Designation: D4943 – 08

Standard Test Method for Shrinkage Factors of Soils by the Wax Method[1]

This standard is issued under the fixed designation D4943; 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 the procedure for determining the shrinkage limit of soils.

1.2 The data obtained using this test method may also be used to calculate shrinkage ratio, volumetric shrinkage, and linear shrinkage.

1.3 This test method is applicable only for cohesive soils.

1.4 Since this test method is performed only on that portion of a soil which passes the No. 40 (425-μm) sieve, the relative consistency of this portion of the soil to the properties of the sample as a whole must be considered when using these procedures to evaluate the properties of a soil.

1.5 The shrinkage limit along with the liquid limit and plastic limit of soils are often collectively referred to as the Atterberg limits in recognition of their formation by Swedish soil scientist, A. Atterberg. These limits distinguish the boundaries of the several consistency states of cohesive soils.

1.6 All recorded and calculated values shall conform to the guide for significant digits and rounding established in Practice D6026.

1.6.1 The procedures used to specify how data are collected/recorded and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the user's objectives; and it is common practice to increase or reduce significant digits of reported data to be commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in analysis methods for engineering design.

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.8 *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 safety hazards, see Section 7 and Note 4.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

C702 Practice for Reducing Samples of Aggregate to Testing Size

D75 Practice for Sampling Aggregates

D420 Guide to Site Characterization for Engineering Design and Construction Purposes (Withdrawn 2011)[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D6026 Practice for Using Significant Digits in Geotechnical Data

E2251 Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids

E11 Specification for Woven Wire Test Sieve Cloth and Test Sieves

3. Terminology

3.1 *Definitions*—All definitions are in accordance with Terminology D653.

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

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

4. Summary of Test Method

4.1 A sample of fine-grained soil is thoroughly remolded with water to form a paste that is at approximately the liquid limit consistency. This paste is used to fill a small dish to form a soil pat. The initial moisture content of the wet soil pat is determined. The soil pat is slowly dried to constant mass. The volume of the dry soil is determined using a water submersion technique. A coating of wax is used to prevent water absorption by the dry soil pat. Then the moisture-content loss to dry the soil to a constant volume is determined and subtracted from the initial moisture content to calculate the shrinkage limit. The measurements are used to compute the soil constants.

5. Significance and Use

5.1 The term shrinkage limit, expressed as a moisture content in percent to the nearest whole number, represents the amount of water required just to fill all of the voids of a given cohesive soil at its minimum void ratio obtained by ovendrying. The shrinkage limit can be used to evaluate the shrinkage potential, crack development potential, and swell potential of earthwork involving cohesive soils.

NOTE 1—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/and the like. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Balance or Scale*—A balance or scale having a minimum capacity of 500 g and meeting the requirements of Specification D4753 for a balance of 0.01-g readability.

6.2 *Suspension Apparatus (optional)*—A device centered on the balance suitable for suspending the soil specimen in a container of water located next to or below the balance or scale.

6.3 *Dish, Shrinkage*—A circular porcelain or monel metal milk dish having a flat bottom about 40 to 45 mm in diameter and about 12 to 15 mm deep.

6.4 *Drying Oven*—An oven, thermostatically controlled, preferably of the forced draft type, and capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber.

6.5 *Humidity Enclosure (optional)*—Small closed container large enough for shrinkage dishes and a small container of water used in dry climates to slow the initial rate of drying.

6.6 *Mortar and Pestle*—Mortar, iron or porcelain, about 125 to 150-mm diameter with rubber tipped pestle.

6.7 *Spatula*—A spatula or pill knife having a blade about 100 mm long by about 20 mm wide.

6.8 *Straightedge*—A stiff metal straightedge of convenient length. The scraping edge must be beveled if it is thicker than 3 mm.

6.9 *Sieve*—U.S.A. Standard series No. 40 (425-µm) sieve conforming to the requirements of Specification E11.

6.10 *Wax*—Microcrystalline or other suitable wax mixture which is not brittle when dry and does not shrink during solidification. Sufficient quantity when melted in the wax warmer to submerge the soil pat.

NOTE 2—A 50/50 mixture of paraffin wax and petroleum jelly will provide an adequate alternative.

6.11 *Sewing Thread*—Fine thread to hold the specimen to dip into the wax.

6.12 *Water,* distilled.

6.13 *Water Bath*—Of sufficient size (for example, 250 mL beaker) to submerge the soil pat when determining indicated mass in water.

6.14 *Wax Warmer*—Sufficient temperature control to avoid overheating.

6.15 *Thermometer (optional)*—A thermometer, in the room temperature range, 0.5° gradations, conforming to the requirements of Specification E2251.

6.16 *Glass or Clear Plastic Plate,* used for calibrating the shrinkage dish, about 80 by 80 mm, about 5 mm thick.

6.17 *Petroleum Base Lubricant,* used to grease the shrinkage dish.

6.18 *Liquid Limit Device and Grooving Tool,* as described in Test Method D4318.

7. Safety Hazards

7.1 Wax melting equipment or hot wax may burn unprotected skin. Overheated wax may burst into flames; therefore, extreme care should be taken when working with hot wax. Do not use an open flame device to heat wax.

8. Sampling

8.1 Take samples from any location that satisfies testing needs. However, use Practices C702 and D75, as well as Guide D420, as guides for selecting and preserving samples from various types of sampling operations.

8.2 Where sampling operations have preserved the natural stratification of a sample, keep the various strata separated and perform tests on the particular stratum of interest with as little contamination as possible from other strata. Where a mixture of materials will be used in construction, combine the various components in such proportions that the resultant sample represents the actual construction case.

8.3 Where data from this test method are to be used for correlation with other laboratory or field test data, use the same material as used for these tests where possible.

8.4 Obtain a representative portion from the total sample sufficient to provide 150 to 200 g of material passing the No. 40 (425-µm) sieve. Mix samples thoroughly in a pan with a spatula or scoop and scoop a representative portion from the total mass by making one or more sweeps with a scoop through the mixed mass.

9. Calibration and Standardization

9.1 Calibrate each shrinkage dish used in accordance with Annex A1. Since the dishes may have different volumes, each dish must be permanently identified.

9.2 The specific gravity (or density) of the wax must be known in advance to at least two significant digits. This can usually be obtained from the manufacturer. If not, determine the specific gravity in accordance with Annex A2. In either case, the specific gravity value should be checked initially and then periodically.

9.3 Maintain the water bath, testing apparatus, and the laboratory environment at about the same temperature while performing both the dish calibrations and the individual test measurement. Temperature differences as large as 5°C will not adversely impact the shrinkage limit when reported to the nearest whole number.

10. Preparation of Test Specimen

10.1 Prepare the test specimen in accordance with the directions in Test Method D4318, using either the wet or dry preparation procedure, except that the moisture content of the soil is adjusted to a consistency that would require about ten blows of the liquid limit device to close the groove along a distance of 13 mm. The amount of water required may exceed the liquid limit by as much as 10 percentage points.

11. Procedure

11.1 Select a shrinkage dish and record its identification designation and its volume (V). The volume of the shrinkage dish is used as the volume of the wet soil pat. Lightly grease the inside of the shrinkage dish.

11.2 Determine the mass of the greased shrinkage dish and record the value as the mass of the empty shrinkage dish (m).

11.3 Place, in the center of the dish, an amount of the wetted soil equal to about one-third the volume of the dish and cause the soil to flow to the edges by tapping the dish on a firm surface cushioned by several layers of blotting paper or similar material. Add an amount of soil approximately equal to the first portion, and tap the dish until the soil is thoroughly compacted and all included air has been brought to the surface. Add more soil and continue the tapping until the dish is completely filled and excess soil stands out about its edge. Strike off the excess soil with a straightedge and wipe off all soil adhering to the outside of the dish.

11.4 Determine the mass of the dish immediately after it is filled and record the struck measure value as the mass of dish plus wet soil pat (m_w).

11.5 Allow the soil pat to dry in air until the color of the pat turns from dark to light.

11.5.1 Drying the soil pat in air may produce cracking of the soil pat due to rapid moisture loss. This is a concern in dry climates. If this problem is encountered, slow the rate of moisture loss by drying the soil pat in a humidity controlled environment.

NOTE 3—The time required to air dry the soil pat will depend on the plasticity of the soil, the initial water content, and the relative humidity. In some cases it may take from 1 to 2 weeks for the color of the soil to turn from dark to light.

11.6 Oven dry the soil pat to constant mass at 110 ± 5°C.

11.7 Determine and record the mass of dish plus dry soil pat (m_d).

11.8 Coat the dry soil pat with wax as follows:

11.8.1 Securely tie the sewing thread (about 30 cm long is adequate) around the soil pat.

11.8.2 Immerse the dry soil pat in molten wax, holding the dry pat with the sewing thread, completely coating the pat. Use a continuous motion into and immediately out of the wax. The immersion should only take a few seconds. Do not allow air bubbles to develop in the wax coating. If air bubbles are present, use a sharp object to cut out the bubble; refill the hole with wax. Repeat the dipping process two or three times to create a smooth wax coating.

NOTE 4—**Precaution:** The melted wax and associated equipment are hot and care should be exercised to avoid burns.

11.8.3 Allow the wax coating and soil pat to cool to room temperature.

11.9 Determine the mass of the wax-coated pat of soil in air and record the value as the mass in air of the dry soil and wax (m_{sxa}).

11.10 Determine the mass of water displaced by the submerged wax-coated pat using either Section 11.10.1 or 11.10.2. Make sure that there are no air bubbles clinging to the surface of the wax-coated pat or thread during this measurement.

11.10.1 Record the mass indicated when the wax-coated pat of soil is suspended from a hanger placed on the balance or scale while submerged in a water bath. This is the indicated mass in water of the dry soil pat and wax (m_{sxw}).

11.10.2 Record the mass indicated when the wax-coated pat of soil is submerged in a water bath placed on the balance or scale while suspended from a hanger separate from the balance or scale. This is the mass of water displaced by the dry soil pat and wax (m_{wsx}).

NOTE 5—There are other acceptable methods of determining the indicated difference of the mass of the soil pat in air and in water.

12. Calculation

12.1 Calculate the mass of the dry soil pat as follows:

$$m_s = m_d - m \quad (1)$$

where:

m_s = mass of the dry soil pat, g,
m_d = mass of the dry soil pat and shrinkage dish, g, and
m = mass of the shrinkage dish, g.

12.2 Calculate the initial moisture content of the soil at the time it was placed in the dish as follows:

$$w = \left[\frac{(m_w - m_d)}{m_s} \right] \times 100 \quad (2)$$

where:

w = moisture content of the soil at the time it was placed in the dish, %, and
m_w = mass of the wet soil and shrinkage dish, g.

12.3 Calculate the volume of the dry soil pat as follows:

12.3.1 Calculate the mass of water displaced by the dry soil pat and wax as follows:

$$m_{wsx} = m_{sxa} - m_{sxw} \quad (3)$$

where:

m_{wsx} = mass of water displaced by dry soil pat and wax, g,
m_{sxa} = mass of dry soil pat and wax in air, g, and
m_{sxw} = indicated mass of dry soil pat and wax in water, g.

12.3.2 Calculate the volume of the dry soil pat and wax as follows:

$$V_{dx} = \frac{m_{wsx}}{\rho_w} \quad (4)$$

where:

V_{dx} = volume of dry soil pat and wax, cm^3, and
ρ_w = density of water, g/cm^3 (use 1.000 g/cm^3, see Note 6).

NOTE 6—Assume density of water equal to 1.000 g/cm^3. Corrections for temperature may be used, if desired.

12.3.3 Calculate the mass of wax as follows:

$$m_x = m_{sxa} - m_s \quad (5)$$

where:

m_x = mass of wax, g.

12.3.4 Calculate the volume of wax as follows:

$$V_x = \frac{m_x}{G_x \rho_\omega} \quad \text{or} \quad \frac{m_x}{\rho_x} \quad (6)$$

where:

V_x = volume of wax, cm^3,
G_x = specific gravity of wax, and
ρ_x = density of wax, g/cm^3.

12.3.5 Calculate the volume of dry soil pat as follows:

$$V_d = V_{d_x} - V_x \quad (7)$$

where:

V_d = volume of dry soil pat, cm^3.

12.4 Calculate the shrinkage limit as follows:

$$SL = w - \left[\frac{(V - V_d)\rho_w}{m_s}\right] \times 100 \quad (8)$$

where:

SL = shrinkage limit, and
V = volume of wet soil pat (= volume of the shrinkage dish), cm^3 .

12.5 If desired, calculate the shrinkage ratio as follows:

$$R = \frac{m_s}{(V_d \times \rho_w)} \quad (9)$$

where:

R = shrinkage ratio.

12.6 If desired, calculate the volumetric shrinkage as follows:

$$V_s = R(w_1 - SL) \quad (10)$$

where:

V_s = volumetric shrinkage, and
w_1 = some given moisture content,% .

12.7 If desired, calculate the linear shrinkage as follows:

$$L_s = 100\left[1 - \left(\frac{100}{V_s + 100}\right)^{1/3}\right] \quad (11)$$

where:

L_s = linear shrinkage.

13. Report: Test Data Sheet(S)/Form(S)

13.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in Section 1.6.

13.2 Record as a minimum the following information (data):

13.2.1 Specimen identifying information, such as Project No., Boring No., Sample No., Depth, etc.

13.2.2 Any special selection and preparation process, such as removal of gravel or other materials from the specimen.

13.2.3 The shrinkage limit to the nearest whole number omitting the percent designation.

13.2.4 If desired, the shrinkage ratio, volumetric shrinkage, and linear shrinkage.

14. Precision and Bias

14.1 *Precision*—Table 1 presents estimates of precision based on the results from the AASHTO Materials Reference Laboratory (AMRL) Proficiency Sample Program of testing conducted on Sample Numbers 113 and 114. These samples were found to be a CL material having 95.0 % fines, a liquid limit of 44, a plastic limit of 22, a shrinkage limit of 14, and a shrinkage ratio of 1.92.

14.1.1 The column labeled "Acceptable Range of Two Results" quantifies the maximum difference expected between two measurements on samples of the same material under the conditions listed in the first column. These values only apply to soils which are similar to proficiency samples 113 and 114.

14.2 *Bias*—The procedure in this test method for measuring the shrinkage limit of soil has no bias because the value of the shrinkage limit can only be defined in terms of this test method.

15. Keywords

15.1 Atterberg limits; linear shrinkage; shrinkage; shrinkage limit

TABLE 1 Table of Precision Estimates

Material and Type Index	Standard Deviation[A]	Acceptable Range of Two Results[A]
Single-Operator		
shrinkage limit	0.75	2.11
shrinkage ratio	0.017	0.048
Multilaboratory		
shrinkage limit	1.44	4.03
shrinkage ratio	0.040	0.112

[A] These numbers represent, respectively, the 1s and d2s limits as described in Practice C670.

ANNEXES

(Mandatory Information)

A1. CALIBRATION OF SHRINKAGE DISH

A1.1 Scope

A1.1.1 This annex describes the procedure for calibrating the shrinkage dish.

A1.1.2 The calibration consists of determining the volume of the shrinkage dish.

A1.2 Preparation of Apparatus

A1.2.1 The shrinkage dish, glass plate, lubricant, and water should all be at room temperature before performing the calibration procedure.

A1.3 Procedure

A1.3.1 Lightly grease the inside of the shrinkage dish and face of the glass plate. The face of the glass plate is greased to provide an adequate watertight seal while moving the dish and glass plate to the scale.

A1.3.2 Determine and record the mass of the greased dish and greased plate.

A1.3.3 Place water into the greased dish to overflowing.

A1.3.4 Remove the excess water by pressing the greased glass plate over the top of the dish. Be sure all of the air is removed from within the dish. Dry the outside of the plate and dish.

A1.3.5 Determine and record the mass of the greased dish, greased plate, and water.

A1.3.6 Calculate and record the value of the mass of water.

A1.3.7 Calculate and record the volume of the shrinkage dish.

A1.3.8 Completely clean the dish and the glass plate and repeat A1.3.1 through A1.3.7 for a second trial.

A1.3.9 If the difference in volume between the two trials is greater than 0.03 cm^3, repeat the procedure until the difference between any two trials is equal to or less than 0.03 cm^3. Average and record the results from the two trials.

A1.4 Calculation

A1.4.1 Calculate the mass of water in the shrinkage dish as follows:

$$m = m_1 - m_2 \quad \text{(A1.1)}$$

where:

m = mass of water in shrinkage dish, g,
m_1 = mass of greased dish, greased plate, and water, g, and
m_2 = mass of greased dish and greased plate, g.

A1.4.2 Calculate the volume of the shrinkage dish as follows:

$$V = \frac{m}{\rho} \quad \text{(A1.2)}$$

where:

V = volume of shrinkage dish, cm^3, and
ρ = absolute density of water, g/cm^3 (use 1.000 g/cm^3, see Note 6).

A2. MEASUREMENT OF WAX DENSITY

A2.1 Scope

A2.1.1 This annex describes a procedure for determination of the wax density.

A2.1.2 The calibration consists of making a cylindrical block of wax and measuring the mass and volume.

A2.1.3 The density value of the wax is required to no more than two significant digits.

A2.2 Apparatus

A2.2.1 Thin plastic tube about 5 cm in diameter and about 4 cm long (after capping).

A2.2.2 Cap or plug to close one end to of the plastic tube (for example, rubber stopper).

A2.2.3 Caliper with 0.01 mm resolution.

A2.3 Procedure

A2.3.1 Lightly grease the inside of the tube and cap one end.

A2.3.2 Pour liquid wax into tube and cool to a solid.

A2.3.3 Remove end plug and extrude the wax cylinder from the tube.

A2.3.4 Use a straight edge to square both ends of the wax cylinder.

A2.3.5 Determine the mass of the wax cylinder (m_{wp}).

A2.3.6 Measure the height of the wax cylinder in four locations (h_{wp}).

A2.3.7 Measure the diameter of the wax cylinder in four locations (d_{wp}).

A2.4 Calculations

A2.4.1 Calculate the volume of the wax cylinder as follows:

$$V_{wp} = \frac{\pi d_{wp}^2 h_{wp}}{4} \quad \text{(A2.1)}$$

where:

V_{wp} = volume of the wax cylinder, cm^3,
d_{wp} = average diameter of the wax cylinder, cm, and
h_{wp} = average height of the wax cylinder, cm.

A2.4.2 Calculate the mass density of the wax as follows:

$$\rho_x = \frac{m_{wp}}{v_{wp}} \quad \text{(A2.2)}$$

where:

ρ_x = mass density of the wax, g/cm^3, and
m_{wp} = mass of the wax cylinder, g.

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to this standard since the last issue (D4943 – 02) that may impact the use of this standard. (Approved June 1, 2008.)

(1) Deleted Introduction and reference to D427.
(2) Added Section 1.6 on significant digits.
(3) Deleted references to D427 and D2726 in Section 2.1.
(4) Changed reference E1 to E2251 in Section 2.1.
(5) Minor non-technical changes and rewording in Section 4.1.
(6) Minor clarification to Section 5.1.
(7) Minor changes to Section 6.2.
(8) Addition of humidity chamber in Section 6.5.
(9) Clarification and alternative added to wax in Section 6.10.
(10) Note 2 added for guidance on alternative wax.
(11) Clarification added to water bath in Section 6.13.
(12) Change in specification of thermometer in Section 6.15.
(13) Clarification added to wax in Section 9.2.
(14) Reference to D2726 removed and replaced with Annex A2 in Section 9.2.
(15) Clarification added to temperature requirement added to Section 9.3.
(16) Symbols added where measurements are made throughout Section 11.
(17) Clarification added to Section 11.5.1.
(18) Guidance added relative to air drying as Note 3.
(19) Clarification and renumbering added to Sections 11.5 to 11.7.
(20) Separated steps in procedure and renumbered Sections 11.8 to 11.10.
(21) Instruction added to Section 11.8.2.
(22) Allow two options to measure the size of the wax coated soil pat in Section 11.10.
(23) Added new method to measure volume in Section 11.10.2.
(24) Added new Section 12.3.1 and Eq 3 to allow two methods of measuring wax coated soil pat.
(25) Modifications to Section 13 to be consistent with data reporting requirements.
(26) Added Annex A2 to provide a method to measure the density of wax.
(27) Removed Section X1. RATIONALE since it referred to D427 which is no longer an ASTM standard.
(28) Removed reference to Report REC 86-2.