Designation: D 5102 – 96

Standard Test Method for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures[1]

This standard is issued under the fixed designation D 5102; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers procedures for preparing, curing, and testing laboratory-compacted specimens of soil-lime and other lime-treated materials (Note 1) for determining unconfined compressive strength. This test method can be used for specimens prepared at the maximum unit weight and optimum water content, or for specimens prepared at other target unit weight and water content levels. Cored specimens of soil-lime should be tested in accordance with Test Methods D 2166.

NOTE 1—Lime-based products other than commercial quicklime and hydrated lime are also used in the lime treatment of fine-grained cohesive soils. Lime kiln dust (LKD) is collected from the kiln exhaust gases by cyclone, electrostatic, or baghouse-type collection systems. Some lime producers hydrate various blends of LKD plus quicklime to produce a lime-based product.

1.2 Two alternative procedures are provided:

1.2.1 Procedure A describes procedures for preparing and testing compacted soil-lime specimens having height-to-diameter ratios between 2.00 and 2.50. This test method provides the standard measure of compressive strength.

1.2.2 Procedure B describes procedures for preparing and testing compacted soil-lime specimens using Test Methods D 698 compaction equipment and molds commonly available in most soil testing laboratories. Procedure B is considered to provide relative measures of individual specimens in a suite of test specimens rather than standard compressive strength values. Because of the lesser height-to-diameter ratio (1.15) of the cylinders, compressive strength determined by Procedure B will normally be greater than that by Procedure A. Results of unconfined compressive strength tests using Procedure B should not be directly compared to those obtained using Procedure A.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3.1 The use of balances or scales to record pounds of mass (lbm) or to record density in pounds of mass per cubic foot (lbm/ft^3) should not be regarded as nonconformance with this test method.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see Section 8.

2. Referenced Documents

2.1 *ASTM Standards:*

C 51 Definitions of Terms Relating to Lime and Limestone (As Used by the Industry)[2]

C 977 Specification for Quicklime and Hydrated Lime for Soil Stabilization[2]

D 653 Terminology Relating to Soil, Rock, and Contained Fluids[3]

D 698 Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49-kg) Rammer and 12-in. (305-mm) Drop[3]

D 2166 Test Methods for Unconfined Compressive Strength of Cohesive Soil[3]

D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[3]

D 3551 Method for Laboratory Preparation of Soil-Lime Mixtures Using a Mechanical Mixer[3]

D 3740 Practice for the Evaluation of Agencies Engaged in the Testing and/or Inspection of Soil and Rock Used in Engineering Design and Construction[3]

D 4753 Specification for Evaluating, Selecting, and Specifying Balances and Scales for Use in Soil and Rock Testing[3]

3. Terminology

3.1 *Definitions:*

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.15 on Stabilization with Admixtures.

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[2] *Annual Book of ASTM Standards*, Vol 04.01.

[3] *Annual Book of ASTM Standards*, Vol 04.08.

***A Summary of Changes section appears at the end of this standard.**

3.1.1 Refer to Terminology D 653 for terms relating to soil and Definitions C 51 for terms relating to lime and limestone.

3.1.2 *Definitions of Terms Specific to This Standard*:

3.1.3 *lime content*—the ratio, expressed as a percentage, of (*a*) the dry mass of lime to (*b*) the dry mass of soil.

3.1.4 *unconfined compressive strength of soil-lime* (q_μ)—the compressive stress at which an unconfined cylindrical specimen of soil-lime will fail in an axial compression test. In this test method, unconfined compressive strength is the maximum axial load attained per unit area or the load per unit area at 5 % axial strain, whichever occurs first during performance of a test.

4. Summary of Test Method

4.1 Dependent on design criteria, a predetermined number of compacted soil-lime specimens are prepared for each specified lime content, unit weight, and water content so unconfined compression testing can be performed on laboratory cured specimens of specified ages. In many instances, duplicate specimens are tested following a 28 and 90-day curing period at room temperature. In some cases, however, a curing period of 7 days at room temperature or accelerated curing conditions may be necessary.

4.2 The amount of soil, lime, and water required for the specimen is determined. The soil-lime-water mixture is compacted in a mold to the desired initial specimen conditions.

4.3 After removal from the mold, specimens are cured for a specified number of days.

4.4 Following the curing period, the soil-lime specimens are loaded in compression to failure. Maximum load or load at 5 % axial strain is used to calculate unconfined compressive strength.

5. Significance and Use

5.1 Compression testing of soil-lime specimens is performed to determine unconfined compressive strength of the cured soil-lime-water mixture to determine the suitability of the mixture for uses such as in pavement bases and subbases, stabilized subgrades, and structural fills.

5.2 Compressive strength data are used in soil-lime mix design procedures: (*a*) to determine if a soil will achieve a significant strength increase with the addition of lime; (*b*) to group soil-lime mixtures into strength classes; (*c*) to study the effects of variables such as lime percentage, unit weight, water content, curing time, curing temperature, etc.; and (*d*) to estimate other engineering properties of soil-lime mixtures.

5.3 Lime is generally classified as calcitic or dolomitic. Usually in soil stabilization, high-calcium hydrated lime [$Ca(OH)_2$] or monohydrated dolomitic lime [$Ca(OH)_2$ + MgO] are used. Lime may increase the strength of cohesive soil. The type of lime in combination with soil type influences the resulting compressive strength.

NOTE 2—The agency performing this test method can be evaluated in accordance with Practice D 3740. Not withstanding statements on precision and bias contained in this method: The precision of this test method is dependent on the competence of the personnel performing it and the suitability of the equipment and facility used. Agencies that meet the criteria of Practice D 3740 are generally considered capable of competent and objective testing. Users of this test method are cautioned that compliance with D 3740 does not, in itself, ensure reliable testing. Reliable testing depends on many factors; Practice D 3740 provides a means of evaluating some of these factors.

6. Apparatus

6.1 *Balance or Scale*:

6.1.1 *Procedure B*, a balance or scale for determining the mass of soil, lime, and water, having a minimum capacity of 20 kg and meeting the requirements of Specification D 4753 for a balance of 1-g readability.

6.1.2 *Procedure A*, a balance or scale, for preparing test specimens for Procedure A and for determining water content, having a minimum capacity of 1000 g and meeting the requirements of Specification D 4753 for a balance of 0.1-g readability.

6.2 *Specimen Dimension Measurement Devices*, dial comparators, calipers, circumferential tape or other suitable devices for measuring the height and diameter of the specimen within 0.1 % of the measured dimension.

6.3 *Specimen Molds*:

6.3.1 *Procedure A*, molds having sufficient capacity to provide specimens with length-to-diameter ratios between 2.00 and 2.50. Molds 50 ± 0.2 mm (2.0 ± 0.01 in.) in diameter by 125 ± 0.2 mm (5.0 ± 0.01 in.) high or 50± 0.2 mm (2.0 ± 0.01 in.) in diameter by 100 ± 0.2 mm (4 ± 0.01 in.) high are commonly used. Split molds may be used. The mold shall have an extension collar assembly made of rigid metal and constructed so it can be securely attached to and detached from the mold.

6.3.2 *Procedure B*, molds with extension collars conforming to the requirements of Method D 698.

6.4 *Tamping Rod or Compaction Hammer*, tamping rod or compaction hammer suitable for mold size and preparation of specimen at desired unit weight.

6.5 *Test Specimen Extruder*—An extruder is required if split molds are not used. The device shall consist of a piston, jack, and frame or similar equipment suitable for extruding specimens from the mold.

6.6 *Containers*, suitable plastic airtight, moistureproof containers for sealing and storing specimens after compaction. The containers should be rigid to protect the specimens from disturbance during handling.

6.7 *Miscellaneous Equipment*, tools such as spatulas, knives, straightedge, trowels, scoops, etc., for use in preparing specimens.

6.8 *Temperature Controlled Room or Cabinet*, a room or cabinet capable of maintaining a temperature of 23.0 ± 1.7°C (73.4 ± 3.0°F) for curing soil-lime specimens. A moist room can be used but is not required.

6.9 *Timer*, a timing device to indicate the elapsed testing time to the nearest second for establishing the rate of strain application prescribed in 13.2.

6.10 *Compression Device and Load Indicator*—The compression device may be any device with sufficient capacity and control to provide the constant strain rate prescribed in 13.2. The device shall be equipped so the compressive load is applied to the specimen without producing eccentric loading conditions. When the compression device is set to advance at a specified rate, the actual rate shall not deviate from the required value by more than ±10 %. For soil-lime specimens with an unconfined compressive strength of less than 100 kPa (15 lbf/in.^{2}), the load indicator shall be of such sensitivity that the applied stress can be calculated to ±0.7 kPa (0.1 lbf/in.^{2}). For soil-lime specimens with compressive strengths of 100 kPa (15 lbf/in.^{2}) or greater, the load indicator shall be of such sensitivity that the applied stress can be calculated to ±5 kPa (0.7 lbf/in.^{2}).

6.11 *Deformation Indicator*—The deformation indicator shall be a dial indicator graduated to 0.02 mm (0.001 in.) or less and having a travel range sufficient to measure 5 % of the length of the test specimen. Another measuring device, such as an electronic deformation measuring device, may be used provided it meets these requirements.

7. Reagents and Materials

7.1 *Hydrated Lime*—Lime that is predominantly calcium hydroxide [$Ca(OH)_2$] or a mixture of $Ca(OH)_2$ and magnesium oxide (MgO) or magnesium hydroxide [$Mg(OH)_2$], or both. Only fresh lime meeting the requirements of Specification C 977 may be used. Bagged lime must be kept sealed because of the tendency for the lime to combine with CO_2 in air.

7.2 *Quicklime*—Lime which is predominantly calcium oxide (CaO) or CaO in association with MgO. Only fresh lime meeting the requirements of Specification C 977 may be used. Bagged lime must be kept sealed because of the tendency for the lime to combine with CO_2 in air.

7.3 *Tapwater*—Tapwater that is free of acids, alkalies, and oils and is suitable for drinking shall be used for wetting the soil.

8. Safety Hazards

8.1 Lime chemically reacts with water and can become hot. Appropriate safety equipment, such as gloves, protective eyewear, respirator, and plastic apron should be worn when handling lime.

9. Technical Hazards

9.1 Perform compaction as quickly as possible after the 1-h mellowing period to minimize additional lime hydration and unrecorded moisture loss.

9.2 When compacting specimens, tamping should be uniform and consistent over the surface of each layer.

9.3 Handle compacted soil-lime specimens so as to prevent disturbance or changes in cross section or loss of moisture.

9.4 Lime can react with some metals such as aluminum and zinc. Therefore, aluminum foil and metal pans and containers consisting of aluminum and zinc should not be used for storing lime or for mellowing or curing the soil-lime mixture.

10. Test Specimens

10.1 *Specimen Size*—Specimens shall have a minimum diameter of 50 mm (2.0 in.), and the largest particle contained within the test specimen shall be smaller than 1⁄10 of the specimen diameter. For specimens having a diameter of 72 mm (2.8 in.) or larger, the largest particle size shall be smaller than 1⁄6 of the specimen diameter.

10.2 Calculate the quantity of soil, lime, and water required for one specimen and the total quantities of each needed to prepare the required number of test specimens at each prescribed lime content, percent of maximum dry unit weight, and water content. The values of maximum dry unit weight and optimum moisture content are determined in accordance with Test Methods D 698. The initial water content of soil, as determined using Method D 2216, is used to calculate the additional water required to bring the soil-lime mixture to the desired moisture contents. Approximately 10 % more material than calculated should be prepared to ensure that enough material is available.

10.3 Mix the soil-lime mixtures in accordance with Method D 3551.

10.4 Select the proper compaction mold in accordance with the procedure to be used.

10.4.1 *Procedure A, (Specimens Having Height-to-Diameter Ratios Between 2.0 and 2.5)*—Prepare specimens by compacting material in at least three layers, using a pressing, kneading or impact action, into a mold meeting the requirements of 6.3.1. Specimens may be molded to the desired unit weight by either: (*1*) kneading or tamping each layer until the accumulative mass of the soil placed in the mold is compacted to a known volume, or (*2*) adjusting the number of layers, the number of tamps per layer, and the force per tamp (Note 3). The ends of the specimen should be perpendicular to the longitudinal axis. Scarify the top of each layer prior to the addition of material for the next layer. After the specimen is formed, remove the mold. Determine and record the mass of the specimen, length of the specimen, and diameter of the specimen at midheight.

NOTE 3—When comparing strength data between laboratories, the details on specimen preparation should be known, as the preparation method affects unit weight which effects strength.

10.4.2 *Procedure B*—Compact specimens in accordance with the procedure given in Test Methods D 698. Scarify the surfaces of the first two layers prior to adding material for the next layer. Take steps to ensure layer heights are approximately equal. After a specimen is formed, extrude the specimen from the mold and determine and record the mass of the specimen, length of the specimen, and diameter of the specimen at midheight.

10.5 After the mass and dimensions of the specimen have been determined, place the specimen in an airtight, moisture-proof container and allow the specimen to cure in accordance with Section 12 on curing test specimens.

11. Conditioning

11.1 Store lime in a plastic, airtight, moistureproof container to keep it dry and free from CO_2.

11.2 Store the soil in an airtight, moistureproof container to preserve the water content.

11.3 Allow the soil-water-lime mixture to mellow for 1 h before compacting (Note 4).

NOTE 4—A 1-h mellowing period is typical, although periods up to 24 h have been used.

12. Curing Test Specimens

12.1 Cure compacted test specimens in a plastic, airtight, moistureproof container at a temperature of 23.0 ± 1.7°C (73.4± 3.0°F) for the specified curing period (Note 5).

NOTE 5—Any curing period may be specified, however, most commonly used curing periods are 7, 28, and 90 days.

12.2 The test specimens should be wrapped and sealed in plastic or placed in rubber sleeves to reduce carbonation. Curing conditions different from those specified should be noted in the report (Note 6).

NOTE 6—When accelerated curing conditions are necessary to expedite the curing process for simulating long-term field conditions, curing temperatures in excess of 48.9°C (120°F) should be avoided. Research indicates that a temperature of 40.6°C (105°F) at various curing times is appropriate for accelerated curing without introducing pozzolanic reactive products that significantly differ from those expected during field curing.[4] A damp cloth placed beneath the soil-lime specimen will help maintain humid conditions for curing and will prevent drying.

13. Procedure

13.1 Randomize the specimens for testing to ensure representative test results.

13.2 Place the specimen in the loading device so it is centered on the bottom platen. Carefully adjust the loading device so the upper platen just makes contact with the specimen. Zero the deformation indicator. Apply the load continuously and without shock so as to produce an axial strain rate of approximately 0.5 to 2.0 % per min. The rate of strain should be selected so the time to failure does not exceed about 15 min (Note 7).

NOTE 7—Softer specimens that will exhibit larger deformation at failure should be tested at a higher rate of strain. Conversely, stiff or brittle specimens that will exhibit small deformations at failure should be tested at a lower rate of strain.

13.3 Record load, deformation, and time values at intervals sufficient to define the shape of the stress-strain curve (usually 10 to 15 points are sufficient). Record the maximum load applied to the specimen.

13.4 Continue loading the specimen until load values decrease with increasing strain or until 5 % strain is reached.

13.5 Make a sketch or take a photograph of the test specimen after the test showing the mode of failure.

13.6 Measure and record the diameter of the failed specimen to 0.2 mm (0.01 in.) in three directions at its midheight.

13.7 The example data sheet shown in Test Methods D 2166 can be used. If this example data sheet is used, the corrected area shall be calculated using the appropriate method given in 14.2. Other data sheets may be used, provided the form contains all required data.

14. Calculation

14.1 Calculate axial strain to the nearest 0.1 %, for each applied load, as follows:

$$\epsilon = \frac{\Delta L}{L_o} \times 100 \quad (1)$$

where:
ϵ = axial strain, %
ΔL = length change of specimen as read from deformation indicator, mm (in.),
L_o = initial length of specimen, mm (in.), and
100 = convert from decimal to percent.

14.2 Calculate the average cross-sectional area for a given applied load (see Fig. 1), as follows:

14.2.1 If the post test measurement of the specimen diameter indicates the specimen diameter did not change during testing, use the original cross-sectional area of the specimen.

14.2.2 If radial deformation occurred during the test, but the specimen maintained a cylindrical shape (assuming the volume of the specimen also did not change) the corrected average cross-sectional area of the specimen shall be calculated as follows:

$$A = \frac{A_o}{(1 - \epsilon/100)} \quad (2)$$

where:
A = average corrected cross-sectional area of specimen, mm^2 ($in.^2$),
A_o = initial average cross-sectional area of specimen, mm^2 ($in.^2$), and
ϵ = axial strain for a given load, %.

14.2.3 If radial deformation increased during the test and the specimen assumed a barrel shape, the average corrected cross-sectional area shall be calculated as follows:

$$A = \frac{A_o}{(1 - 0.6\epsilon/100)} \quad (3)$$

where:
A = average corrected cross-sectional area of specimen, mm^2 ($in.^2$),
A_o = initial average cross-sectional area of specimen, mm^2 ($in.^2$), and
ϵ = axial strain for a given load, %.

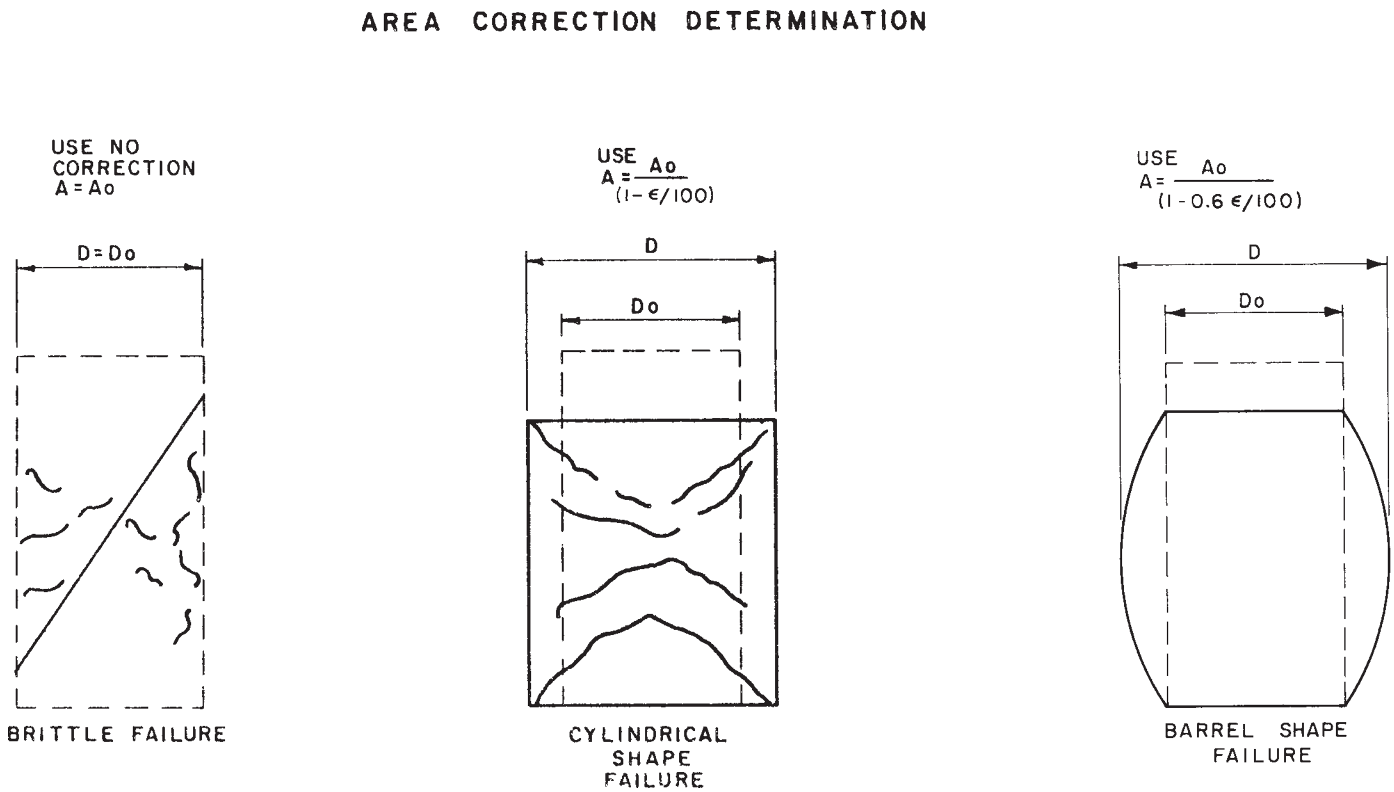
14.3 Calculate the compressive stress for a given applied load, as follows:

$$\sigma = \frac{P}{A} \quad (4)$$

where:
σ = compressive stress, kPa ($lbf/in.^2$),
P = axial load applied to specimen, kN (lbf), and
A = corresponding average cross-sectional area, $mm^2 \times 10^{-6}$ ($in.^2$).

14.4 *Graph*—If desired, a graph showing the relationship between axial strain (abscissa) and compressive stress (ordinate) may be plotted. Select the maximum value of compressive stress or the compressive stress at 5 % axial strain, whichever occurs first; and report as the unconfined compressive strength q_u. Whenever it is considered necessary for proper interpretation, include the stress-strain graph as part of the data reported.

[4] "Lime Stabilization," *State of the Art Report No. 5*, Transportation Research Board, National Research Council, Washington, DC, 1987.



where:
A = average corrected cross-sectional area of specimen, mm^2(in.^{2}),
A_o = initial average cross-sectional area of specimen, mm^2(in.^{2}), and
ϵ = axial strain for a given load, %

FIG. 1 Area Correction Determination

15. Report

15.1 Report the following information:

15.1.1 Soil-lime mixture identification (percent lime, soil sample identification, lime identification, and type of lime).

15.1.2 Classification test data or visual classification, or both, of soil sample.

15.1.3 Length of mellowing period used to prepare mixture in accordance with Method D 3551.

15.1.4 Specimen identification number.

15.1.5 Specimen preparation procedure (A or B) and details of preparation procedure.

15.1.6 Average specimen diameter and height.

15.1.7 Height-to-diameter ratio, as height-to-diameter ratio directly affects strength, as described in 1.2.2.

15.1.8 Average specimen cross-sectional area, mm^2 (in.^{2}).

15.1.9 Strain rate used, percent per minute.

15.1.10 Maximum load, kN (lbf).

15.1.11 Compressive strength, kPa (lbf/in.^{2}).

15.1.12 Strain at failure, percent.

15.1.13 Age of specimen.

15.1.14 Details of curing conditions.

15.1.15 Stress-strain graph, if prepared.

15.1.16 Failure sketch or photograph.

15.1.17 Remarks. Note any unusual conditions or other data considered necessary to properly interpret test results.

16. Precision and Bias

16.1 *Repeatability*:

16.1.1 *Single-Laboratory Precision*—The standard deviation for identical laboratory-prepared specimens increases with average strength.[5]

16.1.2 *Single-Operator Precision*—The single-operator precision of this test method has not yet been determined. The subcommittee is seeking pertinent data from users of this test method.

16.2 *Reproducibility*:

16.2.1 *Multi-Laboratory Precision*—The multi-laboratory precision of this test method has not yet been determined. The subcommittee is seeking pertinent data from users of this method.

16.3 *Bias*—The procedure in this test method for determining unconfined compressive strength of compacted soil-lime mixtures has no bias because the value of unconfined compressive strength can only be defined in terms of the test method.

17. Keywords

17.1 lime content; soil-lime; soil-stabilization; unconfined compressive strength

[5] Liu, T. K., and Thompson, M. R., "Variability of Some Selected Laboratory Soil Test," *Proceedings, National Conference on Statistical Quality Control Methodology in Highway and Airfield Construction*, Charlottesville, VA, 1966.

SUMMARY OF CHANGES

This section identifies the principal changes to this test method that have been incorporated since the last issue.

(1) Added Practice D 3740 as referenced document in Section 2.1 to conform to the recommended D-19 practice.

(2) Added new Note 2 in Section 5 to reference Practice D 3740. Renumbered the remaining notes.

(3) Added Summary of Changes to reflect the changes made in this revision.