°F).
2. Select a clean, dry viscometer that will give a flow time greater than 60 seconds, and preheat to 135°C (275°F).
3. Charge the viscometer by pouring the prepared asphalt sample to the fill line.
4. Place the charged viscometer in an oven or bath maintained at 135°C for a period of 10 min, to allow large air bubbles to escape.
5. Remove the viscometer from the oven or bath, and within 5 min, insert the viscometer in a holder, and position the viscometer vertically in the bath so that the uppermost timing mark is at least 20 mm below the surface of the bath liquid.
6. Establish a 300-mm Hg vacuum in the vacuum system, and connect the vacuum system to the viscometer.
7. After the viscometer has been in the bath for 30 min, start the flow of asphalt in the viscometer by opening the toggle valve or stopcock in the line leading to the vacuum system.
8. Measure to within 0.1 second the time required for the leading edge of the meniscus to pass between successive pairs of timing marks. Report the first flow time that exceeds 60 seconds between a pair of timing marks, and identify the pair of timing marks (Figure A.51).

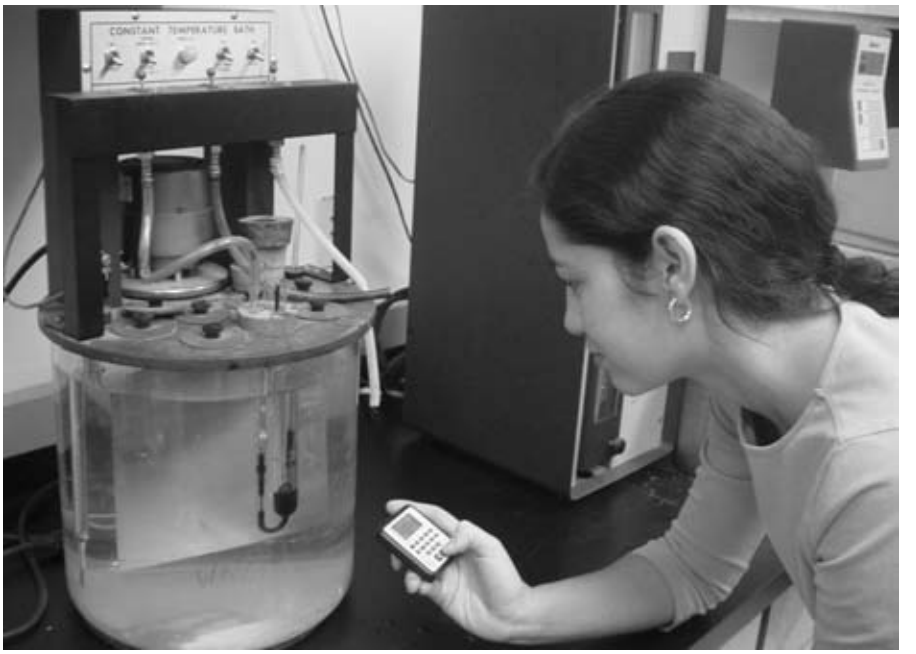

FIGURE A.51 Measuring flow time using a stop watch.

Analysis and Results

- Select the calibration factor that corresponds to the pair of timing marks. Calculate and report the viscosity to three significant figures formula

$$P = Kt$$

where

P = absolute viscosity, Poises
K = selected calibration factor, Poises/s
t = flow time, s

Report

- Absolute viscosity.
- Test temperature and vacuum.

Experiment No. 25
Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

AASHTO Designation

AASHTO T 312-03—Preparing and Determining the Density of Hot-Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor

Purpose

To prepare asphalt concrete specimens to densities achieved under actual pavement climate and loading conditions, or as needed for laboratory testing.

Significance and Use

The Superpave gyratory compactor is capable of accommodating large aggregates. Furthermore, this device affords a measure of compaction ability that permits potential tender mixture behavior and similar compaction problems to be identified. This method of compaction is used for the Superpave volumetric mix design of asphalt concrete mixture, and for field quality control during the construction of HMA pavements.

Apparatus

- Reaction frame, rotating base, and motor (Figure 9.24)
- Loading system, loading ram, and pressure gauge
- Height measuring and recording system
- Mold and base plate

Procedure

1. Specimens must be mixed and compacted under equiviscous temperature conditions of 0.170 ± 0.02 Pa·s and 0.280 ± 0.03 Pa·s, respectively. Mixing is accomplished by a mechanical mixer.
2. After mixing, loose test specimens are subjected to 2 hours of short-term aging in a forced draft oven at the compaction temperature which corresponds to a binder viscosity of 0.28 ± 0.03 Pa·s. During this period, loose mix specimens are required to be spread into a thickness resulting in 21 kg to 22 kg per cubic meter. The sample is stirred after 1 hour to ensure uniform aging.
3. Place the compaction molds and base plates in an oven at the compaction temperature for at least 30 min to 45 min prior to use.

4. If specimens are to be used for volumetric determinations only, use sufficient mix to arrive at a specimen 150 mm in diameter by approximately 115 mm high. This requires approximately 4500 g of aggregates. If needed, specimens with other heights can also be prepared for further performance testing (Figure A.52).
5. Turn on the power to the compactor. Set the vertical pressure to 600 kPa.
6. Set the gyration counter to zero, and set it to stop when the desired number of gyrations is achieved. Three gyrations are of interest: design number of gyrations (N_d), initial number of gyrations (N_i), and maximum number of gyrations (N_m). The design number of gyrations is a function of the climate in which the mix will be placed and the traffic level it will withstand.
7. After the base plate is placed, place a paper disk on top of the plate and charge the mold with the short-term aged mix in a single lift. The top of the uncompacted specimen should be slightly rounded. Place a paper disk on top of the mixture. Depending on the model of the compactor it may be necessary to place a top plate on the mix.

FIGURE A.52 Placing HMA in mold.

8. Place the mold in the compactor and center it under the ram (Figure A.53). Lower the ram until it contacts the mixture and the resisting pressure is 600 kPa.
9. Apply the angle of gyration of 1.25° and begin compaction.
10. When the desired number of gyrations has been reached, the compactor should automatically cease. After the angle and pressure are released, remove the mold containing the compacted specimen.
11. Print the results of specimen height versus number of gyrations.
12. After a suitable cooling period, extrude the specimen from the mold and mark it (Figure A.54).
13. Measure the bulk specific gravity of the test specimens according to ASTM D2726 procedure.

Analysis and Results

- Compute the estimated bulk specific gravity for each desired gyration from the formula

  Estimated bulk specific gravity = net weight of the specimen/$(\pi d^2 h/4)$

  where

  d = mold diameter (150 mm)
  h = specimen height corresponding to the desired number of gyrations

FIGURE A.53 Placing the mold in the gyratory compactor.

FIGURE A.54 Specimen prepared with gyratory shear compactor

- Compute the correction factor C as follows:

$$C = \frac{\text{measured bulk specific gravity}}{\text{estimated bulk specific gravity at } N_m}$$

- Compute the corrected bulk specific gravity by multiplying each estimated bulk specific gravity by the correction factor.
- Compute the percentage of the corrected bulk specific gravity relative to the maximum theoretical specific gravity ($\%G_{\text{mm}}$).
- Draw a graph of the logarithm of the number of gyrations versus the $\%G_{\text{mm}}$ (densification curve) for each specimen.

Report

- Mixture ingredients, source, and relevant information
- Densification table
- Densification curve

Experiment No. 26
Preparation of Asphalt Concrete Specimens Using the Marshall Compactor

ASTM Designation

ASTM D1559—Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus

Purpose

To prepare asphaltic concrete specimens using the Marshall hammer.

Significance and Use

This method is used to design the mix using the Marshall procedure and to measure its properties.

Apparatus

- Either mechanical or manual compaction hammer with 4.5-kg (10-lb) weight and 0.48-m (18-in.) drop height can be used (Figure 9.25)
- Molds with 102-mm (4-in.) inside diameter and 75 mm (3 in.) high, base plates, and collars
- Compaction pedestal, specimen extruder, and miscellaneous items, such as mold holder, spatula, pans, and oven.

Procedure

1. Determine the mixing and compaction temperatures so that the kinematic viscosities of the binder are 170 ± 20 cSt and 280 ± 30 cSt, respectively.
2. Separate all the required sizes of aggregates and oven dry.
3. Weigh 1200 g batches so that gradation would satisfy the midpoint of the specification band. Either a state specification or ASTM D3515 can be followed.
4. Place both asphalt binder and aggregate in the oven until they reach the mixing temperature (approximately 150°C or 300°F).
5. Add the asphalt to the aggregate in the specified amount.
6. Using the mechanical mixer, or manually, mix the aggregates and asphalt thoroughly (Figure A.55). Some agencies require curing the mix as specified in AASHTO R30.
7. Place a release paper inside the mold. Then, place the entire batch of asphaltic concrete in the mold heated to the compaction temperature, and spade with a heated spatula 15 times around the perimeter and 10 times in the middle.

FIGURE A.55 Mixing HMA using a mechanical mixer.

FIGURE A.56 Compacting an HMA specimen using a manual Marshall hammer.

FIGURE A.57 Compacting an HMA specimen using a mechanical Marshall hammer.

8. Put in place a collar and a release paper, and put the mold on the pedestal. Clamp the mold with the mold holder, and apply the required number of blows using either a manual hammer or a mechanical hammer (Figures A.56 and A.57). The typical number of blows on each side is either 50 or 75, depending on the expected traffic volume on the road where the mix is intended to be used. Invert the mold and apply the same number of blows on the other face.
9. After cooling to room temperature, extrude the specimen using an extruding device. Cooling can be accelerated by placing the mold and the specimen in a plastic bag and subjecting them to cold water. Remove the paper disk, as shown in Figure A.58.

Report

- Mixture ingredients, source, and relevant information
- Number of blows on each side of the specimen

FIGURE A.58 Removing paper disk from a Marshall plug.

Experiment No. 27
Bulk Specific Gravity of Compacted Bituminious Mixtures

ASTM Designation

ASTM D2726—Bulk Specific Gravity of Compacted Bituminous Mixtures

Purpose

To determine the bulk specific gravity of compacted asphalt mixture specimens.

Significance and Use

The results of this test are used for voids analysis of the compacted asphalt mix.

Test Specimens

Laboratory-molded bituminous mixtures or cores drilled from bituminous pavements can be used.

Apparatus

- Balance equipped with suitable suspension and holder to permit weighing the specimen while it is suspended from the balance
- Water bath

Test Procedure

1. Weigh the specimen in air and record it as *A* (Figure A.59).
2. Immerse the specimen in water at 25 ± 1°C (77 ± 2°F) while it is suspended from the balance for 3 min to 5 min, and record the immersed weight as *C* (Figure A.60).
3. Remove the specimen from the water, surface dry by blotting with a damp towel (Figure A.61), determine the surface dry weight, and record it as *B*.

Analysis and Results

- Calculate the bulk specific gravity as

$$\text{Bulk Specific Gravity} = \frac{A}{(B - C)}$$

where

A = mass of specimen in air, g
B = mass of surface-dry specimen, g
C = mass of specimens in water, g

FIGURE A.59 Weighing HMA specimen in air.

FIGURE A.60 Weighing HMA specimen in water.

FIGURE A.61 Removing surface water of HMA specimen with a damp towel.

Report

- Report the value of specific gravity to three decimal places.

Experiment No. 28
Marshall Stability and Flow of Asphalt Concrete

ASTM Designation

ASTM D1559—Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus

Purpose

To determine the Marshall stability and flow values of asphalt concrete.

Significance and Use

This test method is used in the laboratory mix design of bituminous mixtures according to the Marshall procedure. The test results are also used to characterize asphalt mixtures.

Apparatus

- Testing machine producing a uniform vertical movement of 50.8 mm minute (2 in./minute), as shown in Figure 9.35
- Breaking heads having an inside radius of curvature of 50.8 mm (2 in.)
- Load cell or ring dynamometer, strip chart recorder or flow meter, water bath, and rubber gloves

Test Procedure

1. Bring the specimen prepared in experiment number 25 to a temperature of 60°C (140°F) by immersing it in a water bath 30 min to 40 min or by placing it in the oven for 2 hours.
2. Remove the specimen from the water bath then "lightly" dry (or oven) and place it in the lower segment of the breaking head. Place the upper segment of the breaking head on the specimen, and place the complete assembly in position on the testing machine.
3. Prepare the strip chart recorder or place the flowmeter (where used) in position over one of the guide rods, and adjust the flowmeter to zero while holding the sleeve firmly against the upper segment of the breaking head.
4. Apply the load to the specimen by means of the constant rate of movement of 50.8 mm/min (2 in./min) until the maximum load is reached and the load decreases (Figure A.62). The elapsed time for the test from removal of the test specimen from the water bath (or oven) to the maximum load determination should not exceed 30 sec.

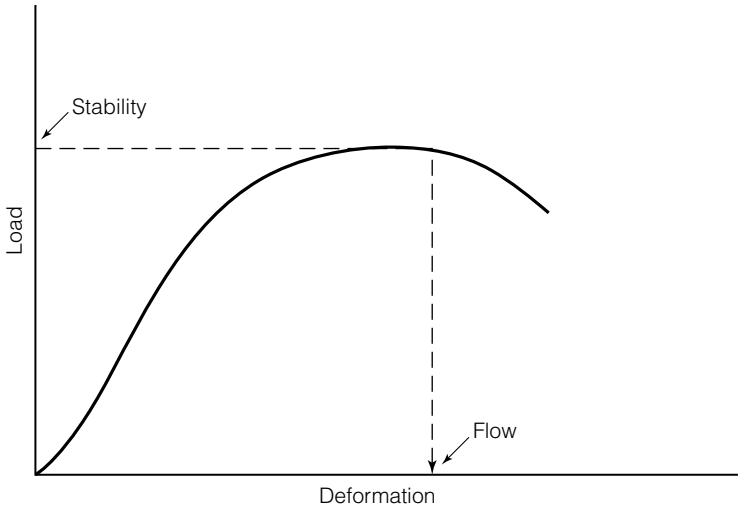

FIGURE A.62 Typical plot of load versus deformation during the Marshall stability test showing the stability and flow.

5. From the chart recorder, record the Marshall stability (maximum load) and the Marshall flow (deformation when the maximum load begins to decrease in units of 0.25 mm or hundredths of an inch). In some machines the maximum load and the flow values are read from the ring dynamometer and the flowmeter, respectively.
6. If the specimen height is other than 63.5 mm (2.5 in.), multiply the stability value by a correction factor (Table 9.11) (ASTM D1559).

Report

- Specimen identification and type (laboratory prepared or core)
- Average Marshall stability of at least three replicate specimens, corrected when required, kN (lb)
- Average Marshall flow of at least three replicate specimens

Experiment No. 29
Bending and Compression Tests of Wood

ASTM Designation

ASTM D143—Standard Methods of Testing Wood

Purpose

To determine modulus of rupture and compressive strength of wood by testing clear specimens.

Significance and Use

These tests provide data for comparing the mechanical properties of various species and data for the establishment of strength functions. The tests also provide data to determine the influence of such factors as density, locality of growth, change of properties with seasoning or treatment with chemicals, and changes from sapwood to heartwood on the mechanical properties.

Static Bending Test

Specimens 50 mm × 50 mm × 760 mm (2 in. × 2 in. × 30 in.) are used for the primary method, and 25 mm × 25 mm × 410 mm (1 in. × 1 in. × 16 in.) for the secondary method. For the loading span and supports, use center loading and a span length of 710 mm (28 in.) for the primary method and 360 mm (14 in.) for the secondary method.

Apparatus

- Testing machine of the controlled deformation type
- Bearing blocks for applying the load.

Test Procedure

1. Place the specimen so that the load will be applied at the center of the span. The load is applied through the bearing block to the tangential surface nearest the pith (Figure A.63).
2. Apply the load continuously throughout the test at a rate of motion of 2.5 mm/min (0.10 in./min) for primary method specimens, and at a rate of 1.3 mm/min (0.05 in./min) for secondary method specimens.
3. Record the load–deflection curve up to or beyond the maximum load. Continue recording up to a 150 mm (6 in.) deflection, or until the specimen fails to support a load of 890 N (200 lb) for the primary method specimens, and up to a 76 mm (3 in.) deflection or until the specimen fails to support a load of 220 N (50 lb) for secondary method specimens.

FIGURE A.63 Wood specimen during static bending test.

4. Within the proportional limit, take deflection readings to the nearest 0.02 mm (0.001 in.). After the proportional limit is reached, the deflection is read by means of the dial gauge until it reaches the limit of its capacity, normally 25 mm (1 in.). Where deflections beyond 25 mm (1 in.) are encountered, the deflections may be read by means of the scale mounted on the moving head.
5. Read the load and deflection of the first failure, the maximum load, and points of sudden change, and plot the load–deformation data.

Analysis and Results

- Calculate the modulus of rupture as

$$R = \frac{Mc}{I}$$

where

R = modulus of rupture, MPa (psi)
M = bending moment = PL/4
P = maximum load, N (lb)
L = span length, mm (in.)
c = distance from neutral axis to edge of sample = $\frac{1}{2}h$
I = moment of inertia = $bh^3/12$
b = average width, mm (in.)
h = average depth, mm (in.)

- Static bending (flexural) failures are classified in accordance with the appearance of the fractured surface and the manner in which the failure develops, as shown in Figure A.64. The fracture failure may be roughly divided into *brash* and *fibrous,* the term *brash* indicating abrupt failure and *fibrous* indicating a fracture showing splinters.

Report

- Specimen identification, dimensions, span length, and other relevant information, such as moisture content
- Load-deflection plot
- Modulus of rupture
- Failure condition.

Compression Parallel to the Grain Test

Specimens 50 mm × 50 mm × 200 mm (2 in. × 2 in. × 8 in.) are used for the primary method, and 25 mm × 25 mm × 100 mm (1 in. × 1 in.× 4 in.) for the secondary method. Be careful that the end grain surfaces are parallel to each other and at right angles to the longitudinal axis when preparing the specimens.

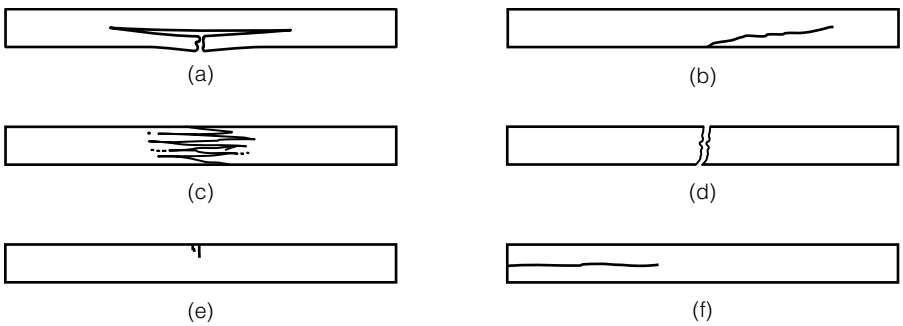

FIGURE A.64 Types of failure in static bending: (a) simple tension (side view), (b) cross-grain tension (side view), (c) splintering tension (view of tension surface), (d) brash tension (view of tension surface), (e) compression (side view), and (f) horizontal shear (side view).

Apparatus

A controlled deformation machine is required. At least one platen of the testing machine is equipped with a spherical bearing to obtain uniform distribution of load over the ends of the specimen.

Test Procedure

1. Place the specimen perpendicularly on the crosshead of the machine, as shown in Figures 10.10(c) and 10.11.
2. Apply the load continuously throughout the test until failure at a rate of motion of 0.003 mm/mm (in./in.) of the nominal specimen length per minute.
3. Measure the deformation over a central gauge length not exceeding 150 mm (6 in.) for primary method specimens, and 50 mm (2 in.) for secondary method specimens. Load–compression readings should be continued until the proportional limit is well passed, as indicated by the curve.

Analysis and Results

- Plot the load versus deflection diagram.
- Determine the modulus of elasticity as the slope of the straight portion of the stress–strain curve.
- Classify the compression failure in accordance with the appearance of the fractured surface (Figure 10.12). In case two or more kinds of failures develop, describe all fractured surfaces in the order of their occurrence; for example, shearing followed by brooming.

Report

- Specimen identification, dimensions, and other relevant information, such as moisture content.
- Load–deformation plot.
- Modulus of elasticity.
- Failure condition.

Compression Perpendicular to Grain Test

Specimens 50 mm × 50 mm × 150 mm (2 in. × 2 in. × 6 in.) are used.

Apparatus

- Controlled deformation machine
- Metal bearing plate 50 mm (2 in.) wide

Test Procedure

1. Position the specimen on the crosshead of the machine, as illustrated in Figure 10.10(d).
2. Apply the load through a metal bearing plate 50 mm (2 in.) wide, placed across the upper surface of the specimen at equal distances from the ends and at right angles to the length. Measure the actual width of the bearing plate. The specimens are to be placed so that the load will be applied through the bearing plate to a radial surface. The load is to be applied continuously throughout the test at a rate of 0.305 mm/min (0.012 in./min).
3. Take load and deformation readings up to 2.5 mm (0.1 in.) compression, after which discontinue the test. Measure the compression between the loading surfaces.

Analysis and Results

- Plot the load versus deflection diagram.
- Determine the modulus of elasticity as the slope of the straight portion of the stress–strain curve.

Report

- Specimen identification, dimensions, and other relevant information such as moisture content
- Load–deformation plot
- Modulus of elasticity

Experiment No. 30
Tensile Properties of Plastics

ASTM Designation
ASTM D638M—Tensile Properties of Plastics

Purpose
To determine the tensile properties of unreinforced and reinforced plastic materials, including composites.

Significance and Use
This test method is designed to produce tensile property data for the control and specification of plastic materials. These data are also useful in characterizing the quality of the material and for research and development.

Apparatus
Testing machine, grips, load indicator, and extension indicator

Test Specimens
Specimens with an overall length of 150 mm, gauge length of 50 mm, width of narrow section of 10 mm, and thickness of 4 mm are used (Figure A.65) (Type M-I specimens, ASTM D638M). For isotropic materials, at least five specimens are tested.

Test Procedure
1. Measure the width and thickness of specimens with a suitable micrometer to the nearest 0.02 mm at several points along their narrow sections.
2. Condition the test specimens at 23 ± 2°C and 50 ± 5% relative humidity for not less than 40 hours prior to the test.
3. Place the specimen in the grips of the testing machine, taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachment of the grips to the machine.

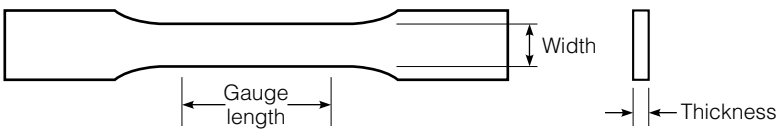

FIGURE A.65 Plastic specimen for tension test.

4. Attach the extension indicator (Figure A.66). When the modulus is required, the extension indicator must continuously record the distance the specimen is stretched (elongated) within the gauge length, as a function of the load through the initial (linear) portion of the load–elongation curve.
5. Set the speed of testing at a rate of travel of the moving head of 5 mm/minute and start the machine (Figure A.67).
6. Record the load–extension curve of the specimen.
7. Record the load and extension at the yield point (if one exists) and the load and extension at the moment of rupture.

Analysis and Results

- Tensile strength is

$$\sigma = P_{\max}/A_o$$

where

σ = tensile strength, MPa (psi)
$P_{\max}$ = maximum load carried by the specimen during the tension test, N (lb)
A_o = original minimum cross-sectional area of the specimen, mm^2 ($in.^2$)

- Percent elongation
If the specimen gives a yield load that is larger than the load at break, calculate the percent elongation at yield. Otherwise, calculate the percent elongation at break. Do this by reading the extension (change in

FIGURE A.66 Extensometer on plastic specimen.

FIGURE A.67 Tension test on a plastic specimen.

gauge length) at the moment the applicable load is reached. Divide that extension by the original gauge length and multiply by 100.

- Modulus of elasticity
  Calculate the modulus of elasticity by extending the initial linear portion of the load–extension curve and by dividing the difference in stress of any segment of section on this straight line by the corresponding difference in strain. Compute all elastic modulus values using the average initial cross-sectional area of the test specimens in the calculations.

Report

- Complete identification of the material tested
- Method of preparing test specimen, type of test specimen and dimensions, and speed of testing
- Tensile strength, percent elongation, and modulus of elasticity.